THE LATE QUATERNARY HISTORY OF THE CUMBERLAND LOWLAND

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[Plates 1 and 2]

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I. INTRODUCTION

The geography and geology and history of human settlement of the Cumberland Lowland is decribed and the choice of sites for the investigation of the vegetational history of the region discussed in relation to these factors. The principles underlying the presentation and zonation of the pollen diagrams are set out.

FOREWORD

The main reason for this work was to try to discover whether the pollen analytical technique could successfully be used to discriminate detailed differences in ecological history attributable to small and simple differences in habitat conditions within a fairly small region. The choice of the Cumberland Lowland offered the additional advantages of allowing the investigation of the significance of the Scottish Readvance Glaciation and the chronology and extent of the post-Glacial marine transgression and regression. Moreover, the history of human settlement of the area is comparatively simple. At the time when the work was begun there also seemed to be some virtue in extending the general vegetation history of Great Britain into this north-western region for the light it might throw on climatic history and the comparisons it might offer with Ireland. It was also felt that a fuller knowledge of the development of the lowland vegetation might lead eventually to a better understanding of the ecological history of the surrounding upland areas.

Of the parts which follow this introduction, three are devoted entirely to the presentation of factual information derived from a number of sites together with the minimal interpretation which is necessarily implied in the very zonation of the pollen diagrams. The next part presents data from sites associated with changes in land and sea level and goes on to discuss the chronology of these changes. The final three parts, which are of a more speculative nature, strive to interpret these data in terms of the ecological history of the region and to derive such conclusions as seem valid about the geographical processes, climatic changes and history of human settlement.

All the work on which this paper is based was carried out between 1949 and 1961 whilst the author was a member of the University Sub-department of Quaternary Research, Cambridge. Any valuable contribution which it may contain is due to the constant help and guidance of Professor Harry Godwin, F.R.S., and to the author's colleagues during that time, particularly Dr A. G. Smith, Dr R. G. West, Dr E. H. Willis, Dr F. Oldfield and Miss R. Andrew. The help given by Miss C. A. Lambert is acknowledged with especial gratitude. In the early stages of the work the advice of Professor S. E. Hollingworth and of the late Professor W. B. R. King was of inestimable value. In the field the work was greatly facilitated by the ready co-operation of the landowners on whose property it was carried out and by those who helped either physically or with good advice, amongst them Dr D. A. Ratcliffe, Dr B. Seddon, Mr B. Blake, Mr W. H. Alp, Miss K. S. Hodgson and Miss C. Fell. Mr H. Gunther and Mrs C. Daniel drew the maps for this Introduction and Mr L. Pancino prepared many of the other diagrams. To all of these the author is most grateful, but his greatest debt is undoubtedly to Mr E. Blezard, Curator of Tullie House Museum, Carlisle, whose depth of understanding of Cumberland natural history has been an inspiration to many and whose personal interest in this work has so often revitalized the author when his enthusiasm has flagged.

Geography and geology of the region

The county of Cumberland lies in the north-west corner of England, between the Pennine Hills and the sea, from about 54° 10′ N on the west coast and 54° 40′ N inland near Penrith to 55° 0′ N at the head of the Solway Firth and 55° 15′ N in the north-east where it meets the boundaries of Scotland and Northumberland. In the north-east of the county the high Pennines join the Southern Uplands of Scotland and the greater part of the south-west is occupied by a part of the mountainous English Lake District (or Lakeland Hills). Between these two blocks of high ground the Rivers Caldew, Petteril, Eden, Irthing, Lyne and their tributaries drain wide lowland valleys into the head of the Solway Firth near Carlisle. The lowland extends south-westwards from the Carlisle district around the edge of the Lake District Hills narrowing to about 11·5 km (7 miles) near St Bees Head and to less than 1·5 km (1 mile) farther south.

The Cumberland Lowland, as the term is used in this paper, is arbitrarily defined as that part of the area described above which lies below the 230 m (750 ft.) contour of altitude and excluding valleys below that level but less than 5 km (3 miles) wide. On the west coast the data are thought only to be valid as far south as the River Irt which enters the sea near Ravenglass (54° 21′ N). Between the Lake District Hills and the Pennines, the county boundary with Westmorland, which there runs along the Rivers Eamont and Eden and Crowdundale Beck (about 54° 40′ N), is used. The northern boundary lies along the River Lyne from the Solway Firth to Bewcastle, then south-south-eastwards across the River Irthing to Denton Fell, thereby excluding the upland moorland areas of the Irthing catchment and the Tyne Gap. Thus defined, the Cumberland Lowland forms a crescent the arms of which are the coastal strip and the Eden–Petteril valleys, with a slight north-eastern extension. It is the south-eastern part of a more extensive, more natural, unit which includes all the lowland bordering the Solway Firth. The central area of the crescent is frequently referred to as the 'Carlisle Plain', the eastern arm as 'Edenside' and the western arm as the 'coastal fringe'. The hills which border so much of the region rise steeply from the 230 m (750 ft.) contour, or from just below it, except in the district immediately north-west of Penrith where the tract of Carboniferous Limestone rises gently westwards to the foot of the steeply climbing Ordovician hills.

The Cumberland Lowland contains few striking topographic features which are not ascribable to drift deposits, either Glacial or post-Glacial in origin. The River Eden, however, has carved deeply through the drift and into the underlying sandstone creating a gorge along several miles of its course. On each side of the river the sandstone occasionally rises above the 230 m (750 ft.) contour, as at King Harry's Common (240 m 800 ft.) and Lazonby Fell (245 m 811 ft.), but these 'islands' of higher land are never more than 2 km^2 (1 square mile) in extent. In the south-west, the normally gentle meeting of the coastal fringe with the sea is broken at St Bees Head by a block of sandstone about 13·5 km^2 (5 sq.miles) in area rising to 147 m (486 ft.) O.D. forming a cliffed coastline 91 m (300 ft.) high and about 5 km (3 miles) long.

Apart from these features, where the solid rock is exposed or covered with a thin layer of sedentary soil or peat, the whole region is shrouded in glacial drift which in turn is partially covered by post-Glacial deposits. Trotter & Hollingworth (1932*a*) have compared the sequence of glacial drifts in the region with that in Southern Scotland (Charlesworth 1926) and in Northumberland (Smythe 1912) and have suggested correlations with drift sheets elsewhere in England. Smith (1931) correlated the glacial episodes of Cumberland with those of the Isle of Man. The general sequence of glaciations and interglacials developed by these authors seems to have been generally accepted (Charlesworth 1957) in spite of the contrary views of Carruthers (1939, 1947, and in Hollingworth *et al.* 1950).

An early glaciation of Scottish origin (the Early Scottish) has been proposed to account for the occasional outcrops of boulder clay below the Main Glaciation drift and separated from it by laminated clays, as at Langwathby (Goodchild 1875), or sand and gravel, as near Whitehaven (Eastwood, Dixon, Hollingworth & Smith 1931). This early boulder clay is usually deeply weathered and rich in Scottish erratics. It is to this glaciation that the transport of Lake District rocks to the east coast of England via the Tyne Gap (150 m 500 ft. O.D.) is attributed together with the piling of ice around the Isle of Man. These distributions can only be explained by assuming a great reservoir of ice in the northern part of the Irish Sea which flowed outwards, overtopping the Lake District and forcing ice up the Eden Valley. The melting of this ice is documented only by gravel, sand and laminated clay in isolated occurrences indicating that the ice certainly retreated from the lower ground. But the only evidence for a temperate climate before the onset of the next glacial phase is a tooth of ox found in sand beneath Main Glaciation boulder clay near Appleby (Dakyns, Tiddeman & Goodchild 1897). Since it is not known whether Early Scottish drift occurs beneath this sand, this evidence indicates, at the most, a climate tolerable by this animal at any time before the onset of the Main Glaciation. There is therefore no critical evidence for an interglacial period in the modern sense of the term (West & Godwin 1958; Jessen & Milthers 1928) between the deposition of the Early Scottish drift and that of the Main Glaciation.

At the onset of the Main Glaciation, ice moved outwards from the Lake District Hills on to the coastal fringe, the Carlisle Plain and the Eden Valley. Ice from Scotland deflected the north-bound Lake District ice westwards around the northern fringe of the hills and southward down the west coast. The ice ponded up in Edenside escaped over Stainmoor (440 m 1400 ft. O.D.) and Grayrigg (260 m 850 ft. O.D.) and across a col into the South Tyne valley at 570 m (1900 ft.) O.D. The distribution of erratics suggests that the ice in the Eden Valley during the maximum of the Main Glaciation stood about 760 m (2500 ft.) above present sea level and only the highest of the northern Lake District peaks can have escaped glaciation. The absence of well-marked frontal moraines in the region and the wide distribution of kettle-holed sand and gravel drift suggest that there was little intermittent forward movement during the general retreat from the Main Glaciation, except in the case of the Gosforth Oscillation (Trotter, Hollingworth, Eastwood & Rose 1937), but that the ice melted more or less *in situ* from its shallower edges northward towards Scotland.

After the ice had vacated the region, there was a separate readvance from Scotland onto the Carlisle Plain and the coastal lowland known as the Scottish Readvance Glaciation (Trotter 1929; Trotter & Hollingworth 1932*a*). The distinct and separate nature of this glaciation depends on the evidence of large areas of sand, gravel and water-deposited clay of the retreat from the Main Glaciation which are overlaid by and partly incorporated into an overlying boulder clay containing Scottish erratics. The time interval between the two glaciations is unknown but must have been long enough for the withdrawal of ice north of the Solway Firth and the accumulation of considerable depths of varved clay later over-ridden by the readvancing ice (e.g. at Linstock Castle, Lanercost). A peat bed exposed beneath supposed Scottish Readvance boulder clay south of St Bees Head and from which plants of temperate modern distribution were recovered (Eastwood *et al.* 1931), is not now available for study. Similar deposits in the same cliff are not covered by boulder clay and date from the late-Glacial and post-Glacial periods after the Scottish Readvance (Walker 1956). It is possible that the boulder clay above the originally described peat was not in its primary position and that the plants contained in the peat were therefore no indication of conditions during the Main Glaciation–Scottish Readvance interval. The Readvance was probably rapid and of short duration. Only a few drumlins were formed and pre-existing drumlins of the Main Glaciation were only slightly modified. It left no terminal moraine but, at its maximum, the outflow of the Eden and adjacent rivers was blocked by ice and the lake so formed drained eastwards for a short period through the Gilsland overflow at 133 m (450 ft.) O.D. In the earliest stage of retreat the level fell to 121 m (400 ft.) O.D. and drainage was westwards to the Irish Sea. Although the stages of its retreat northwards are well documented by overflow channels (e.g. Hollingworth 1931), the outwash fans are small and the strand-lines and notches of pro-glacial lakes were impersistent. These features suggest that the ice was relatively clean and that it melted fairly rapidly.

There is evidence, therefore, for three invasions of the region by ice: the Early Scottish

Glaciation, the Main Glaciation and the Scottish Readvance. The Main Glaciation is undoubtedly a part of the Newer Drift Glaciation of Great Britain and there is little evidence within the region of the length or climatic character of the intervals before it and between it and the Scottish Readvance Glaciation.

The main event which has considerably modified the topography left by the melted ice, apart from local solifluction, soil creep, etc., has been the inundation of the coastal areas by the sea and the consequent modification of the river valleys, particularly in their lower reaches.

The officers of the Geological Survey (Dixon *et al.* 1926; Eastwood 1930; Eastwood *et al.* 1931; Trotter *et al.* 1937) have traced the extent of maximum inundation as it is documented by marine and estuarine clays and beaches now above the tidal range. An earlier lower sea level is attested by the frequent occurrence of 'submerged forest' off the present shore line. This organic material is variable in composition and origin. Near St Bees, one exposure shows tree stumps rooted in weathered boulder clay; at Beckfoot, a dark, friable, oxidized peat with branches of trees and leaves rests on a grey clay above boulder clay; at Glasson, a dark brown freshwater swamp mud is separated from the underlying boulder clay by a thin layer of blue stoneless clay. These variations only represent the variety of organic accumulation on the ground surface before the inundation, largely determined by local topography and drainage. In most localities any marine deposits which might have covered the 'submerged forest' have been eroded away, but at Glasson a terrace of marine alluvium is seen to overlie the organic mud in a cleanly eroded section. There is little doubt, therefore, that a land surface formerly relatively higher than that of the present was inundated by the sea.

The relative recovery of the land which followed has left the alluvia and beaches of the transgression out of reach of the modern sea. The raised beach has developed where drumlins, or similar drift sources of pebbles, protruded from the high sea and were subject to the long-shore currents of the Solway or other relatively strong streams. The beach links islands of boulder clay in the Bowness region which, as evidenced by the alluvia, must have been several miles from the continuous coastline at the maximum transgression. Along the open coast (e.g. Maryport district) it simply fringes the boulder clay plain and runs across the mouths of the minor stream valleys (e.g. Black Dubb). The top of the raised beach rises from about 8·5 m (28 ft.) O.D. near Ravenglass to 9 m (30 ft.) O.D. near Maryport and 9·5 m (32 ft.) O.D. at Beckfoot, representing elevations of about 3·3 m (11 ft.), 4·3 m (14 ft.) and 4·7 m (15·5 ft.) respectively. North of Maryport, the raised beach seems divisible into two levels but these are indistinct and do not occur in the south of the region.

Two distinct terraces of marine alluviation ('warp') are distinguished by the Geological Surveyors, both of them falling slightly in level towards the present sea. The highest level of the upper terrace varies irregularly between 8·5 m (28 ft.) O.D. and 7·5 m (25 ft.) O.D. throughout the region and is usually separated from the lower terrace by a cliff about 1 m (3 ft.) high. A similar cliff separates the lower terrace from the modern storm-washed salt marsh and another marks the boundary between that and the marsh inundated by ordinary tides. This modern salt marsh is being eroded by the channel of the River Eden at Brough Marsh and another cliff has formed as a result. The abrupt cliffs between the various levels of alluvium can only be explained as the results of erosion by a sea normally below the level of the terrace it is eroding. This might demand a fall of the sea well below the terrace level and a subsequent eroding rise but, where the sea is aided by strong meandering channel currents, a still-stand or merely a slowing of a relative fall in sea level might suffice. All the developments described above are in fact in estuarine regions where channel scour may well have played a part. Nevertheless, each erosion cliff must imply at least a temporary retardation in the emergence of the land or the fall of the sea.

The top of the highest parts of the raised beach corresponds roughly to the general level of the upper terrace of marine alluvium, or rises slightly above it. Since both, in the main, are coastal deposits it seems reasonable to regard them as roughly contemporary. This is confirmed by the stratigraphic relationships of the two deposits. At Cross Beck, near Maryport, sandy terrace alluvium and raised beach can be seen above and below the upper terrace deposit or, in places, interdigitating with it. That part of the raised beach was formed not later than the deposition of the upper terrace is evidenced at Newton Arlosh, where beach gravels are completely surrounded by upper terrace deposits. Near Beckfoot, however, raised beach lies on top of the upper terrace, whilst near Ravenglass it appears to rise from beneath the lower terrace. All these variations can best be explained if it is recognized that the beach probably started to form as soon as the rising sea reached suitable deposits. As the sea continued to rise, the beach was built up and shifting currents from time to time mixed its edges with the accumulating sandy alluvium. As the relative sea level fell the beach would be modified by it for as long as it was washed by the sea and beach gravel would here and there be redistributed over the terrace alluvium. The erosion of the lower terrace might well have been contemporary with the building of the second level in the beach, but this is impossible to demonstrate directly by stratigraphy. Only where the uppermost level of the raised beach has been breached (e.g. near Crosscannonby), however, is the lower terrace found on its landward side confirming that the main body of the beach was formed before the lower terrace.

These changes in the relative levels of land and sea are most readily explained in terms of an initial eustatic rise of the sea at first exceeding but finally being surpassed by an isostatic recoil of the land (e.g. Charlesworth 1957). The level of the top of the raised beach, rising northwards, accords well with the levels of the post-Glacial '25 ft.' raised beach of the north-west of Britain. The first emergence would be slightly earlier in the north of the region and it may be that this time factor accounts for the absence of a lower level in the beach south of Maryport. Such an interpretation, however, would imply that the two levels of the beach were very closely placed in time.

The river systems draining the region must have been affected by these changes in base level, at least in their lower courses. During the early period of low relative sea level it is probable that the rivers excavated quite deep valleys in the soft drift lowlands but, with the rising sea, these valleys would be flooded and the transporting power of the streams diminished. A multiplicity of terraces exists along most of the river valleys but, although those at similar levels have been grouped for ease of mapping and description, it is not possible certainly to equate any riverine stage with events on the coast. Ignoring the uppermost group of terraces, which are restricted in distribution and probably of late-

Glacial date, alluvial terraces are well developed up to about 110 m (350 ft.) O.D. in the Irthing valley, about 60 m (200 ft.) O.D. on the Gelt and about 45 m (150 ft.) O.D. on the Eden, but hardly exist on the Rivers Ehen and Irt. The development of terraces clearly depends on a complex of geographical factors, amongst which the base level,

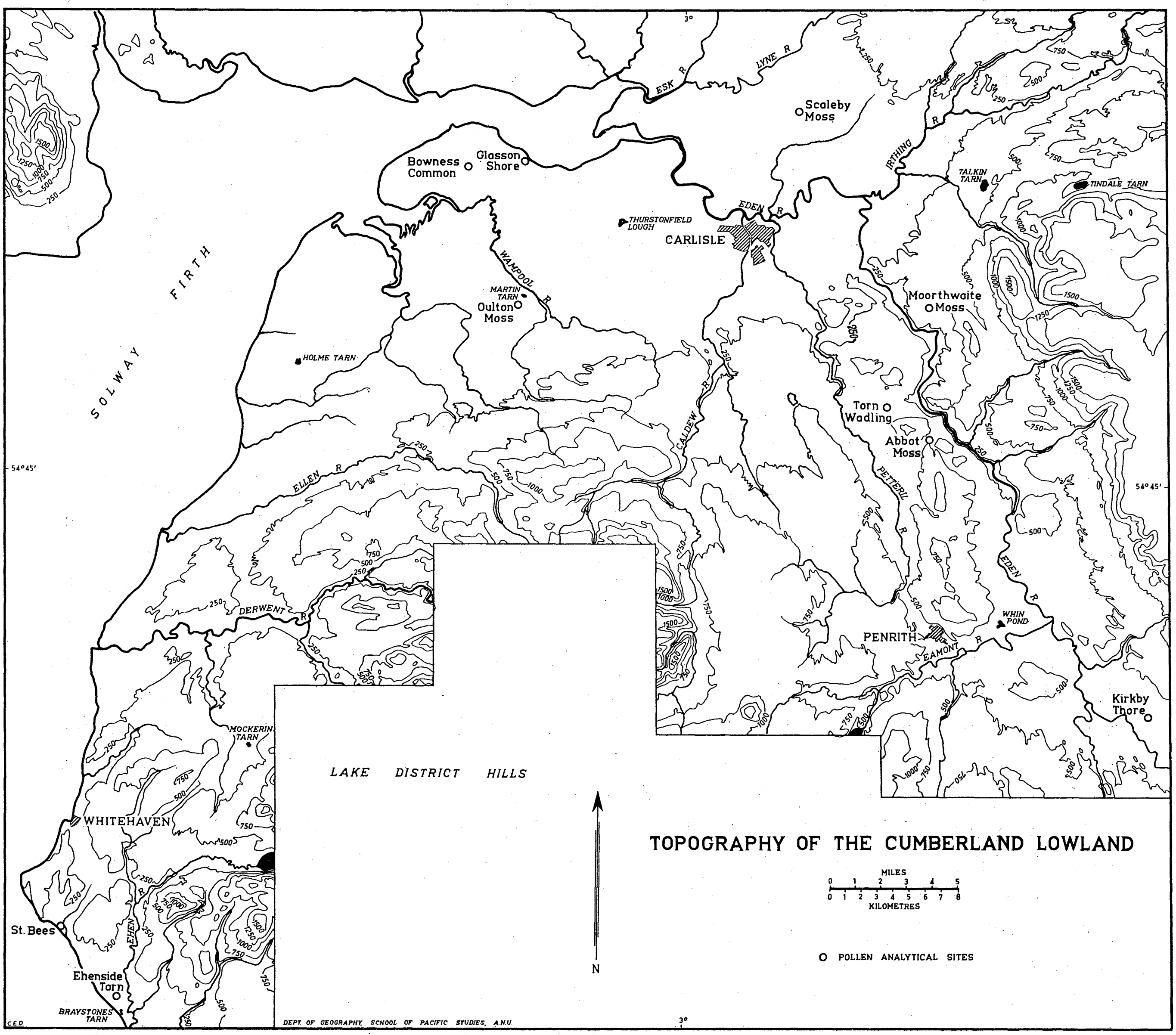


FIGURE 1. The contrasting topography of the three parts of the Cumberland Lowland and the position of the pollen analytical sites. (Topographic data derived from Ordnance Survey maps by permission.)

represented by the sea, is only one although a most important one in the estuaries. Nevertheless, it is useful to note that at no time during the post-Glacial period was the area of riverine flood plain more than twice its area at the present day.

The hollows in the glacial drift are invariably partly filled with sand and gravel, but many also contain peat bogs (e.g. Hayton Moss, Moresby Moss, Hallsenna Moor) or fens (Bigland's Moss). Large bogs have developed on some of the marine deposits near the

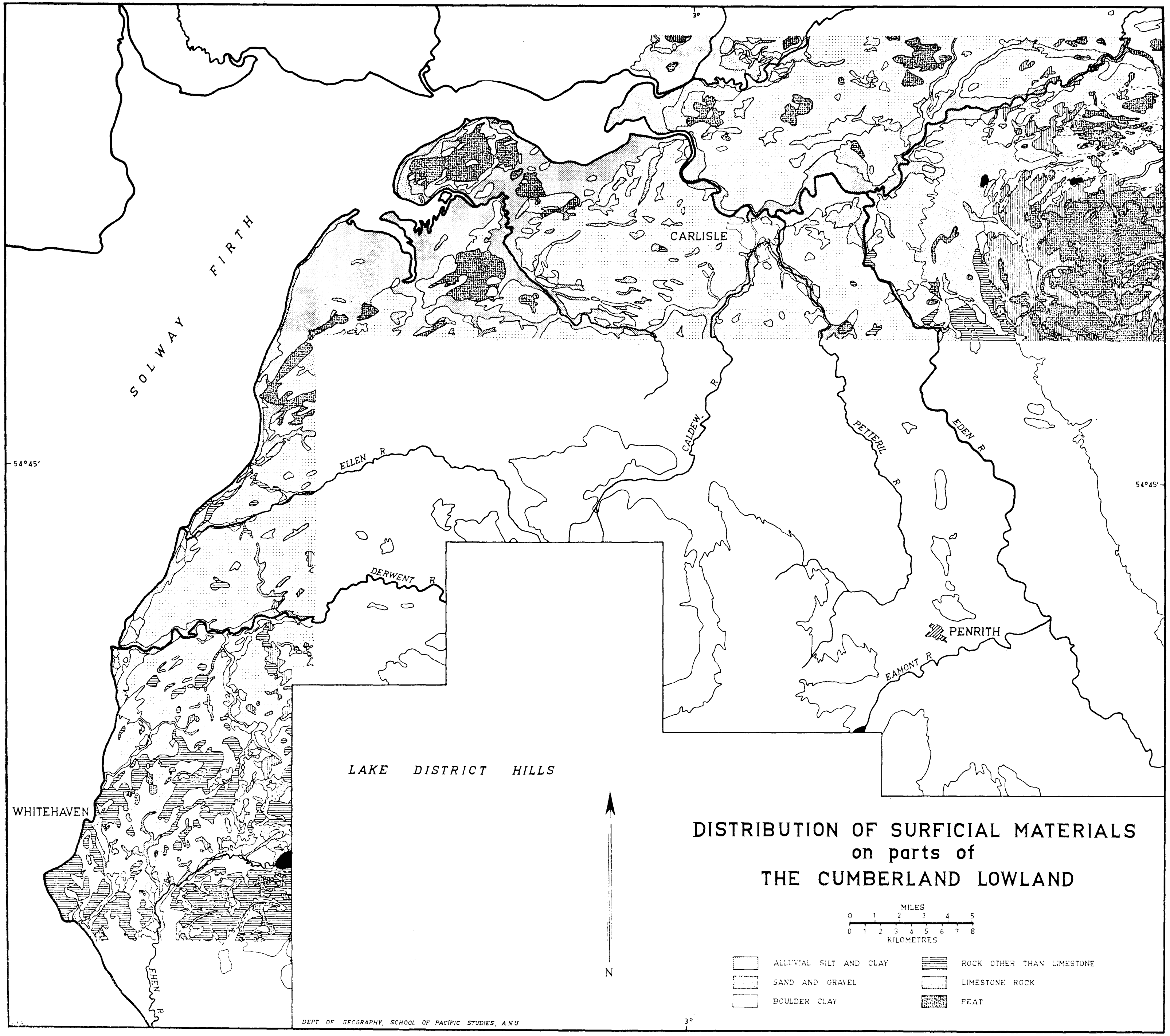


Figure 2. Distribution of surficial materials in those parts of the Cumberland Lowland covered by the 1 in. series Geological Survey sheets, drift edition, to illustrate the variety of these materials in the three parts of the region. (Geological data derived from Geological Survey maps by permission.)

coast (e.g. Bowness Common, Wedholme Flowe, Salta Moss) and smaller ones on associated river alluvium (e.g. Pow Beck valley, St Bees). Some of the lower drift hills carry bogs which are totally ombrogenous (e.g. Broomhill Moss) but the main spread of Pennine blanket bog does not extend far below the 500 m (1500 ft.) contour, although on the western margins of the Lake District fells it is not uncommon down to 300 m (700 ft.) O.D.

The nature and distribution of these various superficial deposits allows the Cumberland Lowland to be divided into subregions.

The first of these lies between the River Petteril and the foothills of the Pennines, including the Eden Valley (figure 1). Here the topography is broken; there are very few areas which are even moderately flat. The dominant topographic unit is the steep-sided hill or ridge, separated from its neighbours by deep, narrow, channels in which the drainage is often impeded. There are also many completely enclosed hollows of a variety of depths and sizes but all with steep banks. A little solid rock, mostly coarse-grained sandstone, outcrops at the surface. The hilltop soils are light, leached and covered by a mor humus where they have escaped disturbance. In the hollows has accumulated much of the finer grain material from above, although, even so, the soils are but rarely clayey. Many such localities are perennially waterlogged. Between these two contrasting situations are the steep, unstable, slopes.

Between the River Petteril and the sea, bounded in the south-west by the River Calder, lies an area of quite different topography. Extensive, rolling, boulder clay flats are cut by steep-sided, wide, meandering channels, usually flat bottomed and containing misfit streams. Little, if any, solid rock reaches the surface. Soils are heavy and overall drainage is poor, with a strong tendency to fen development in the valley bottoms. Some of the channels contain swifter-flowing rivers or streams which have deposited alluvium along their banks. Although undisturbed soils are now very rare, in the few profiles observed there is strong evidence of leaching in the uppermost metre but no sign of podzol development.

South of the River Derwent, the third area has characteristics intermediate between those of the other two, than either of which it is much smaller. Small patches of solid rock, mostly limestone and sandstone, frequently occur at the surface. For the rest, broad sweeps of boulder clay are punctuated here and there by small, sharp-featured, patches of sand and gravel. Drainage is good, except on the larger boulder-clay tracts.

These last two areas are much more susceptible to wind blast from the south-west than is the first. There is no significant rainfall gradient across the region and, except for the very edge of the coast, snow lies almost as long in the west as the east.

Human settlement and land use

There are no records of Palaeolithic occupation of the region. The rich spreads of Mesolithic (Sauveterrian) flints (Clark 1955; Raistrick 1934), so common in the Central Pennines, seem not to extend into the Cumberland Lowland. Nevertheless, Mesolithic microliths, axes and choppers have been recovered from coastal sites in Cumberland and North Lancashire (Barnes & Hobbs 1951; Nickson & MacDonald 1956; Lacaille 1954; Dixon *et al.* 1926) and there is little doubt that some Mesolithic settlement did take place around the northern edge of the Irish Sea (cf. the Larnian of Ireland: Movius 1942). The chronology of such limited sites as exist in Cumberland is difficult to assess and it is conceivable that all this material might better be referred to Piggott's (1954) Secondary Neolithic (cf. de Valera 1961).

Polished stone axes attributed to the Neolithic (Collingwood 1933) or the Secondary Neolithic (Piggott 1954), and usually made from Lake District ('Langdale') tuff (Plint 1962; Fell 1954; Bunch & Fell 1949), are not uncommon in the Cumberland Lowland, particularly on the coastal fringe and in the Eden Valley immediately north of Penrith. There are concentrations around Ehenside Tarn (Darbishire 1874; Fair 1932; Piggott 1954) and, to a lesser degree, near 'Long Meg', the megalithic circle north-east of Penrith. Collingwood (1933) supposed the megalithic circles to be artifacts contemporary with the polished stone axes on account of their similar geographical distributions. There is no certain evidence for this correlation however. Moreover, the sharp distinction between Neolithic ceremonial circles and later Bronze Age sepulchral circles is not now so clear (e.g. Fletcher 1958; Hodgson & Harper 1951). Collingwood (1933) held the view that the megalithic circles of the coastal region, being smaller and simpler in arrangement, preceded those grander examples in the east of the region. The origin of megalithic monuments seems now to have been associated with the activities of the Beaker people (Atkinson 1956; Daniel 1958). In the Eden Valley, Beaker remains are no less well associated with megalithic circles than are polished stone axes. In the west, where Beaker remains are, on the whole, rare pottery fragments of the period, together with later Bronze Age material, have been excavated from round cairns at Mecklin Park (Spence 1937). The main invasion by Beaker people seems to have taken place from the east through the Tyne Gap (Raistrick 1931) and over Bowes Moor into the upper Eden Valley (Fell 1950). It seems quite likely that they brought the megalithic circle, already fully developed, to the east of the region and that the people of the coast succeeded in making but poor imitations of the originals. There seems no good reason for supposing that this process did not begin whilst the Neolithic users of polished stone axes were still dominating the west and continued into the period of Bronze Age settlement there (figure 3).

Bronze implements or weapons are very rare in the region and can only reflect occasional ownership at the periphery of the trading area. Burials in Bronze Age technique, often including Bronze Age pottery, are relatively frequent. Collingwood (1933) illustrates the extension of the settled zone to the foothills of the Lake District during Bronze Age time in terms of the distribution of certain, or supposed, Bronze Age barrows and cairns. This movement he associates with an extension of forest clearance using the stone axe-hammer. Although it is true that some certain artifacts of the Bronze Age are found higher up hillsides than are those of earlier times (excluding the Neolithic axe quarries), the case is much less strong if the mounds of stones so common between 150 m (500 ft.) and 300 m (1000 ft.) O.D. in West Cumberland, and which might well not be Bronze Age barrows, are excluded (Walker 1965*a*; Cherry 1961). The most that can safely be concluded is that the area of settlement during the Bronze Age overlapped that of Neolithic time and, on the whole, extended it to slightly higher ground. There is little certain evidence for the occupation of valleys at that time.

Specifically Iron Age remains are very scarce. Only a few La Tène objects are recorded. This is not to say that Iron Age economic influences were not felt, yet it must indicate that they caused no great acceleration of increase in population or in settled area.

So far as can be gathered from the very limited data, it seems likely that, when the Romans entered the region in about A.D. 75, they found a loosely organized human community, probably at a variety of stages of agricultural and economic development. The most advanced centres were the settlements and forts of the 'British Settlement' type, but there were probably also many isolated farms and family holdings and crannogs of the

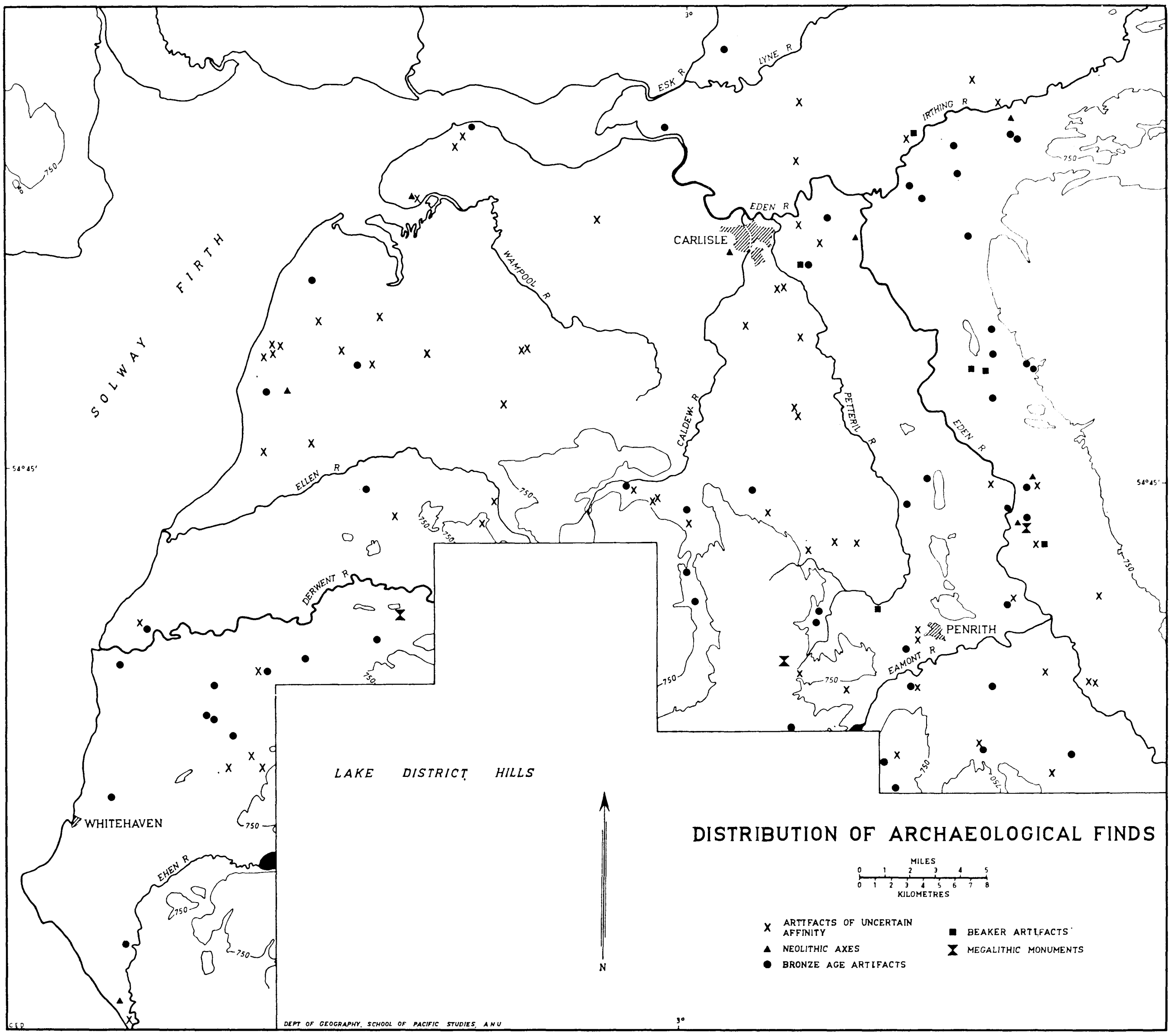


FIGURE 3. Distribution of archaeological material in the Cumberland Lowland based on records in the literature.

Milton Loch kind (Piggott 1955). The region formed part of the kingdom of the Brigantes who had earlier and intermittently fought with and against the Romans. In spite of their final submission, the strife of the period immediately prior to the Roman occupation must have deleteriously affected their normal farming lives. Order was clearly established before the Roman forces finally withdrew during the fourth century A.D. Marching castles (e.g. Kirkby Thore, Brougham-Penrith) were established and the growth of urban civil centres such as Old Carlisle (near Wigton) and Papcastle (Cockermouth) possibly further withdrew people from their agricultural pursuits. A network of roads was laid down and Hadrian's Wall, sweeping across the north of the region to Bowness-on-Solway, was extended by a system of forts and towers guarding the coast as far as St Bees Head (Blake 1955; Bellhouse 1958). Ravenglass was the major port of the region. Richmond (1963) is of the opinion that agriculture developed as never before under Roman rule, but whilst this may have ultimately been the case there must have been a considerable depopulation of the countryside which took some little time to overcome (cf. Richmond 1958).

The period following the Roman evacuation of Lowland Cumberland may not have been unsettled (Blake 1955). The early Celtic Christians were active in the area and Carlisle retained its importance as an administrative centre. Romanized British princes ruled the region and northward and westward into Scotland (Rheged and Strathclyde) and seem to have maintained the peace, although no new urban development seems to have gone on.

Celtic place names on the Cumberland map probably relate to this post-Roman period (Armstrong, Mawer, Stenton & Dickins 1952) and even, perhaps, to the later period of Anglian settlement. The latter seems to have had a strong impact only in a few scattered localities, although the religious monuments there are amongst the finest in Britain (Willett 1957). The British chiefs waged intermittent war against the occasional sorties of the English kings but there was probably a very slow spread of English people and ideas into Cumberland which was not really significant before about A.D. 650 (Hunter Blair 1956). It seems very probable, therefore, that agricultural practices established in the Roman times were only slowly modified by the Anglian techniques which revolutionized the farming of the south and east of England and contributed so much to the decimation of the forests there.

It is very likely that the richer centres of Cumberland suffered the Viking plundering which opened with the attack on Lindisfarne in A.D. 793 and continued with the sack of Iona in A.D. 795. The main Scandinavian settlement of the north-west of England, however, seems to have been by Norsemen spreading secondarily from bases in Ireland and the Isle of Man (Hunter Blair 1956; Kendrick 1930; Shetelig 1940). It was a peaceful immigration of farmers, for the most part, and probably began early in the ninth century. New balances of power also developed in the late ninth century and throughout the tenth which finally served to aline Cumberland politically with the rest of England and to reduce the earlier association with Scotland (Strathclyde) to insignificance (Kirby 1962). English agricultural systems, with emphasis on tillage and crop-growing, would only slowly gain ground in a society given largely to herding. The Norse farming system was also based primarily on grazing and it is probable that at this time Lowland Cumberland was still predominantly pastoral outside the remaining forest remnants. The impact of the Norsemen was certainly very considerable and it is likely that the extent of cleared and settled area increased markedly at this time, particularly in the valleys around the edges of the hill country.

The relative inefficiency of farming in Cumberland, compared with the rest of England, may be judged by the fact that William II sent a band of south-countrymen to the region to instruct the natives in husbandry. Some time later, the establishment of the great religious houses (Wetherall Priory *ca.* A.D. 1106, St Bees *ca.* A.D. 1120, Calder Abbey A.D. 1134, Holmcultram Abbey A.D. 1150, Lanercost Priory A.D. 1169) led to increased, and more effective, agricultural efforts. Not only did the monks possess and farm large acreages themselves, but the many small landowners must have been encouraged by their example.

Under Henry I the 'forest laws' were first applied to a great part of Cumberland. This in itself is a measure of the ubiquity of land still unfarmed or only sporadically used. From A.D. 1130 onwards the Pipe Rolls contain innumerable records of the illegal creation of purprestures and escheats and 'wastes' all of which imply forest clearance for pasture, fuel or building material. The ecological effects of pannage of swine, widely practised in the region, are not known but must have reduced the regeneration of oak and hazel preferentially over that of birch and elm. All the historical records indicate the gradual conversion of the remaining woodland to agricultural land, pastures and meadows in the vicinity of settlements and the creation of low-grade pasture and scrub-woodland in the remoter districts during the thirteenth, fourteenth and fifteenth centuries. The pattern of settlement, determined by the local laws of inheritance, spread the patches of well-tended land widely over the landscape. Isolated farms, rather than close-knit villages, were the rule.

Although the widespread estates of the Cistercian abbeys carried many sheep, oxen and pigs remained much more important in Cumberland than they were further south (cf. Trow Smith 1957). The pig must have proved the ideal farm animal for the forest remnants and the 'wastes' (where roots and rhizomes, if not acorns, would be available). Feeding on the autumn crops of the woodlands, the pig would provide a meat supply well into the winter. Oxen were almost certainly animals of the demesne and of the summer farms in the hills. Although the records abound with references to pasture, and there are some mentions of meadow, arable land rarely figures in them. This may, of course, be partly the selective effect of the records themselves which are largely pleas against the 'forest law' to which agricultural land near the homesteads would not be subject. Nevertheless, it is difficult to envisage anything but a rapidly spreading pastoral economy growing barely sufficient crops to satisfy the needs of men and of a minimum of over-wintering beasts. Indeed, oats were amongst the imports to Skinburness in 1299 (Grainger 1929). The steadily growing success of the wool trade from the end of the thirteenth century to the late sixteenth century must have contributed considerably to the tendency to concentrate on pastoral rather than arable development (Elliott 1961). The rather disorganized farming to which copy-hold tenure, with periodic grants of waste and purprestures in the 'forest', gave rise is illustrated in the inquiry of 1573 when it was said that 'What number of acres every man holdeth cannot be presented because they were never measured...' and 'No several pasture saving in the domains. There is a common or bare waste which belongeth only to the customary tenants for cattle' (Grainger & Collingwood 1929).

By the middle of the sixteenth century greater order was achieved in the neighbourhood of the bigger settlements. An open-field system, variable in detail of management from place to place, had become established around the religious centres and their 'granges' and the relatively few nucleated villages which had grown up on the estates on the better land (Elliott 1960). The *infields* were continuously under crop (mainly barley, oats and pulses), whilst the *outfields* were cropped in rotation and thrown open to common pasture from Lammas to Michaelmas for three years then pastured continuously for six or nine years. Hay was taken from the low-lying Lammas meadows, the stubble of which was also grazed. During the late sixteenth and the seventeenth centuries oats took precedence over barley and a little wheat was grown. Hemp and flax became common minor crops.

During the monastic period, therefore, a great increase in farming activity took place. Slowly, 'manorial' farming systems were established on the few large estates, but the main development was in the exploitation of the remaining woodlands for grazing which made the region amongst the greatest wool producers of the time, even though the quality was poor. By the middle of the seventeenth century only small and carefully conserved patches of forest remained. The relative scarcity of timber at this time, at least in Holmcultram, can be judged by the measures to conserve Wedholme Wood in A.D. 1640 for the regular repair of the sea dyke. Yet in the eighteenth century wooden boat-building was a major industry at Whitehaven. By the end of the century a local naturalist could write, 'The soil...is very sterile and barren producing only Fern, Heath, Bent and a lean hungry Grass unless by the sides of the Rivers or where the nature of the soil is changed by Burning, Liming or manure' (Robinson 1709).

By the end of the eighteenth century the region was almost devoid of woodland except for carefully preserved hunting parks of the nobility (e.g. Whinfield Park: Prevost 1961) and a very few attempts at re-afforestation were being made (Bailey & Culley 1797). A flourishing local tanning industry died for want of oak bark. Regenerating woodland was felled long before it reached maturity. In 1770 wheat and turnips were only just becoming widely grown in lowland Cumberland. Simple rotations, but no leys, were in use in some parts but on others a rigid perennial division of land was still maintained. Enclosure of former open-fields was now almost complete although much common land was still shared for pasture. More than half the area of holding was permanently under pasture whilst another considerable fraction was kept for hay for winter feed. Sheep were kept the year round on common land. The better pastures fed four sheep or 0·7 cows per acre. Pigs were no longer important (Young 1770).

The industrial prosperity of the eighteenth century, which saw the main development of the big Cumberland coastal towns, must have had the effect of withdrawing labour from the land whilst providing more certain local markets. In a farming economy based almost entirely on sheep-grazing, however, these local demands probably contributed little to the average farmer's income for even yet the 'improvers' had made but little headway. In the nineteenth century a more progressive attitude towards agriculture seems to have developed (Dickinson 1852), the cattle were much improved and, over some short periods, grain crops were grown in quantity in the region. Yet the tendency remained, as it does at the present day, to meet every slight economic recession by a return to increased grazing at the expense of crop growing. Lowland Cumberland is still predominantly a grazier's country with dairy and beef cattle on the better ground and sheep on the shorter pastures.

Although changes in detail have undoubtedly occurred, the Cumberland Lowland probably attained the present broad pattern of land use by the end of the eighteenth century. By then the greater part of the natural forests had been replaced by ill-managed grassland. The afforestation which has been attempted from place to place and time to time has not been lastingly successful until very recent years.

The history of land utilization in the Cumbrian Lowland is marked into four periods. The first extended from the arrival of Neolithic man until the arrival of the Romans and was a period marked by a steady extension of the settlement area together with the increasingly rapid and permanent destruction of the forests and a progress from the nomadic to the settled or semi-nomadic habit. The second period was initiated by the Roman occupation and probably encouraged by their withdrawal. The new materials which the Romans brought and the communication and defence system which they established and left allowed an intensification of farming which was, however, still based on the grazing animal. It was substantially unaffected by Anglian settlement although considerably extended by the Norsemen. The monastic period, the third significant time, revolutionized Cumbrian agriculture. Although sheep became even more common and valuable than before, a more rational system was introduced which included the development of villages in some areas and simple agriculture rotations in the fields around them. The dissolution of the monasteries transferred their holdings to secular lords, many of whom did not live in the region, with a consequent overall deterioration in farming efficiency. The fourth period began when a greater variety of crops was more readily accepted and dependence on sheep thereby reduced during the nineteenth century. At the same time, however, the possibilities for efficiently over-wintering cattle were increased, so that Cumberland nevertheless remained predominantly pastoral. The first period must have made considerable inroads on the forest which were accentuated and extended during the second. By the third period the paucity of forested land was already causing concern and by the beginning of the fourth period there was virtually no woodland left.

The only near-natural plant communities which now remain on the Cumberland Lowland are those of the peat bogs but most of these have been disturbed. Some of these bogs are the products of hydroseral processes in small lakes in kettle holes (e.g. Abbot Moss, Blackdub) or in other depressions in the glacial drift (e.g. The Faugh, Orton Moss). They have commonly been cut for fuel over part of their surfaces. The old cutting hollows contain regenerating communities of *Sphagnum* spp. with *Calluna vulgaris*, *Erica tetralix*, *Oxycoccus quadripetalus*, *Rhynchospora alba* and *Eriophorum vaginatum* amongst the commonest plants. The drier fragments of the surface frequently carry planted or subspontaneous trees of *Pinus sylvestris* and *Betula pubescens*, both of which regenerate freely amongst an undergrowth dominated by *Calluna vulgaris*. Another type of bog occurs on convex slopes and the flatter hill tops even at comparatively low elevations (e.g. Bolton Fell, 110 m (361 ft.) O.D.) and must owe its maintenance to the intense oceanicity of the climate. The peat is only about 3 m thick at the deepest points and cutting and erosion around the edges have effectively modified the surface vegetation so that *Calluna vulgaris* and *Eriophorum vaginatum* now share the dominance while *Sphagnum* spp. play a comparatively small role. The largest continuous areas of bog are those lying over deposits of the post-Glacial marine transgression (e.g. Bowness Common, Wedholme Flowe). Their detailed histories are probably diverse but until comparatively recent times they must have been fine examples of true raised bogs, their central areas carrying a characteristic mosaic of vegetation in which

Sphagnum spp. figured largely. Exploitation of these peat deposits, first for fuel and now for litter, and the use of mechanical equipment and frequent burning in these processes, has now transformed their surface so that bushy *Calluna vulgaris* is almost ubiquitous. In abandoned cuttings, however, wet mire communities regenerate.

Some of the higher land on the poor sandy soils of the Eden Valley (e.g. Lazonby Fell) bears *Calluna*-dominated heaths over shallow peat or podsols. These heaths are grazed by sheep and regularly burned. It is difficult to suppose what their vegetation might be without this treatment. Reafforestation, largely by pine, has been attempted in some such localities. Many of the least-disturbed soil profiles on Edenside, even at altitudes as low as 90 m (300 ft.) O.D., demonstrate the former commonness of podsols but give no indication of the vegetation which lived on them.

The other clearly differentiated vegetation in the region is that of the extensive salt marshes around the coast of the Solway Firth. All stages in the development and decay of salt marsh can be found, largely as a result of the vagaries of the Solway channels. A number of distinct levels occur in the salt marsh deposits, the upper of which are now almost devoid of halophytic species. All have been heavily grazed by sheep and, to a lesser extent, by cattle, at least throughout the historic period so that truly natural communities are rare and of very limited extent.

The sites investigated

The sites were chosen in order that a minimum number should nevertheless yield a maximum body of information on the main problems envisaged. On the whole, an attempt was made only to use sites the topography of which would have been conducive to the development of uncomplicated hydroseres over long periods (e.g. kettle holes). In each area a pair of sites was sought in order that a comparison of inter-site and inter-area differences might more critically be made. Details of each site are included in the relevant parts of this paper but a comment on their general distribution is appropriate here.

In order to investigate the stratigraphic position of the Scottish Readvance Glaciation and its effects on the vegetation, two sites on the drift of this glaciation, viz. Scaleby Moss and Oulton Moss, and two sites close to its margin but in the drift of the Main Lakeland Glaciation, viz. Abbot Moss and Moorthwaite Moss, were selected. A further comparison was provided by the same site pairs between the boulder clay 'plains' on the one hand and the more broken topography of the sand and gravel outwash on the other. A differing pairing of the same sites contrasted the steeply sloping margins of Oulton Moss and Abbot Moss with the gentler topography of the *immediate* surroundings of Scaleby Moss and Moorthwaite Moss. The altitudes of the sites above sea level, namely about 7 m (25 ft.) to about 120 m (400 ft.) were not thought to be sufficiently different for this factor itself to have differentially affected the vegetation history. It was expected that Ehenside Tarn, Oulton Moss and Scaleby Moss would provide data about the coastal areas, without accumulation there having been directly affected by marine transgression, whilst Moorthwaite Moss and Abbot Moss were inland sites around which the vegetation might have been expected to have been totally unaffected by coastal changes. Bowness Common, on the other hand, was chosen because of its clear relationship to the changes in relative land

and sea levels so that the chronological position and the significance of these phenomena for vegetation history could be assessed.

The investigation of Ehenside Tarn was important partly because of its position in the south-west of the region on the coastal fringe and partly because of its established association with Neolithic settlement. The general distribution of archaeological materials also affected the choice of other sites. Certainly Neolithic artifacts are recorded along the very fringe of the coast; the results from Bowness Common might be expected to show some relationship to this in contrast with those from Scaleby Moss, Moorthwaite Moss and Abbot Moss. On the other hand, Moorthwaite Moss and Abbot Moss are in an area of considerable Beaker settlement which is almost entirely unrecorded west of the River Petteril or north of the River Eden. The scatter of Bronze Age material is wider, so that any effects of the population of that time might be expected to be reflected more or less equally in the pollen diagrams from all the sites.

The pollen diagrams

Wherever the site conditions allowed, series of samples for pollen analysis were only made after a thorough stratigraphic investigation of the deposits. These investigations were intended primarily to allow the reconstruction of the processes of accumulation at each site and so provide some control, not only of the choice of the samples for pollen analysis but also of the interpretations of the diagrams themselves. The stratigraphic data themselves were frequently of direct value in assessing ecological changes in and around the sites themselves. Where possible, at least one series of samples was collected at each site from the point where the longest and least interrupted history of accumulation was expected and where vegetation changes of the most severely local kind were likely to be poorly represented.

The vertical interval of sampling, much of which was carried out with a Hiller-type borer, was determined partly by considerations discussed below and partly by the suspected rates of accumulation of the various materials. Particularly close sampling was usually carried out around major stratigraphic breaks or horizons of special archaeological or geological significance. Only very rarely did the vertical interval between samples exceed 10 cm. Except in special cases the vertical thickness of each sample was restricted to 1 cm. All samples were stored wet and prepared by treatment with dilute potassium hydroxide followed by acetolysis and chlorination. The pollen grains were then stained and mounted in glycerine jelly or glycerine. The debris sieved off after the potash masceration was examined and rough assessments made of the abundance of the various identifiable and unidentifiable constituents. These results are normally presented with the pollen diagrams and provide another valuable control on interpretation comparable with that of the stratigraphic record.

A pollen spectrum is a good estimate of the actual pollen content of a sample only if a sufficient number of pollen grains contribute to it. The size of this 'sufficient number' depends on the number of different pollen types present in the sample and the accuracy with which their separate frequencies need to be determined. In general practice the total number of pollen grains counted from a sample is usually *much* greater than the number of types identified and no serious error is introduced here. Throughout a diagram, however, the number of types may change suddenly as, for instance, between the end of the late-Glacial and the beginning of the post-Glacial. In such cases the frequencies of any particular pollen type from sample to sample have significance which is not constant because the bases on which they are calculated (i.e. the 'pollen sum') should be related to the number of types in the sample. In most parts of pollen diagrams this consideration is not likely to be a serious source of error because the number of types counted varies only slightly from one sample to the next.

Attempts to improve the accuracy with which the frequencies of individual types can be determined have led to the use of very large 'pollen sums' in much recent critical work. The minimum total count which gives a dependable and reproducible estimate of the real frequency of types in a sample is clearly smaller for the few types which contribute the bulk of the sample than it is for those which occur only rarely in it. On the other hand, where the same 'pollen sum' is used for calculating the frequencies of both common and rare types, the random error in the assessment of the latter remains much greater than in the assessment of the former. Comparable percentage changes at very different absolute levels, e.g. 40 to 20% and 0·4 to 0·2%, are not equally significant. Only the use of exceedingly large 'pollen sums' can give the assessment of very small frequencies useful statistical significance. These limitations apply particularly to comparisons between two samples only. Where a change in frequency progresses in one direction through a series of samples the validity of this change is enormously enhanced. It is evident, therefore, that for a given effort, i.e. a given total of pollen grains to be counted in a whole diagram, more reliable information can be obtained by counting a large number of closely spaced samples than by counting very large 'pollen sums' in a few widely spaced samples, provided always that the 'pollen sum' of each sample is large compared with the number of types in it.

In the analyses presented in this paper, therefore, detail was investigated by close sampling rather than by recourse to large counts of a few samples. Moderately small 'pollen sums' were used (150 to 500 grains) in numerous samples, closely placed (2 to 5 cm). Little significance is attached to the appearance of a pollen type in an isolated sample, whatever its frequency there, except as a record of its presence. Similarly, changes of frequency which in reality represent only differences of a very few grains between a pair of counts are not generally used for interpretation. Progressive changes of frequency in one direction through a series of samples, however small, are given considerable weight, as are phenomena which occur in comparable positions in several diagrams from different sites or from different points at one site. In order to detect significant changes to which pollen types individually present in insignificant amounts contribute, such types have often been grouped together. Indiscriminate grouping produces biologically meaningless results and every effort has been made to include only ecologically similar plants within any one group.

In the majority of the analyses reported in this paper the primary counts and zonation were based on pollen sums comprising the tree types only. Improved technique, and sheer abundance of data, now result in pollen diagrams which include a wealth of information about the vegetation they represent far in excess of that required for this kind of zonation. Details of the floristic composition of communities, ecological differentiation from place to place as well as information on the processes of change from time to time can be discerned. Without detriment to the standard zonation scheme, therefore, additional 'zonations' may often be applied to pollen diagrams in order that these details and processes may be more easily compared from site to site within a region. In order to retain its chronological validity, the standard zonation must depend *only* on the widely distributed, anemophilous, physiognomic dominants of the vegetation and on major changes in their components. These are the criteria which have been used in the standard zonation of the diagrams presented in this paper. A subsidiary zonation might not seek chronological validity as its primary aim, however; rather should it attempt to define both periods of change and periods of stability in the vegetation represented at a site and in this way to focus attention on process and change and ecological differentiation. But the data from each site are themselves complex and derive from a variety of ecological situations. In order to achieve anything, therefore, each subsidiary zonation must apply only to closely related ecological groups. In the primary diagrams from the Cumberland Lowland one subsidiary zonation has been applied throughout whilst a second, related only to forest clearance phenomena, has also been used where it seemed appropriate to the data. The first subsidiary zonation is based on the curves for trees, shrubs and land herbs. Where the significance of changes is in doubt, the plants of wetter habitats, including trees such as *Betula* and *Alnus*, have been excluded from consideration in favour of those more certainly restricted to dry land. In practice, as might have been expected, this subsidiary zonation has resulted mainly in the subdivision of the standard British zonation. Partly because of this parallelism and the basis on which the subsidiary zonation is founded and partly because the same sequences of events were detected in almost all the diagrams under consideration, this subsidiary zonation is thought to have some limited and approximate chronological value within the Cumberland Lowland and has been styled the 'Cumbrian Zonation'. It is certainly not anticipated that it will prove of any value outside the region. Moreover, since the later zones are only represented at Ehenside Tarn, their chronological validity is suspect, although their descriptive usefulness remains. The extensive, but variable, impact of human activities on the vegetation during the last 5000 years has been such that it is unlikely that a chronologically valid zonation of wide application will ever be achieved which does not depend on a physical dating technique. In the present work every effort has been made to dissociate the initial zonation from the more obvious manifestations of human activity, but it would be misleading to pretend that many of the features used in this zonation might not be amongst the more subtle effects of human interference with the ecosystem. Until human economic prehistory is much better documented than at present, any zonation of post-Mesolithic vegetation history must remain chronologically suspect.

In zoning the pollen diagrams an attempt has been made to distinguish regional from local phenomena. Thus, in the post-Glacial period the general trends of the curves for the commoner trees which were certainly not contributing to any hydrosere, viz. *Quercus*, *Pinus* and *Ulmus*, were used to give a very broad general indication of changes in the forest at large. The technique employed was to recalculate the frequencies of these pollen types as percentages of their combined sum and then to smooth the resulting curves arithmetically. Although a general picture of progressive changes amongst the physiognomic dominants of the dry-land forest was obtained in this way, it was hardly representative of the vegetation as a whole so that the positions of zone boundaries, generally indicated as described above, were finally fixed by taking a wider range of pollen types into consideration.

Parts II to V present primary data in a manner in which they can readily be used by other workers in the field. Parts VI to VIII are interpretative and in these re-grouping and recalculation of data have been carried out in order better to illustrate particular points or to test particular hypotheses. The basis of each new calculation is indicated in the text and in the diagram itself and all are derived from the data presented in the earlier papers, much of the detail contained in which is omitted from the recalculated diagrams as presented. Different groupings of types from those used in these papers will doubtless suggest themselves and might, indeed, have greater use. But, with a technique subject to so many fundamental and unassessable variables as is pollen analysis, it seems likely that only in very exceptional circumstances will it be possible to obtain greater certainty about the general vegetational history of an area than is obtained from this rather unsubtle analysis.

II. STRATIGRAPHY AND POLLEN ANALYSIS AT SCALEBY AND OULTON MOSSES

Scaleby Moss and Oulton Moss both lie in hollows in Scottish Readvance drift near Carlisle in Cumberland. Both bogs have developed over lakes initiated during the late-Glacial period. Pollen diagrams have been prepared from both localities and zoned according to the standard British scheme and a local Cumbrian scheme which allows closer subdivision within the small region of the Cumberland Lowland. Radiocarbon assay of samples from Scaleby allows absolute dates to be assigned to some of these zones. The deposits at Scaleby cover a period extending from about 9000 B.C. to about 1000 B.C. and at Oulton from a rather earlier date to the beginning of the Christian era. The ecological history of the mires has been reconstructed so far as the pollen analytical and stratigraphic data allow. Amongst the most interesting subfossil remains recorded are those of *Betula nana*, *Hippophaë rhamnoides*, *Humulus* or *Cannabis*, *Koenigia islandica*, *Montia fontana* spp. *fontana*, *Salix herbacea* and *Pilularia globulifera*.

Introduction

Scaleby and Oulton Mosses are both in the vicinity of Carlisle, about 22 km (13 miles) apart, and both occupy hollows in the drift of the Scottish Readvance Glaciation (figure 4*c*). Scaleby lies on a low hill just above 30 m (100 ft.) O.D. and Oulton Moss on a similar, if rather smaller, hill about 18 m (60 ft.) O.D. Both were close to the maximum extent of the post-Glacial marine transgression but at neither site were marine deposits laid down. It was reasonable to expect, therefore, that the stratigraphic and vegetational histories recorded in these sites would have sufficient common features to provide a standard pollen analytical chronology which might later be extended to more remote districts, and the suitability of the Scaleby deposits for radio-carbon dating provided a welcome link with the absolute chronology.

Geography and stratigraphy

Scaleby Moss (Nat. Grid Ref. 431635)

Scaleby Moss lies 8 km (5 miles) north-north-east of Carlisle on a low spur of boulder clay between Brunstock Beck to the south and a minor tributary of the River Lyne to the north. The boulder clay slopes rise gently from these streams forming a rim about 2 km (about a mile) wide rising to about 35 m (115 ft.) O.D. around the saucer-like depression containing the bog. The long axis of this hollow runs in a north-easterly to south-westerly direction and is 3 km ($1\frac{1}{2}$ miles) long; the hollow is rather less than 2 km (1 mile) wide at its widest point. The immediate environs are similar, gently rolling, boulder clay hills but only 8 km (5 miles) east, and even closer to the south, is the more rugged terrain formed by the outwash sand and gravel of the Main Glaciation. Similar sands, outwash of the retreat of the Scottish Readvance Glaciation, cover several square miles near the mouth of the River Lyne, 4 km (2 miles) north-west of Scaleby. The site is now 8 km (5 miles) from the limits of high tides in the estuaries of the Rivers Eden and Esk, but at some time during the post-Glacial period the waters of the Lyne and the Eden were at least ponded back by a relatively higher sea level and broad alluvial tracts were formed within 5 km (3 miles) of the Moss.

The hollow clearly once contained a single large raised bog, but the surface peat has by now been almost entirely cut away for fuel and the underlying alluvium, exposed across the basin at one point, divides it roughly into two sections, the western Moorcock Plantation and the eastern Scaleby Moss in the narrow sense (figure 4*a*). Moorcock Plantation is covered by a mixture of pine and birch trees and the same mixture has been planted at least around the margins of Scaleby Moss itself whilst much of the surface is covered by the subspontaneous progeny. The peat cutting, at its peak in the Middle Ages when the

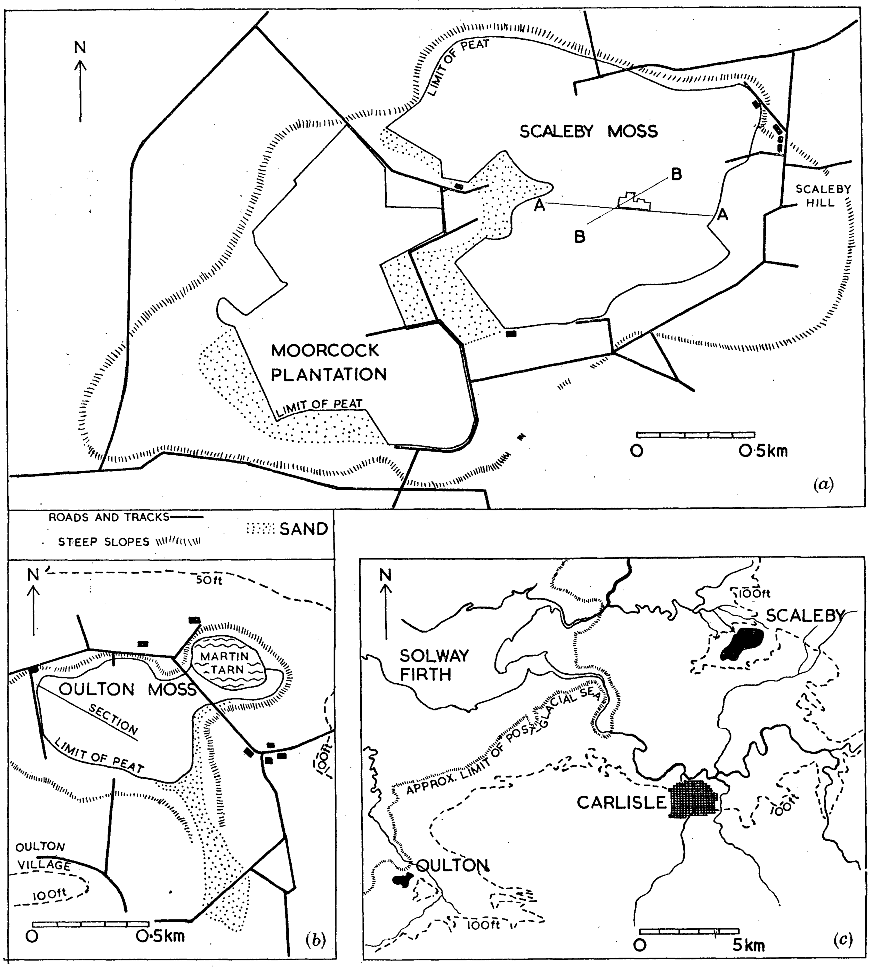


FIGURE 4. Scaleby and Oulton Mosses, Cumberland. (*a*) Scaleby Moss, showing its position in a hollow together with Moorcock Plantation, the position of the remnant of uncut peat and the positions of the series of borings. (*b*) Oulton Moss, showing its position in a basin together with Martin Tarn, and the position of the series of borings. (*c*) The positions of Scaleby and Oulton Mosses relative to the main topographical features, the post-Glacial marine limit and Carlisle.

Moss supplied Carlisle with its main source of fuel, has left a fairly level surface, pitted with hollows marking the final depth of cutting and now filled with regenerating *Sphagnum* communities together with *Eriophorum vaginatum*, *Calluna vulgaris*, *Eriophorum angustifolium*, *Trichophorum caespitosum* and *Erica tetralix*. A small table of peat standing above the general surface of the bog and covered by a uniform stand of *Calluna vulgaris* is thought to represent the last remnant of the original surface and is still being cut back by local inhabitants. The stratigraphy was explored by two series of borings radiating from this remnant and limited to Scaleby Moss in the strict sense (figures 4*a*, 5).

Section *A* ran from the exposed alluvium overlying boulder clay, which now marks the western edge of the Moss, to a point near its eastern margin where cutting had disturbed even the lowermost muds; the line of section ran along the southern face of the upstanding remnant of the upper peats. Section *B* crossed this table from the south-westerly corner and extended for some distance on either side. In addition, the deposits were observed in a pit dug down to the boulder clay in the position of boring 11 on Section *A* for the collection of samples for radiocarbon dating.

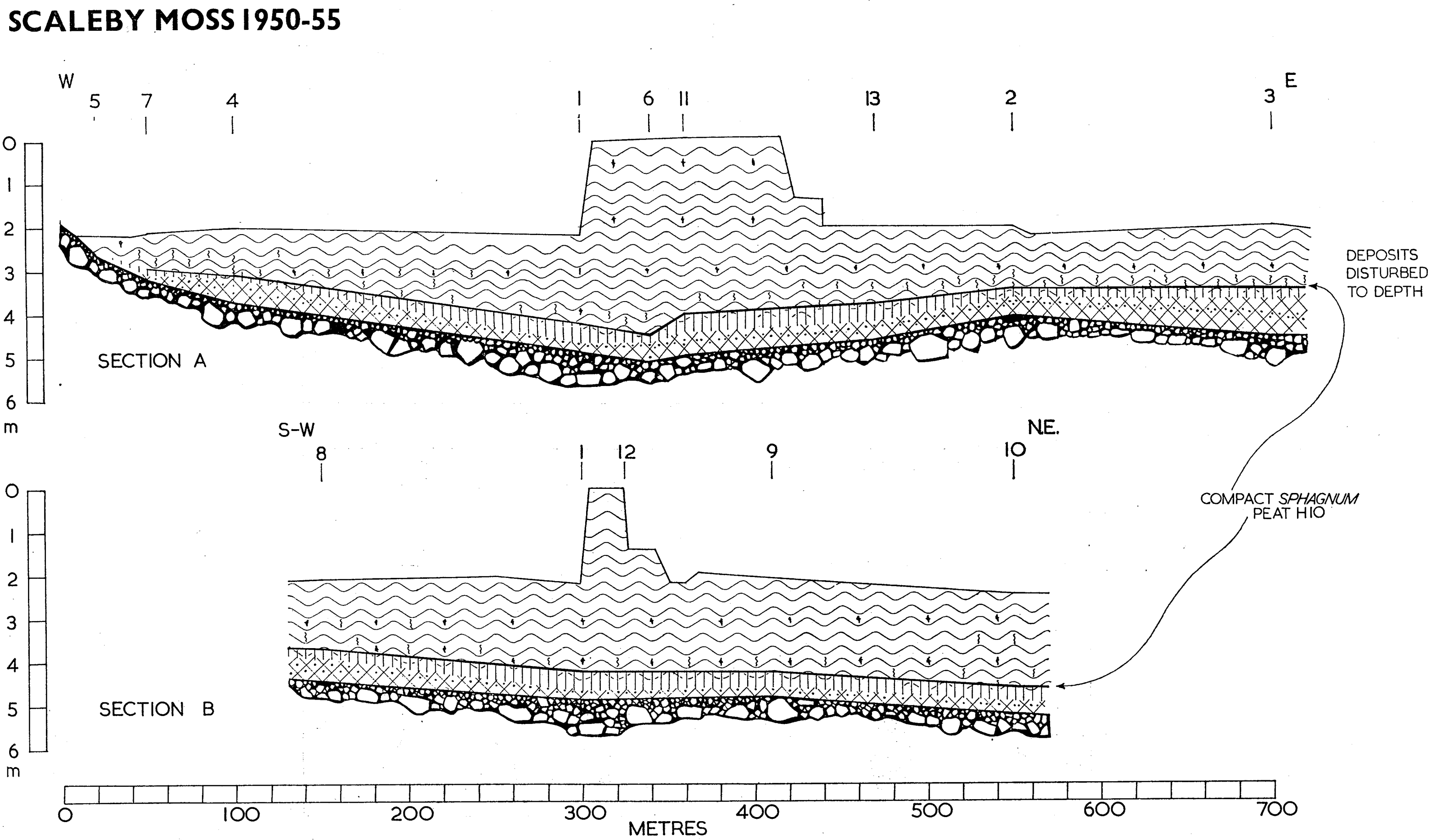


FIGURE 5. Scaleby Moss. Stratigraphy of deposits along Sections *A* and *B* (cf. figure 4*a*).

The boulder clay is sandy at its surface, but nowhere does more than 5 cm of sand intervene between the unchanged pink or greyish bouldery clay and the overlying organic mud, nor is there any sign of a major discontinuity at this level. Above the clay lies 40 to 50 cm of fine brown nekron mud, with a few sandy laminae near the base, and broken by a conspicuously sandy, laminated, band about 10 cm thick in which are embedded pebbles up to 2 cm in greatest dimension. Two such pebbles were cleanly fractured, presumably after deposition, but the two parts remained closely adherent until removed from the mud. These nekron muds are considerably compressed but the sand laminae running through them show no sign of contortion. The sandy band of mud is usually separated from the overlying band of coarser detritus mud by upper nekron mud containing only occasional fruit stones of *Potamogeton* spp. and rootlets of *Equisetum* sp. Here and there, however, the coarser detritus mud, rather rich in *Equisetum*, *Carex* and *Menyanthes* remains but showing very distinct horizontal lamination, directly overlies the sandy nekron mud. This coarse detritus mud is often about 20 cm thick and contains occasional *Sphagnum* plants towards the top where it is sealed by a 4 to 6 cm layer of compact, dark brown, mud with a greasy consistency, rich in remains of *S. cuspidatum* and nutlets of *Carex* sp. Above this band, *Sphagnum* peat extends to the surface. Within it, clear stratigraphical boundaries are difficult to identify in the borer but a range of humification from H5 to H7 is usual. Both *Eriophorum vaginatum* and *Calluna vulgaris* occur throughout the peat but are conspicuously more frequent in the lowest metre. Marked stratigraphic changes can be seen on the faces of the remnant of the younger deposits. On the south face a number of alternating bands of highly humified (H8) *Sphagnum–Calluna* peat and fresher (H3) *Sphagnum* cf. *papillosum* peat lie between 75 and 140 cm below the present surface, the most well marked break between the former and the latter being at about 95 cm at boring point 6 (figure 5). It is difficult to trace any of these 'recurrence surfaces' very far horizontally, however, and the most obvious one at point 12, again about 90 cm below the surface, is certainly of considerably greater age than that at point 6 about 40 m distant (Godwin, Walker & Willis 1957).

The greatest total depth of organic deposits recorded at Scaleby is about 5 m. The nekron muds are evidence that a lake formerly occupied the hollow in the boulder clay, during which time there was at least one distinct period when inorganic material from the edges of the basin commonly spread across it. The lake was probably fairly shallow, for it was soon colonized by sedges and finally overgrown by *Sphagnum*–rich bog communities which converted it to a raised bog.

Oulton Moss (Nat. Grid Ref. 254513)

Oulton Moss lies 12 km (9 miles) west-south-west of Carlisle and 3 km (2 miles) north of Wigton (figure 4*c*). An uneven hill of Scottish Readvance Boulder Clay, 5 km (3 miles) long from west to east and 2 km ($1\frac{1}{2}$ miles) wide from north to south, is bounded on the north and east by the River Wampool and on the south by the Comire Sough and the Wiza Beck, all of which are misfit streams in glacial overflow channels. To the west the hill falls to the artificial Cuddyarch Sough beyond which lies the alluvial spread laid down by the post-Glacial sea at its maximum extent, part of which is obscured by a large raised bog (Wedholme Flow). The hill rises fairly steeply from 12 m (40 ft.) O.D. in the channels to a peripheral ridge which rises, here and there, to 30 m (100 ft.) O.D. The central area is a large shallow and irregular depression in which the combined basin of Oulton Moss and Martin Tarn is deeply sunk. The main basin which contains the Moss is 1 km ($\frac{3}{4}$ mile) from west to east and rather less ($\frac{1}{2}$ mile) from north to south. An irregular, shallow, extension in the south-east corner contains the headstream of the Comire Sough which drains the bog surface. A deeper arm from the north-east corner contains Martin Tarn, surrounded by a fen and woodland, but is probably considerably shallower than the basin of the Moss and divided from it by a ridge of drift, now partly overgrown by peat.

To north, south and east of Oulton Moss the undulating boulder clay surface runs from the Solway to the foothills of the Lake District between 30 m (100 ft.) and 45 m (150 ft.) O.D. frequently cut by deep, steep-sided, glacial overflow channels which mark stages in the retreat of the Scottish Readvance ice (Trotter 1929) and in many of which considerable thicknesses of post-glacial alluvium have accumulated. Westward and north-westward, however, the boulder clay occurs on the surface only where drumlins rise through the post-Glacial marine terraces and the bogs which, in part, cover them. Oulton Moss is now over 6 km (4 miles) from the high water mark of ordinary tides but marine alluvium lies only 1 km ($\frac{1}{2}$ mile) from its edge and during its deposition the Wampool, Wiza and Waver valleys must have so flooded as to render the Oulton Hill an island.

The surface of the Moss lies at about 12 m (40 ft.) O.D. and has been at least partially cut over for fuel, presumably to supply the village of Oulton near its southern edge. The eastern end is covered by a plantation of pine with some birch and subspontaneous stands of these are scattered on other parts of the Moss. The undergrowth of the plantation is *Calluna*-dominated with *Rubus fruticosus* and *Molinia caerulea* common. The rest of the surface is also *Calluna*-rich with varying contributions from *Sphagnum* spp., *Trichophorum caespitosum*, *Eriophorum vaginatum* and *Myrica gale*.

The stratigraphy was explored by a single line of borings running into the Moss in a south-easterly direction from the north-west corner (figure 4*b*, 6). This series was supplemented by a number of isolated borings in the arm of the hollow extending towards Martin Tarn and in the far south-eastern corner of the Moss, in all of which only shallow bog peat was found overlying a few centimetres of organic mud. It is evident that the section (figure 6) crosses the deepest part of the basin and the steep sides and great depth of the latter beneath the organic fill confirm that it originated as a glacial kettle hole. The deposits were not bottomed in the middle but the indications of nearby borings suggest that they are nowhere more than about 15 m thick. The margins of the basin are in coarse grey sand and gravel which outcrops on the surface here and there around the edges of the Moss. The lower part of the basin, however, is bounded by a stony clay, grey in the top few centimetres but becoming very stiff, pink, and impenetrable beneath. It is assumed that this is the surface of the boulder clay. The basal organic deposit is a buff fine detritus mud, moderately clayey in the basal 10 cm which also include a few narrow horizontal layers of coarse sand. In the bottom of the basin the full thickness of this fine detritus mud may be as much as 120 cm but on the margins it is much thinner and contains a greater mixture of sand and silt. It is covered by a layer of light buff clay-mud, rather silty at the base, which is continuous marginally with a grey sandy clay. This clay-mud may be as much as 50 cm thick but is usually 10 to 20 cm thick. In the deeps of the basin it grades upwards into a buff nekron mud, almost entirely free of macroscopic detritus but containing occasional horizontal laminae of coarse sand. It is covered by up to 40 cm of fine detritus mud, rich in rootlet fragments, a similar deposit to which immediately overlies the clay mud on the margins of the basin. In the central region this mud becomes coarser at the top and grades into mud rich in *Carex* remains and containing some leaves of *Sphagnum cuspidatum*. Marginally, this stratigraphic position is occupied by up to 20 cm of dark brown, very compressed mud, rich in *S. cuspidatum* remains with *Equisetum* rootlets and occasional *Carex* stems. This is usually overlain by coarse *Carex–Phragmites* peat,

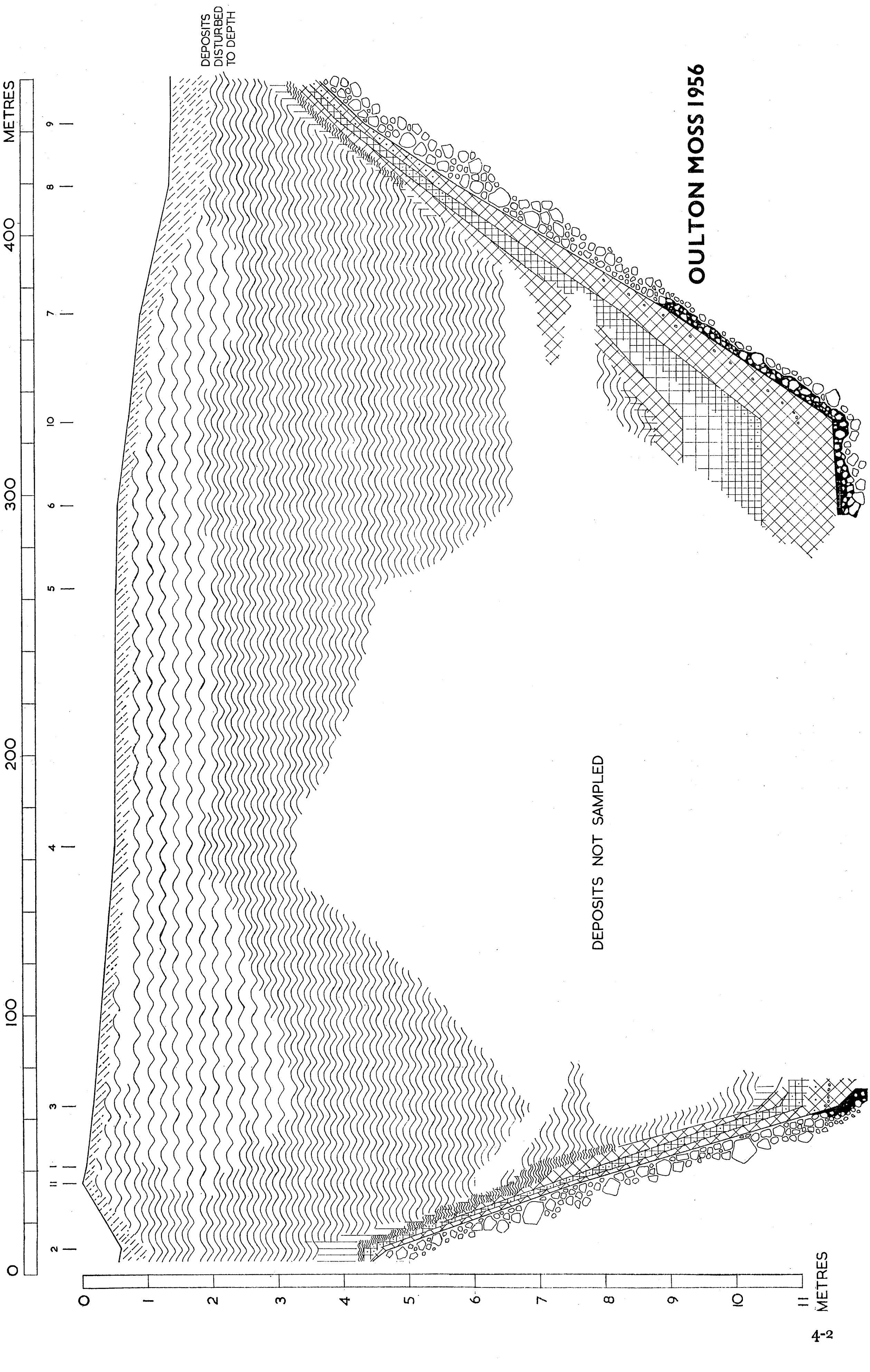


FIGURE 6. Oulton Moss. Stratigraphy of deposits along section (cf. figure 4*b*).

thickening marginally and containing rare fragments of *Alnus* wood. All these deposits, in the middle as well as at the edges of the basin, are covered by unconsolidated *Sphagnum* peat (H 7–8). For great depths in the middle of the section the deposit is so liquid, if indeed it is anything more than a suspension of detritus in water, as to prevent the borer from sampling. It is clear, however, that for a very long time the basin contained a thriving *Sphagnum* mire of the most unstable kind, probably a floating mat of *Sphagnum* with occasional tufts of *Erica tetralix*, *Calluna vulgaris* and *Eriophorum vaginatum*. As the marginal regions filled with the remains of this community, the centre of the raft became continuous and a substantial thickness of peat was formed there. After at least a metre of this kind of accumulation in the centre, however, conditions there changed to allow the accumulation of a less humified *Sphagnum* peat (H 3–4), containing fragments of *Eriophorum* and *Calluna*, which immediately underlies the present surface over the greater part of the Moss.

The earliest deposits in the basin represent accumulation under open water in eutrophic conditions. For a time during this accumulation, however, the lake was relatively unproductive and the clay-mud was deposited. The marginal occurrence of these muds suggests that the water level at the time of their deposition cannot have been much lower than is the bog surface now. Oligotrophic conditions supervened which probably suspended accumulation in the middle of the basin until a *Sphagnum*-dominated mat had grown out from the edges.

Pollen diagrams and chronology

At Scaleby Moss samples for pollen analysis were collected, in 1950, from the peat face at point 6 (figure 5) and the series was extended to the bottom of the deposits by a boring at the same point. These results are presented in one continuous diagram (Scaleby Moss A, figure 9). In 1955 the deposits were sampled for radiocarbon dating. A pit was dug from the cut surface in front of the peat face at point 11 (figure 5) to the underlying boulder clay and a continuous monolith sample removed for laboratory examination and sampling. The peat face immediately above this pit was slumped and eroded so the upper deposits were sampled by a similar monolith from a fresh face at point 12 (figure 5). The lowest mud and peat represented in the first monolith was pollen analysed at close intervals and the results are shown in the diagram Scaleby Moss B (figure 7). In other parts of the monolith, pollen analysis was used only to localize horizons identified pollen analytically in diagram A (figure 9). Horizontal slices were then cut from appropriate levels in both monoliths and dated by radiocarbon assay. The dates were then applied to the equivalent pollen-analytical levels in diagram A (Godwin *et al.* 1957; Godwin & Willis 1959*a*; Godwin & Willis 1960). Samples were also collected from alongside the pollen analytical samples taken from the lowermost deposits for the determination of the relative organic and inorganic contents at the various levels. A glass tube of 1·6 cm bore was pressed into the peat face for 4 cm at the appropriate level. The tube containing the sample was then removed and the peat extruded for analysis. The results (figure 7) show organic content as percentages of dry weight at 100 °C of each sample of 8·0 cm^3 natural wet volume. The remainder of the lower portion of that monolith was then divided into sections for the extraction and identification of macroscopic plant remains (table 1, p. 45). The stratigraphic descriptions appropriate to the two pollen diagrams are as follows:

Scaleby Moss A (*point* 6, *figures* 5 *and* 9); *upper peat section*. Zero is uncut peat surface

cm	
0–64	dark brown *Sphagnum* peat with very occasional *Calluna* fragments. H 3
64–68	*Eriophorum vaginatum* in *Sphagnum* peat. H 3
68–75	dark brown *Sphagnum* peat. H 3
75–79	light brown *S. cuspidatum* peat. H 5
79–80	medium brown, compressed, 'greasy', *S. cuspidatum* mud with *Menyanthes* epidermis. H 9
80–85	light brown *Sphagnum* peat. H 5
85–95	*Eriophorum vaginatum* in *Sphagnum* peat. H 5
95–106	dark brown *Sphagnum–Calluna* peat, rich in rootlets, with occasional *Eriophorum vaginatum*
106–126	light brown *Sphagnum* peat with occasional *Calluna* remains. H 5
126–142	light brown *Sphagnum* peat with abundant *Calluna* remains. H 5
142–156	light brown *Sphagnum–Eriophorum vaginatum* peat. H 5

Scaleby Moss A (*point* 6, *figures* 5 *and* 9); *continuation downwards in boring*. Zero is uncut peat surface

cm	
156–165	light brown, rather muddy, *Sphagnum* peat. H 6
165–436	dark brown *Sphagnum* peat with occasional *Calluna* remains. *Eriophorum vaginatum* abundant at 274–276 cm and 310–315 cm. H 5
436–444	coarse detritus mud with *Sphagnum* and *Carex* remains and *Menyanthes* seeds
444–450	black, 'greasy', compact *Sphagnum–Carex* mud
450–465	coarse detritus mud with *Sphagnum* and *Carex* remains
465–477	grey-brown, finely sandy, mud with *Equisetum* rootlets
477–510	medium brown fine detritus mud, slightly sandy throughout, but increasingly so towards the base
510+	grey sand, clay and gravel over impenetrable boulder clay

Scaleby Moss B (*point* 11, *figures* 5 *and* 7); *pit section*. Zero is top of pollen diagram, about 350 cm below the uncut surface

cm	
0–33	medium brown, compact, *Sphagnum–Eriophorum vaginatum* peat with frequent *Calluna* fragments. H 7
33–35	*Eriophorum vaginatum* in *Sphagnum* peat
35–41	very compact, 'greasy', *S. cuspidatum* mud. H 9
41–51	light brown, friable, *Sphagnum* peat with common *Menyanthes* and *Equisetum* remains and occasional *Carex* stems. H 3
51–69	Compact, laminated, coarse detritus mud with abundant *Menyanthes* and *Equisetum* remains
69–80	greyish brown, fairly coarse detritus mud with abundant *Equisetum* roots. Slightly clayey and silty with abundant pebbles, some fractured
80–97	medium brown, slightly laminated, fine detritus mud, commonly with *Equisetum* remains

cm	
97–110	medium brown, slightly laminated, slightly silty fine detritus mud
110–118	as above, with occasional *Equisetum* remains
118–131	as above with frequent laminae of fine sand
131+	coarse gravelly clay over boulder clay

At Oulton Moss there seemed to be no place suitable for the collection of a single series of pollen samples at which all stages in the infilling of the basin were well represented. Accordingly, in 1956, the upper deposits were sampled in boring 11 (figure 6) although, even there, it was impossible to open the borer between 600 and 650 cm depth. The lower deposits were sampled in boring 10 (figure 6) where they were well developed but where much of the later part of the sequence was missing or not sampleable. Material for the extraction of macroscopic plant remains was obtained from a number of borings made to the same level within 2 m of boring 10. The appropriate stratigraphic descriptions are as follows:

Oulton Moss A (*point* 11, *figures* 6 *and* 10). Zero is ground surface

cm	
0–10	disturbed peat
10–75	dark brown *Sphagnum–Molinia* peat with occasional *Calluna* fragments. H4
75–243	golden-brown *Sphagnum* peat with occasional *Calluna*. H2 *Eriophorum vaginatum* common 130–150 cm
243–250	compact *Sphagnum cuspidatum* peat. H7
250–363	medium brown *Sphagnum* peat containing much *S. cuspidatum*. H5–7. *Eriophorum vaginatum* at 280 cm
363–377	light brown *Sphagnum cuspidatum* peat. H8
377–395	medium brown *Sphagnum–Calluna* peat. H7
395–450	light brown *Sphagnum cuspidatum* peat with occasional *Calluna* fragments. H9
450–600	medium brown *Sphagnum–Calluna* peat with rare *Eriophorum vaginatum*. H8
600–650	unsampled: borer would not open
650–660	dark brown amorphous peat. H9
660–692	black, compact, 'greasy', mud, with *Sphagnum cuspidatum*, *Carex* and *Equisetum* remains
692–705	medium brown fine detritus mud with *Sphagnum* remains and rare *Menyanthes* seeds
705–722	medium brown fine detritus mud with rare *Equisetum* remains
722–739	grey-brown, silty, clay-mud with pebble
739–760	buff, slightly clayey, nekron mud with coarse sand layer at 750 cm
760+	grey sandy clay

Oulton Moss B (*point* 10, *figures* 6 *and* 8). Zero is ground surface

cm	
0–15	disturbed peat
15–105	medium brown *Sphagnum* peat with occasional *Calluna*, *Eriophorum vaginatum* and *Molinia* remains. H3–5

cm	
105–550	medium brown *Sphagnum–Calluna* peat with rare *Eriophorum vaginatum*. H 8
550–750	unsampled: borer would not open
750–773	dark brown *Sphagnum–Calluna* peat with *Eriophorum vaginatum*. H 6
773–785	dark brown, rather fluid, peat. H 9
785–800	coarse detritus mud, with *Sphagnum cuspidatum*
800–844	medium brown fine detritus mud with abundant rootlets
844–910	buff nekron mud, almost free of detritus, slightly clayey towards the base and with sand laminae at 852, 853, 856, 872, 879 and 886 cm
910–950	grey-brown clay mud without organic detritus
950–965	grey slightly silty clay mud
965–1075	buff fine detritus mud with occasional silty laminae and coarsely sandy band at 1020–1022 cm
1075-	Red sand over boulder clay

The zonation of the pollen diagrams was carried out independently for each diagram but the parallelism is such as to allow their joint description. Zones C 1 to C 4 of the local Cumbrian Zonation (parts of Zone I of the British Standard Zonation), although represented elsewhere in Cumberland, are not covered by any of the deposits from Scaleby or Oulton. Radiocarbon dates are attributed to the zonation as a result of assays from Scaleby samples only, the exact pollen analytical positions of which are shown in figures 7 and 9.

British Zone I. Cumbrian Zones C 1 to C 4

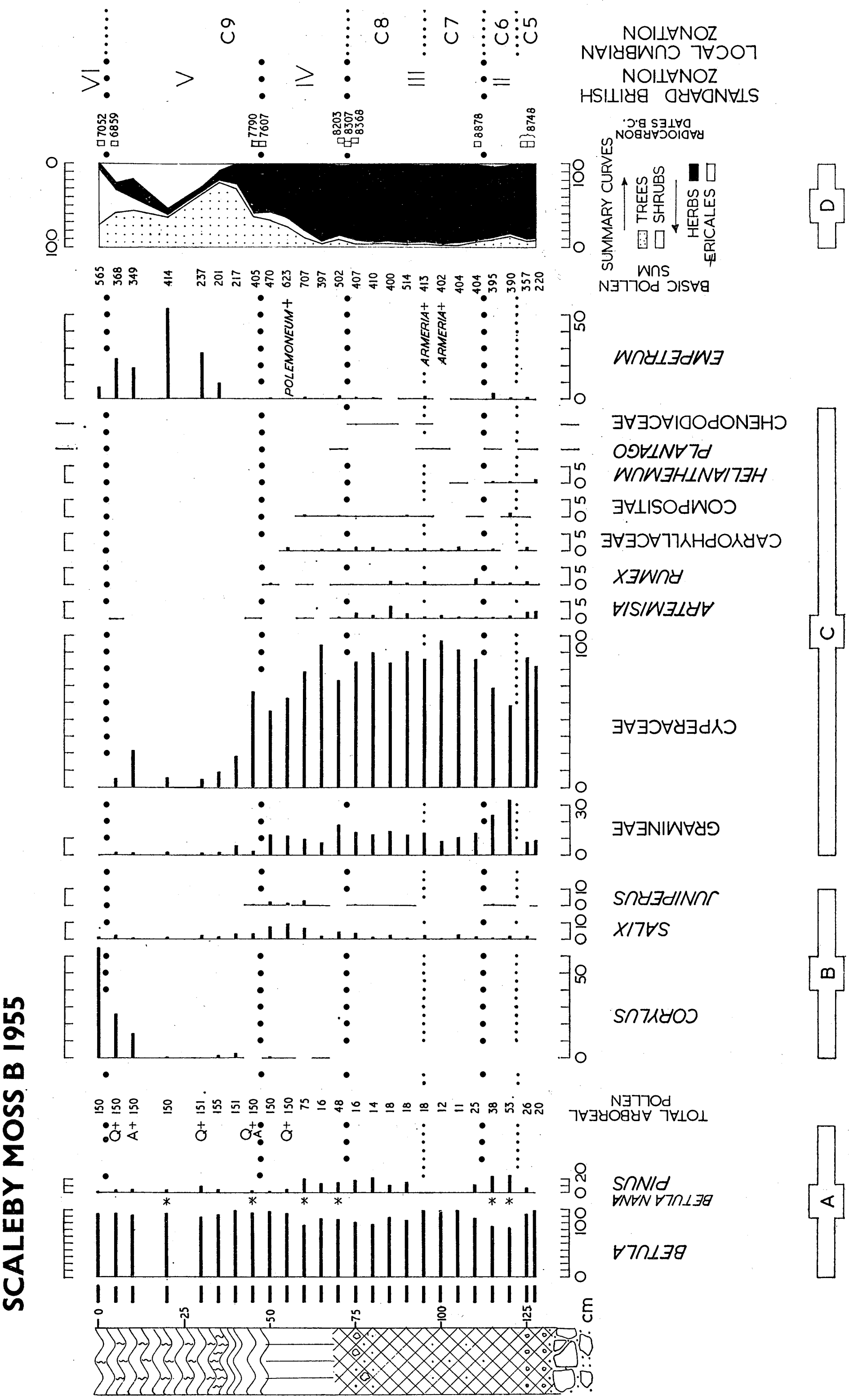
Not represented at Scaleby or Oulton.

British Zone II

Cumbrian Zone C 5 Scaleby B, 127–122 cm
Oulton B, 1065–1110 cm

Dry-land herb pollen dominant over that of trees and shrubs, although the latter become increasingly frequent through the zone. *Betula* pollen almost totally dominant amongst trees; *Pinus* pollen is low throughout. *Artemisia* and *Rumex* values fall through the zone. *Empetrum* values are low and variable. In addition to Gramineae and Cyperaceae, six types at Scaleby and seven types at Oulton contribute to the total land herb curve (Group C). An additional nine types at Scaleby and nine types at Oulton (excluding *Calluna*) are included amongst non-aquatic herbs of otherwise uncertain ecological provenance (Group E). At Scaleby, Cyperaceae are much more abundant than Gramineae; at Oulton, Gramineae are about twice as abundant as Cyperaceae. At Oulton, the frequency of *Betula* cf. *nana*, whilst low throughout, falls through the zone. *Juniperus*, insignificant at Scaleby, rises to a maximum and falls to the end of the zone at Oulton. It seems probable that only the upper part of the zone is represented at Scaleby. A date of 8748 ± 207 B.C. was obtained for a combined sample spanning 123–127 cm at Scaleby B.

Cumbrian Zone C 6 Scaleby B, 122–112 cm
Oulton B, 1110–960 cm


SCALEBY MOSS B 1955
BETULA
BETULA NANA
PINUS
TOTAL ARBOREAL POLLEN
CORYLUS
SALIX
JUNIPERUS
GRAMINEAE
CYPERACEAE
ARTEMISIA
RUMEX
CARYOPHYLLACEAE
COMPOSITAE
HELIANTHEMUM
PLANTAGO
CHENOPODIACEAE
EMPETRUM
POLEMONEUM+
ARMERIA+
BASIC POLLEN SUM
SUMMARY CURVES
TREES
SHRUBS
HERBS
ERICALES
RADIOCARBON DATES B.C.
STANDARD BRITISH ZONATION
LOCAL CUMBRIAN ZONATION
A
B
C
D
cm

SCALEBY MOSS B 1955

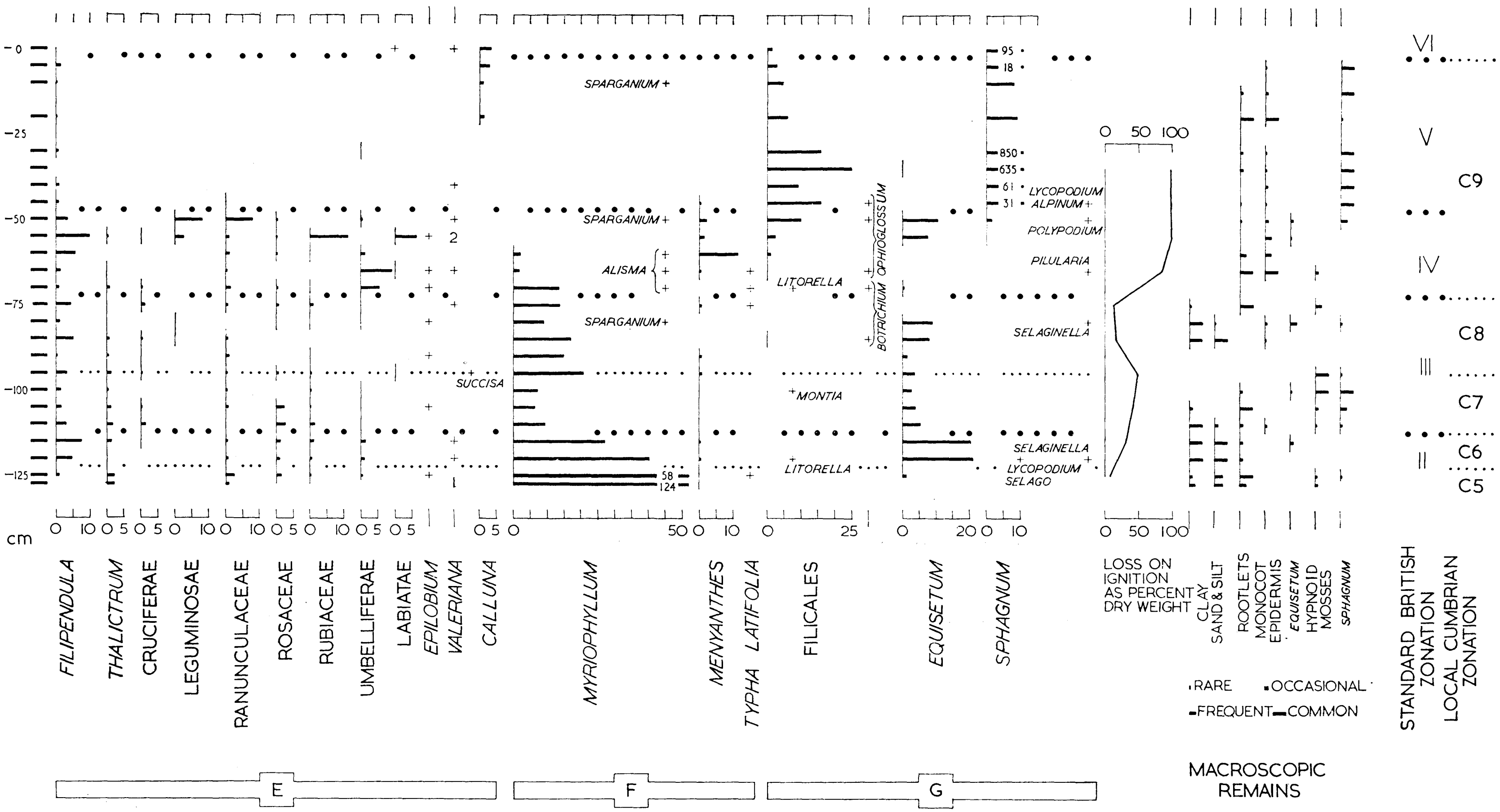
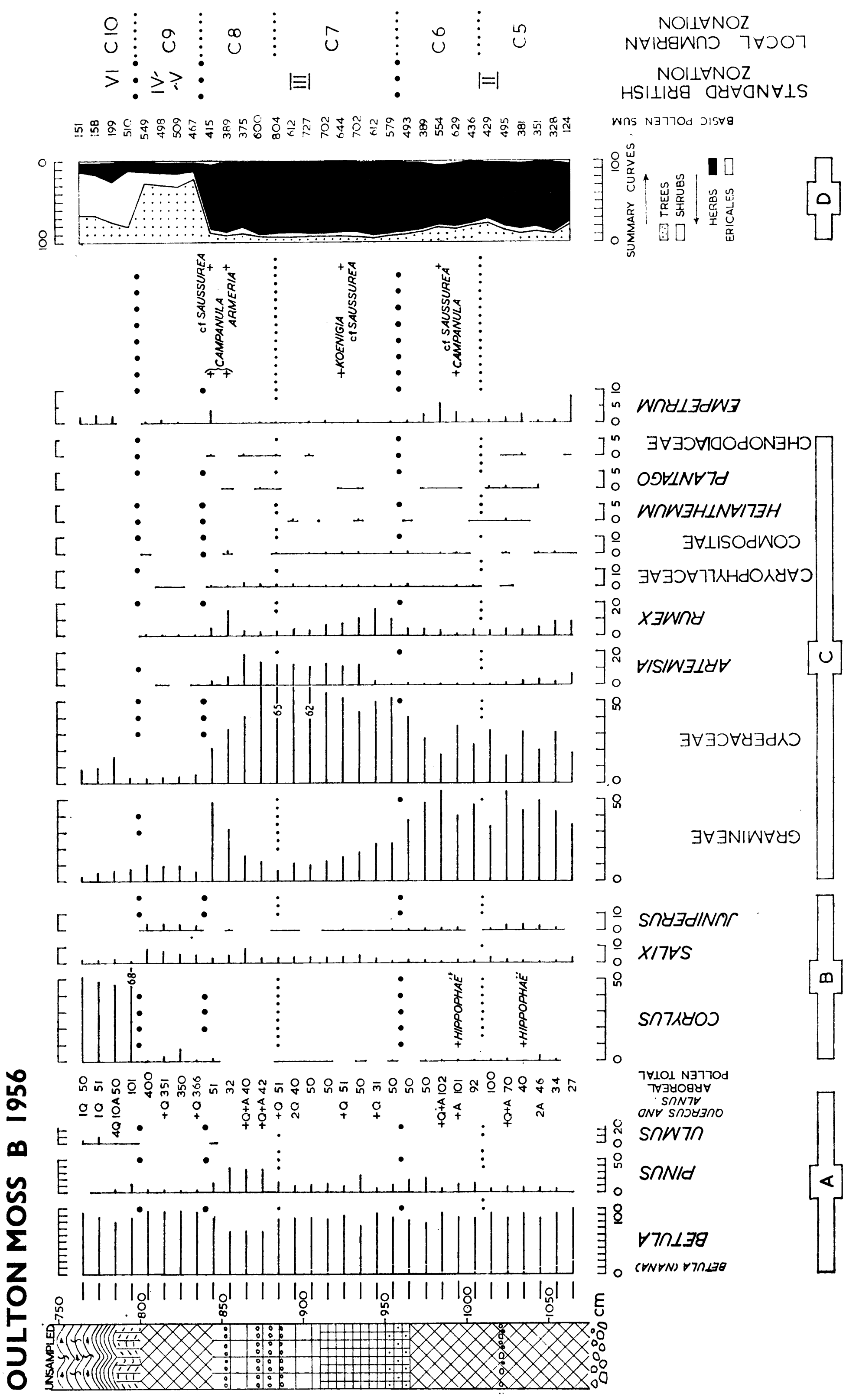


Figure 7. Scaleby Moss B. Pollen diagram through the late-Glacial and early post-Glacial deposits. Section A: individual trees. Section B: individual shrubs. Section C: individual land herbs. Section D: summary curves for land flora (A+B+C+Ericales). Section E: individual taxa of uncertain ecology. Section F: individual aquatic herbs. Section G: individual Pteridophyta and Bryophyta. The pollen frequencies in Section A are shown as percentages of the sum of Section A pollen (= arboreal pollen total) of the appropriate sample. The pollen and spore frequencies in the other sections are shown as percentages of the basic pollen sum (A+B+C+Ericales) of the appropriate sample.


OULTON MOSS B 1956
BETULA (NANA)
PINUS
ULMUS
QUERCUS AND ALNUS ARBOREAL POLLEN TOTAL
CORYLUS
SALIX
JUNIPERUS
GRAMINEAE
CYPERACEAE
ARTEMISIA
RUMEX
CARYOPHYLLACEAE
COMPOSITAE
HELIANTHEMUM
PLANTAGO
CHENOPODIACEAE
EMPETRUM
SUMMARY CURVES
TREES
SHRUBS
HERBS
ERICALES
BASIC POLLEN SUM
STANDARD BRITISH ZONATION
LOCAL CUMBRIAN ZONATION
UNSAMPLED
cm

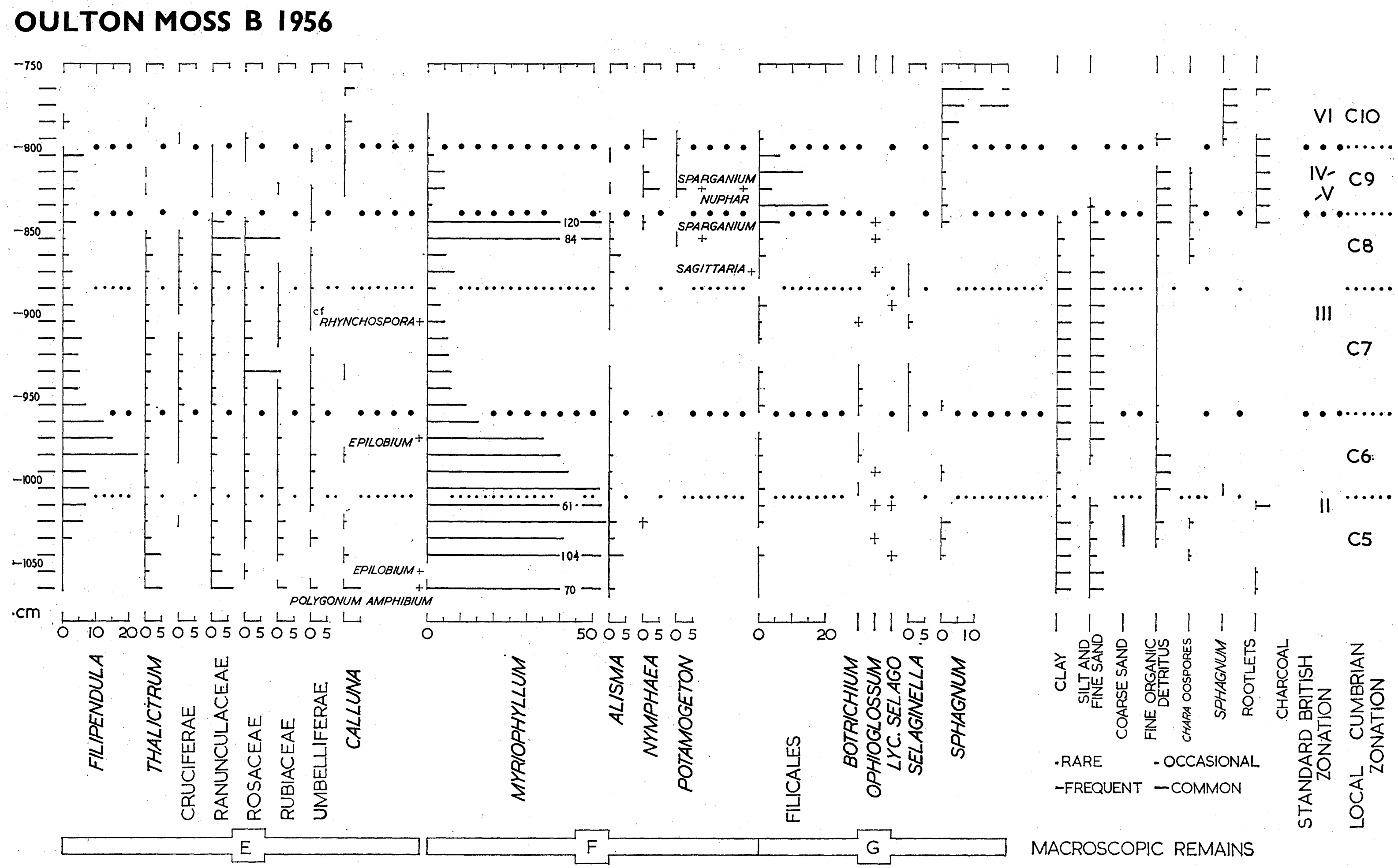


FIGURE 8. Oulton Moss B. Pollen diagram through the late-Glacial and early post-Glacial deposits. Section A: individual trees. Section B: individual shrubs. Section C: individual land herbs. Section D: summary curves for land flora (A+B+C+Ericales). Section E: individual taxa of uncertain ecology. Section F: individual aquatic herbs. Section G: individual Pteridophyta and Bryophyta. The pollen frequencies in Section A are shown as percentages of the sum of Section A pollen (= arboreal pollen total) of the appropriate sample. The pollen and spore frequencies in the other sections are shown as percentages of the basic pollen sum (A+B+C+Ericales) of the appropriate sample.

Dry-land herb pollen dominant over that of trees and shrubs and increasing this dominance from the base to the top of the zone. *Pinus* pollen more frequent than formerly, representing about 20% of combined *Pinus* and *Betula* frequencies. *Artemisia* and *Rumex* values low, the latter beginning to rise at the top. *Empetrum* attains a maximum at the top of the zone at Scaleby and in the middle at Oulton. *Juniperus* is consistently present but not important. *Betula* cf. *nana* is present throughout, becoming more frequent near the top at Oulton. At Scaleby, Cyperaceae, although reduced from Zone C 5, remains slightly more abundant than Gramineae; at Oulton the relative positions are reversed. In addition to Cyperaceae and Gramineae six types at Scaleby and eight types at Oulton contribute to Group C; the corresponding figures for Group E are 8 and 9.

British Zone III

Cumbrian Zone C 7 — Scaleby B, 112–95 cm
Oulton B, 960–885 cm

Tree and shrub pollen represents only 10% or less of the total pollen of land plants. At Scaleby, *Pinus* is insignificant and at Oulton it is low in comparison with *Betula* and with its own values in preceding and subsequent zones. *Betula* cf. *nana* is not recorded from Scaleby and is variable in frequency at Oulton. *Juniperus* is hardly significant, but *Salix* is more abundant than in earlier zones. The Gramineae values fall and Cyperaceae values rise through the zone. At Oulton, an initial maximum of *Rumex* is succeeded and replaced by a rise in, and maintained high values of, *Artemisia*. These phenomena, together with slight changes in the frequencies of *Salix*, Gramineae and Cyperaceae might justify a division of the zone at 940 cm. A similar, but even less justifiable, division might be made at 105 cm at Scaleby. At Scaleby and Oulton nine types in addition to Gramineae and Cyperaceae contribute to Group C; corresponding figures for Group E are nine at Scaleby and eight at Oulton. Radiocarbon assay of a sample from 109·5 to 111·5 cm at Scaleby, gave a date of 8878 ± 185 B.C. for the early part of this zone.

Cumbrian Zone C 8 — Scaleby B, 95–72 cm
Oulton B, 885–840 cm

Dry-land herbs maintain their high combined frequency in comparison with trees and shrubs. Amongst the latter *Pinus* is much more important than formerly, rising to 20% of total tree pollen at Scaleby and almost double these values at Oulton where, however, it falls away at the top of the zone. *Betula* cf. *nana* is absent from Scaleby and only sporadic in occurrence at Oulton. *Salix* is slightly more abundant than formerly but *Juniperus*, though present, is hardly significant. At Scaleby the zone is very uniform, except for a central maximum of *Artemisia* which might be taken to divide an early part in which *Rumex* and Caryophyllaceae are equally frequent from a later part where *Rumex* is insignificant and Caryophyllaceae correspondingly more frequent. At Oulton, Gramineae values rise from the bottom of the zone and become greater than the falling values for Cyperaceae at 860 cm. The same level marks the point where *Artemisia* falls and *Rumex* rises sharply before itself falling to the end of the zone. *Empetrum* increases almost imperceptibly at the top of the zone at Scaleby but has a pronounced if isolated maximum in a roughly corresponding position at Oulton. Although Group C contains, in addition to

Gramineae and Cyperaceae, six types at Scaleby and nine types at Oulton, all but three of these (*Artemisia*, *Rumex* and Caryophyllaceae) are sparingly and inconsistently present. The same is true of Group E which contains ten types at Scaleby and seven types at Oulton. The radiocarbon age of a Scaleby sample straddling the boundary between this zone and the next above, i.e. 71·5 to 73·5 cm, was determined as 8307 ± *ca.* 350 B.C. A sample immediately beneath this, 73·5 to 75·5 cm, was dated as 8368 ± 215 B.C.

On the criterion of the balance between dry-land herbs on the one hand and trees and shrubs on the other, the top of zone C8 probably lies at 470 cm in Scaleby diagram A and at 705 cm in Oulton diagram A. The samples below these levels are probably, but not certainly, all referable to Zone C8, differences in the recorded values for *Juniperus*, *Artemisia*, etc., in the two Oulton diagrams resulting from the different basis of calculation.

British Zones IV and V

Cumbrian Zone C9 Scaleby A, 470–385 cm; B, 72–2 cm
Oulton A, 705–660 cm; B, 840–800 cm

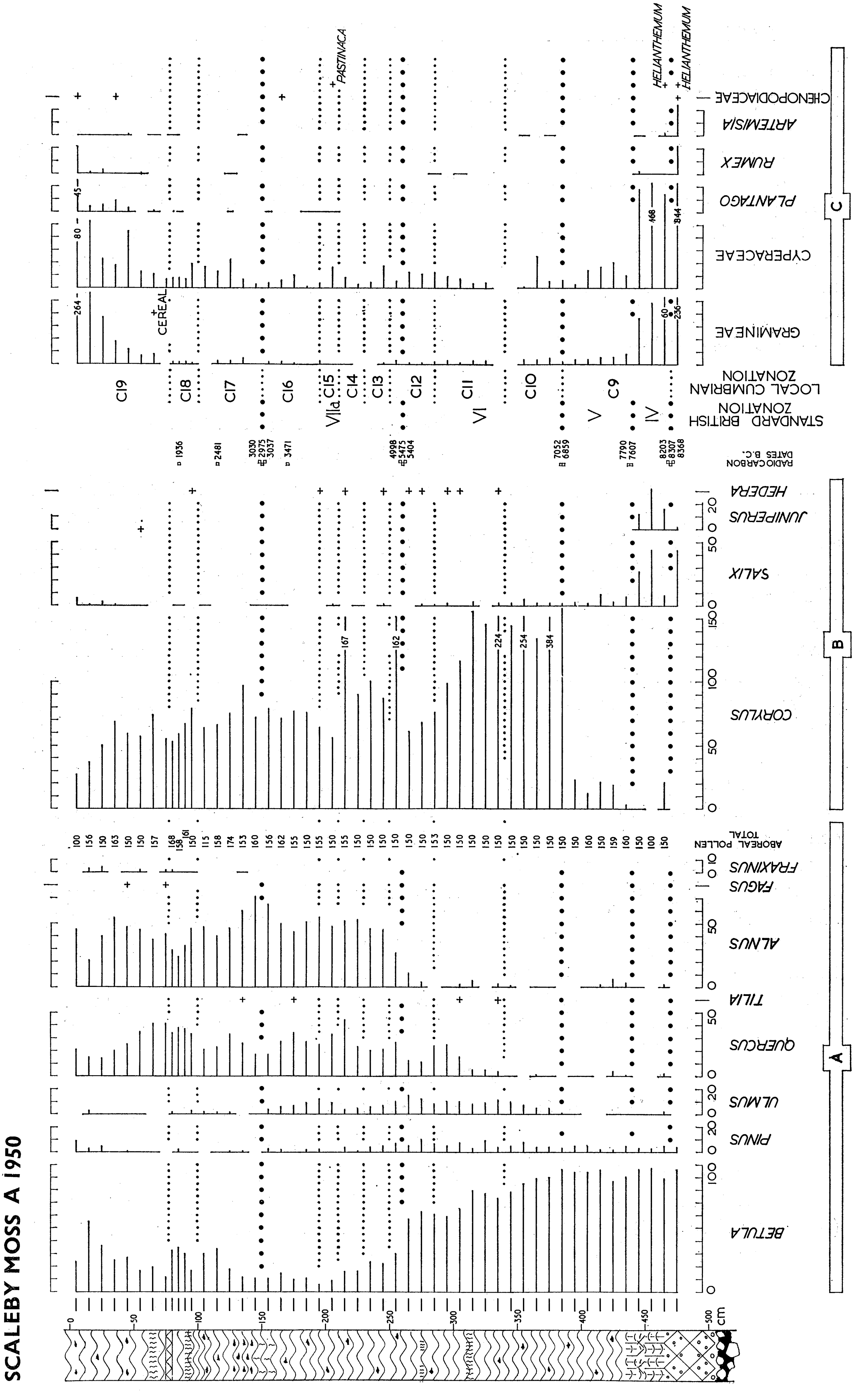
Trees and shrubs more abundant than dry-land herbs, high values of Gramineae and Cyperaceae being discounted in the face of stratigraphic evidence for reedswamp at this stage. *Betula* is the dominant tree and *Pinus*, though undoubtedly representing local trees, is erratic in level, nowhere exceeding 10% of total arboreal pollen. Infrequent occurrences of other tree pollen are thought to be due to contamination of samples at some stage. *Corylus* occurs here and there in considerable frequencies and is consistently present in slowly increasing values towards the top of the zone. *Juniperus* and *Salix* occur in higher frequencies than they have ever previously attained. Herbs of Groups C and E often persist into the lower part of the zone in insignificant amounts, except for *Filipendula* and Umbelliferae which are often abundant. At Scaleby, a subdivision of the zone into British Zones IV and V has been attempted. The border has been drawn where *Juniperus*, *Salix*, Gramineae and Cyperaceae curves fall from high to low values (A440 cm, B47 cm) and where *Corylus* becomes consistently present in diagram A. Zone V so defined, however, contains a great expansion of *Empetrum* of which there is some indication in Oulton A but none in Oulton B. It seems very likely, therefore, that Zone C9 was a period of very varied vegetation and rapid seral change both in hydroseres and in the surrounding country and its subdivision is hardly justifiable. At Scaleby B a date of 8203 ± 193 B.C. was obtained by radiocarbon assay of a sample from 69·5 to 71·5 cm. Another sample from the top of the zone, 3·5 to 5·5 cm, gave a date of 6859 ± 192 B.C.

Two samples straddling the boundary between supposed Zones IV and V at 46·5 to 48·5 cm and 44·5 to 46·5 cm gave dates of 7607 ± 209 B.C. and 7790 ± 183 B.C. respectively.

British Zone VI

Cumbrian Zone C10 Scaleby A, 385–340 cm; B, 0 cm
Oulton A, 655 cm; B, 765 cm

Corylus is the most abundant type attaining values between 100 and 350% of total arboreal pollen. *Betula* values fall as *Ulmus* values rise from the base to about 10% *AP* (Arboreal pollen total) at the top. *Pinus* values do not exceed 5% *AP*. *Salix*, though low in


SCALEBY MOSS A 1950
BETULA
PINUS
ULMUS
QUERCUS
TILIA
ALNUS
FAGUS
FRAXINUS
ABOREAL POLLEN TOTAL
CORYLUS
SALIX
JUNIPERUS
HEDERA
RADIOCARBON DATES B.C.
STANDARD BRITISH ZONATION
LOCAL CUMBRIAN ZONATION
GRAMINEAE
CYPERACEAE
PLANTAGO
RUMEX
ARTEMISIA
CHENOPODIACEAE
HELIANTHEMUM
PASTINACA
CEREAL
A
B
C
cm

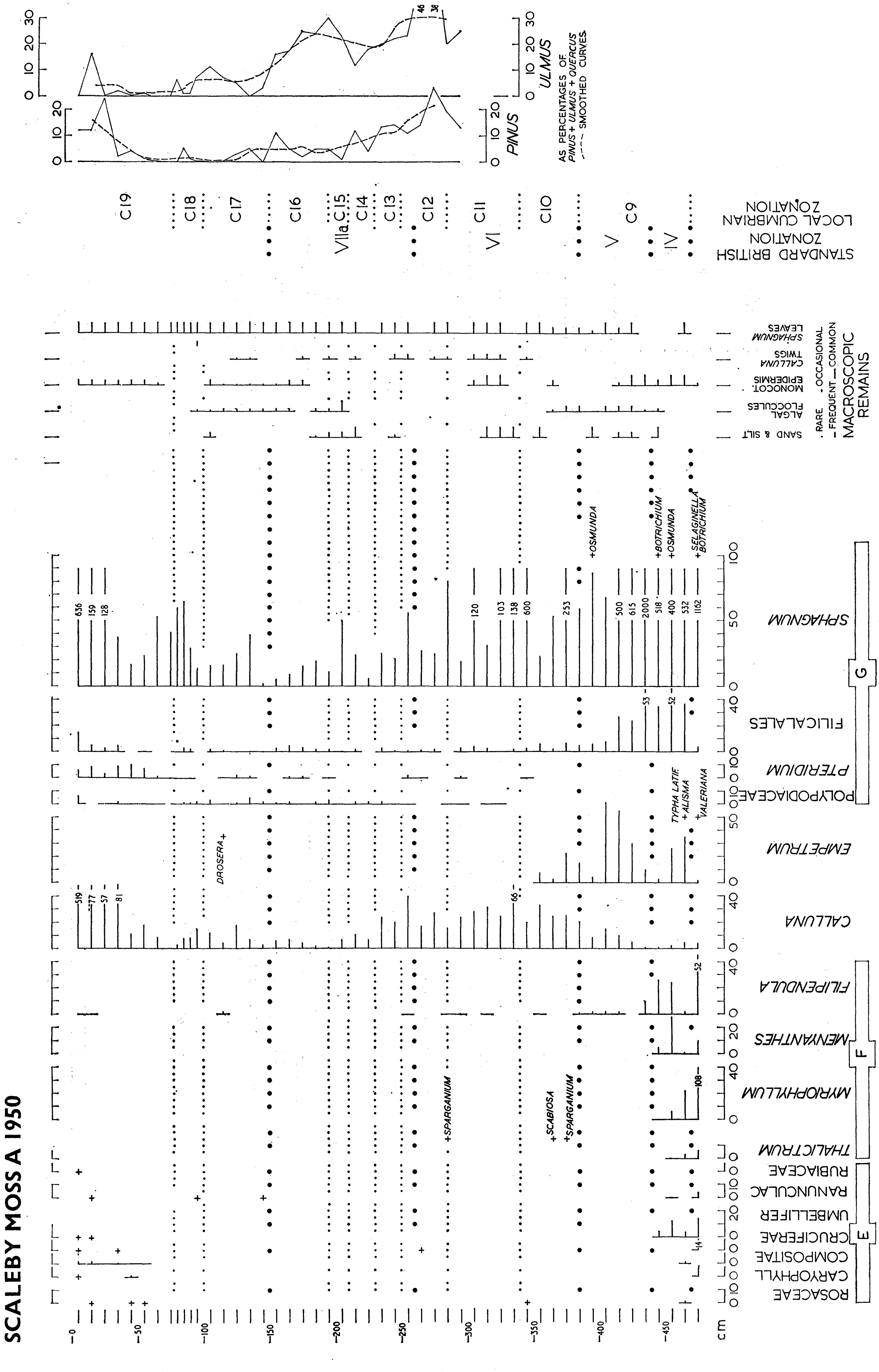
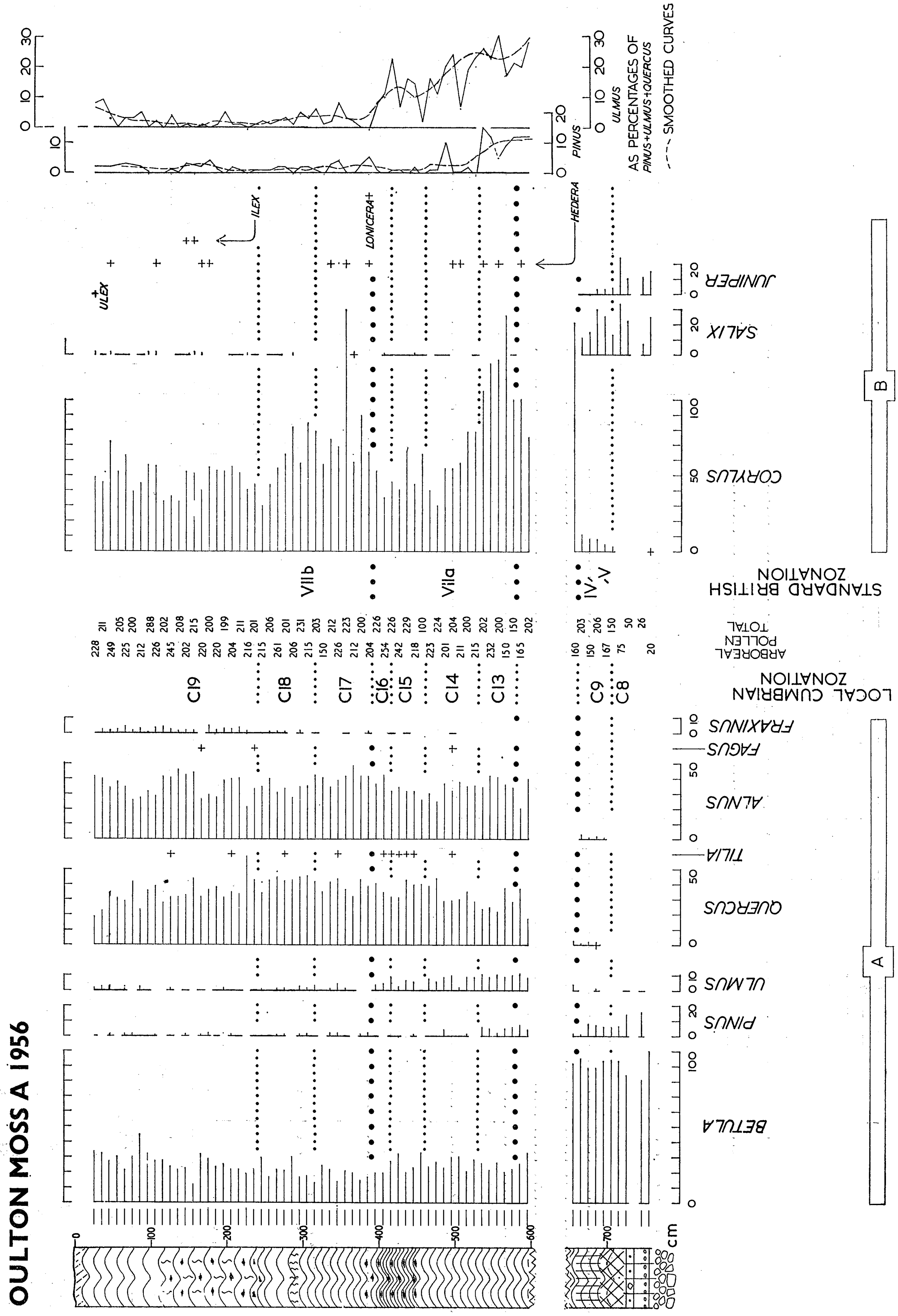


FIGURE 9. Scaleby Moss A. Pollen diagram through the post-Glacial deposits. Section A: individual trees. Section B: individual shrubs. Section C: individual land herbs. Section E: individual taxa of uncertain ecology. Section F: individual aquatic herbs. Section G: individual Pteridophyta and Bryophyta. The frequencies of pollen or spores of all taxa are shown as percentages of the arboreal pollen total (Section A) of the appropriate sample.


OULTON MOSS A 1956
BETULA
PINUS
ULMUS
QUERCUS
TILIA
ALNUS
FAGUS
FRAXINUS
LOCAL CUMBRIAN ZONATION
C8
C9
C13
C14
C15
C16
C17
C18
C19
ARBOREAL POLLEN TOTAL
STANDARD BRITISH ZONATION
IV, V
VIIa
VIIb
CORYLUS
SALIX
JUNIPER
ULEX
ILEX
LONICERA
HEDERA
PINUS
ULMUS
AS PERCENTAGES OF
PINUS+ULMUS+QUERCUS
SMOOTHED CURVES
A
B
cm

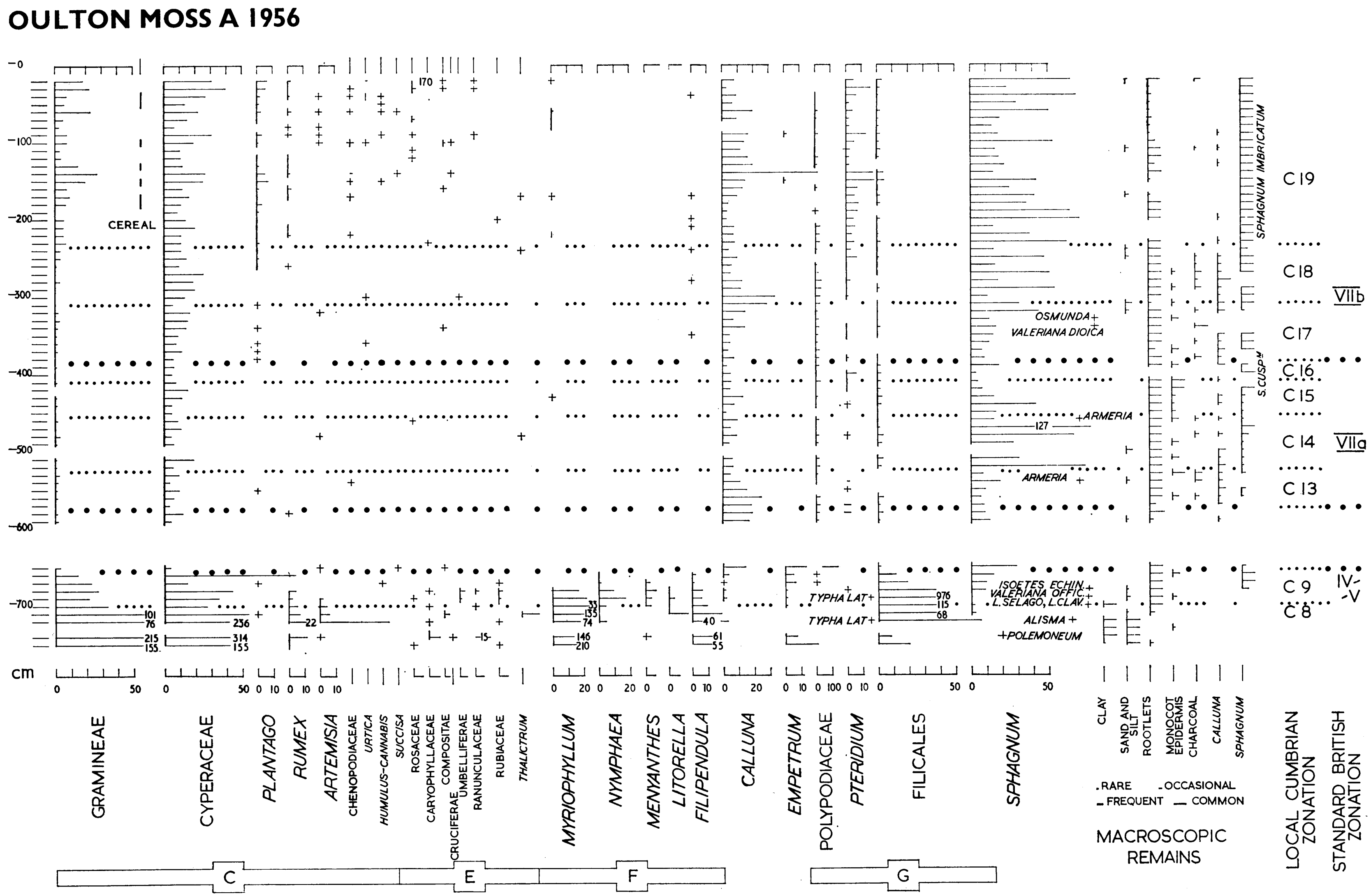


FIGURE 10. Oulton Moss A. Pollen diagram through the post-Glacial and the partial late-Glacial deposits. Section A: individual trees. Section B: individual shrubs. Section C: individual land herbs. Section E: individual taxa of uncertain ecology. Section F: individual aquatic herbs. Section G: individual Pteridophyta and Bryophyta. The frequencies of pollen or spores of all taxa are shown as percentages of the arboreal pollen total (Section A) of the appropriate sample.

value (2 to 10% *AP*), is a significant contributor. *Empetrum* is still important. The beginning of the zone is radiocarbon dated at Scaleby B (−0·5 to 1·5 cm) to 7052±194 B.C.

Cumbrian Zone C11 Scaleby A, 340–285 cm
Oulton A, not recorded

Betula values continue to fall slowly. *Pinus* remains as before and *Ulmus* remains consistently at about 10% *AP*. *Quercus* rises from zero at the bottom to a well marked peak of 25% *AP* at the top of the zone. Occasional grains of *Tilia cordata* are recorded and *Alnus*, though sporadic, occurs in quantities unlikely to be the result of contamination. *Corylus* falls from very high values at the base to about 100% *AP* at the top. *Salix* is hardly significant but *Hedera* occurs sparingly throughout.

The 'Boreal–Atlantic Transition'

Cumbrian Zone C12 Scaleby A, 285–250 cm
Oulton A, 595–580 cm

The rise of *Alnus* values from zero at the base to 45% *AP* at the top is associated with considerable fluctuations in the values of other tree types. *Betula* at first remains constant then resumes its fall at an accelerated rate. *Quercus* values fall sharply then rise again, whilst *Ulmus* reacts less strongly and in the opposite direction. The fall in *Quercus* is undoubtedly real, if temporary, in a vegetational sense for in frequencies calculated on a pollen sum of *Pinus*+*Ulmus*+*Quercus*, *both* the other components rise substantially in reaction to the *Quercus* fall. In the main diagram *Pinus* levels do not change markedly. *Corylus* continues to fall, but a sudden rise at the top of the zone heralds the generally higher values which follow. *Hedera* is sparingly represented. At Scaleby the border between British Zones VI and VII falls just below the top of Zone C12, at 260 cm, drawn midway up the rising *Alnus* curve. Radiocarbon assay of three samples straddling this horizon in diagram B (not published here) gave a mean date of 5292 B.C. for the appropriate level.*

British Zone VIIa

Cumbrian Zone C13 Scaleby A, 250–230 cm
Oulton A, 580–530 cm

Pinus values fall to a well marked minimum at which the slope of the smoothed curve (as a percentage of *Pinus*+*Ulmus*+*Quercus*) begins to fall less steeply. The equivalent smoothed curve for *Ulmus*, although falling somewhat, maintains generally high values (*ca.* 20%). Other tree curves are rather variable and show no general trend but *Corylus* is considerably higher than in the previous zone.

Cumbrian Zone C14 Scaleby A, 230–210 cm
Oulton A, 530–460 cm

Pinus values, as indicated by the smoothed curve (as percentage of *Pinus*+*Ulmus*+*Quercus*), fall to new low levels and *Ulmus* sustains a marked, but temporary, fall. *Quercus*,

* The date of the sample straddling the horizon and of that immediately beneath are closely similar, viz. 5475 ± *ca.* 350 B.C. and 5405 ± 146 B.C. whilst the date of the sample immediately above the first is 4998 ± 131 B.C. This variation seems insufficient to demand any major retardation of growth of the bog at this time particularly in the absence of any stratigraphic confirmation and the large error attributed to the date of the middle sample. The date of the VI–VIIa boundary is therefore taken as the mean of these three dates, viz. 5292 B.C. (cf. Godwin 1960).

steady through most of the zone, rises at the top. *Corylus* falls to a minimum at Oulton but values are indecisive at Scaleby. Single grains of *Tilia cordata* and *Fagus sylvatica* occur at Oulton and the first *Fraxinus* grain is recorded there.

Cumbrian Zone C15 Scaleby A, 210–195 cm
Oulton A, 460–415 cm

Ulmus values rise to a well defined maximum. *Quercus*, steady at first, falls slightly at the top. *Alnus* and *Betula* vary dependently. *Tilia cordata* is frequent at Oulton. *Corylus*, lower at Scaleby, is perhaps slightly higher than formerly at Oulton. *Fraxinus* is rare at Oulton.

Cumbrian Zone C16 Scaleby A, 195–150 cm
Oulton A, 415–390 cm

Ulmus values fall steeply almost to zero. *Pinus* recovers very slightly. *Quercus*, *Alnus* and *Betula* values behave rather differently at the two sites. *Tilia cordata* is rare. *Corylus* rises slightly. At Scaleby B a major recurrence surface was identified which corresponded pollen analytically with a level of 170 cm in the diagram from Scaleby A and which was dated by radiocarbon assay to 3471 ± 130 B.C.

The top of this zone corresponds with the end of British Zone VIIa and was dated in diagram Scaleby B to a mean age of 3014 B.C. by the radiocarbon assay of three samples.

British Zone VIIb

Cumbrian Zone C17 Scaleby A, 150–100 cm
Oulton A, 390–315 cm

A rather ill-defined zone in which *Alnus* remains at about its post-Glacial maximum and *Quercus*, though variable, is rather lower than *Alnus*. *Ulmus* recovers somewhat, the top of the zone marking the height of its recovery. *Corylus*, higher than before at Oulton, falls slightly at Scaleby. *Tilia cordata* is rare and *Fraxinus* only sporadically occurring.

At Scaleby, diagram B identified a minor recurrence surface pollen analytically equated with the level 115 cm in diagram A and radiocarbon dated, from the locality of diagram B, at 2481 ± 130 B.C.

Cumbrian Zone C18 Scaleby A, 100–77 cm
Oulton A, 315–240 cm

The *Ulmus* curves fall again to zero and remain intermittent above this zone. *Quercus*, on the whole, is higher, and *Alnus* lower, than formerly but the irregularly rising *Betula* confuses these values. *Fraxinus* becomes consistently present in the upper part of the zone. *Corylus* falls to a minimum.

At Scaleby, a minor recurrence surface at the locality of diagram B is identified pollen analytically as equivalent to the 85 cm level in diagram A. It is probably the counterpart of the main recurrence surface in the locality of diagram A at that level and was dated by radiocarbon assay at 1936 ± 130 B.C.

British Zone VIII

Cumbrian Zone C19 Scaleby A, 77–5 cm
Oulton A, 240–25 cm

Quercus values fall rather systematically. *Alnus* values fluctuate rather markedly and *Betula*, on the whole, rises. *Corylus* is not variable in any consistent manner. *Fagus* pollen is recorded from the lower part of this zone at both sites. *Ulmus* values are insignificant but *Fraxinus* is fairly consistently present in significant quantity. The rise of *Pinus* at the top at Scaleby and of *Ulmus* near the top at Oulton are difficult to interpret in view of their positions at the top of the diagrams.

The plant list

In addition to the records in the pollen diagrams, macroscopic remains were identified from a number of samples at each site and were referred to appropriate pollen analytical zones as shown in table 1. Some of these records, as well as some pollen records, call for special comment.

Armeria

Pollen identified as *A. maritima*, type B (Iversen 1940) is recorded from Zone C7 (III) at Scaleby and Zone C8 (III) at Oulton. These records agree closely with the known late-Glacial occurrence of this plant (Godwin 1956) but those from Zones C13 and C14 (VIIa) at Oulton are less usual and imply the proximity of open habitats during what was a predominantly forested period (cf. Godwin 1959).

Betula nana

The identification of pollen of *B. nana* has been attempted using the criteria described by Terasmaë (1951) and Walker (1955*a*). The identification is undeniably difficult and uncertain because the characters used are variable and hard to observe. Perhaps too there may be hybrids. The frequencies of *B. nana* pollen indicated on the diagrams, therefore, are minimum frequencies representing certain identifications, but because of the difficulties referred to they are presented as part of the total *Betula* curve. It is clear that, whilst most abundant in the late-Glacial Zones C5, 6, 7 and 8, *Betula nana* persisted, at Scaleby, into the early post-Glacial Zone C9 (IV–V). Its presence in Zone C6 at Oulton is confirmed by the recovery of a single fruit from the appropriate horizon. Those records merely confirm the known distribution of this species in the past (Godwin 1956).

Betula cf. *pubescens*

This category includes an eroded catkin scale from Zone C6 at Scaleby and a fruit from the same zone at Oulton, confirming that the *Betula* pollen of the late-Glacial diagrams derives at least in part from local birch trees. The post-Glacial records from Oulton are more abundant and more certainly referable to *B. pubescens* rather than *B. verrucosa*.

cf. *Humulus*

All attempts separately to identify pollen of *Humulus lupulus* and *Cannabis sativa*, including the electron photomicrography of carbon replicas (Bradley 1958) have failed (cf. Andersen 1954; Walker 1955*a*). The single grain from Zone C9 (IV–V) at Oulton dates from a time when fen woodlands probably existed in the basin and for this reason might most safely be referred to *Humulus*. The variety of ecological conditions during Zone C19 (VIII)

TABLE 1

		Scaleby						Oulton									
		II		III			IV–V	II	III	IV–V	VI	VIIa				VIIb	
species	remains	C 5	C 6	C 7	C 7–8	C 8	C 9	C 6	C 8	C 9	C 10	C 13	C 14	C 15	C 16	C 17	C 18
Betula nana	fr	.	.	.	.	.	.	+	.	.	.	.	.	.	.	.	.
Betula cf. *pubescens*	fr+sc	.	+	.	.	.	.	+	.	++	.	.	++	++	.	+	.
Carex rostrata	fr	+	+	+	.	.	.	.	.	.	.	.	.	.	.	.	.
C. cf. *contigua*	n	.	.	+	.	.	.	.	.	.	.	.	.	.	.	.	.
Carex sp.	n	++	++	++	++	++	.	.	.	++	.	+	++	.	.	.	+
Empetrum nigrum	f.st	+	++	.	.	.	.	.	.	.	.	.	.	.	.	.	.
Hippuris vulgaris	s	.	+	.	.	.	.	.	.	.	.	.	.	.	.	.	.
Juncus sp.	s	.	.	.	.	.	+	.	.	++	.	+++	.	+	.	.	.
Menyanthes trifoliata	s	+	+	.	+	.	.	.	.	.	.	.	.	.	.	.	.
Montia fontana ssp. *fontana*	s	.	+	.	.	.	.	.	.	.	.	.	.	.	.	.	.
Myriophyllum alterniflorum	s	+++	+++	+	++	.	.	++	.	.	.	.	.	.	.	.	.
Nymphaea alba	s	.	.	.	.	.	.	.	+	+	+	.	.	.	.	.	.
Oxycoccus palustris	l	.	.	.	.	.	.	.	.	.	.	.	.	.	+	++	.
Potamogeton berchtoldii	f.st	++	+++	.	.	.	.	+	.	.	.	.	.	.	.	.	.
P. praelongus	f.st	++	++	.	.	.	.	++	.	.	.	.	.	.	.	.	.
P. trichoides	f.st	++	+	.	.	.	.	+	.	.	.	.	.	.	.	.	.
P. cf. *acutifolius*	f.st	.	+	.	.	.	.	.	.	.	.	.	.	.	.	.	.
Potamogeton sp.	f.st	+++	++	+	.	.	.	++	.	.	.	.	.	.	.	.	.
Potentilla palustris	s	++	+	+	+	.	.	.	.	.	.	.	.	.	.	.	.
Potentilla sp.	s	.	.	.	.	+	.	.	.	.	.	.	.	.	.	.	.
Ranunculus flammula	s	++	++	+++	+++	++	.	.	.	.	.	.	.	.	.	.	.
R. sect. *Batrachium*	s	+++	+++	+	++	.	.	++	.	.	.	.	.	.	.	.	.
Ranunculus sp.	s	++	++	+	+	+	.	.	.	.	.	.	.	.	.	.	.
Rorripa islandica	s	.	.	.	.	.	.	+	.	.	.	.	.	.	.	.	.
Salix herbacea	l+t	.	.	++	++	.	.	.	.	.	.	.	.	.	.	.	.
Schoenoplectus cf. *lacustris*	n	.	.	+	.	.	+	.	.	.	.	.	.	.	.	.	.
Thalictrum flavum	s	.	.	.	.	.	.	+	.	.	.	.	.	.	.	.	.
cf. *Trichophorum caespitosum*	n	.	.	+	+	.	.	.	.	.	.	.	.	.	.	.	.
Veronica scutellata	s	.	.	+	.	.	.	.	.	.	.	.	.	.	.	.	.
Polypodium sp.	sp	.	.	.	.	.	.	.	++	++	.	.	.	.	.	.	.
Equisetum sp.	stem	.	.	++	.	.	.	.	.	.	.	.	.	.	.	.	.
Acrocladium sp.	l+stem	.	++	.	.	.	.	.	.	.	.	.	.	.	.	.	.
moss fragments	l	.	++	.	++	.	.	.	.	.	.	.	.	.	.	.	.
Characeae	oosp	++	.	.	.	.	.	.	+	.	.	.	.	.	.	.	.

fr = fruits; f.st = fruit stones; l = leaves; n = nutlets; oosp = oospores; s = seeds; sc = catkin scales; sp = sporangia; t = twigs. + = rare; ++ = occasional; +++ = frequent.

however can hardly be hazarded, although the grains recorded there were isolated from *Sphagnum* peat, and on these data alone neither species seems more likely than the other.

Koenigia islandica

As was forecast by Godwin (1956) a number of pollen grains of *Koenigia islandica* have now been recovered from British late-Glacial deposits (Whitrig Bog Zone III, Godwin (1956); Burn of Benholm Zone II, Donner (1960); Ballaugh, Isle of Man Zone III, Mitchell (1958)). The identity of the single grain from Zone C7 (III) at Oulton is quite certain, being distinguished from the grain of *Sagittaria* sp. in the succeeding zone by its smaller size, clearly defined, elongate, slightly depressed, pores and slender echinae clearly projecting beyond the surface of the exine (Hedberg 1946; Erdtman 1952; Hafsten 1958). *K. islandica* has been found living only in Skye (Raven 1952) in the British Isles.

Montia

A record of a single pollen grain of *Montia* sp. from Zone C7 (III) at Scaleby suggests the persistence there of the genus represented by a seed in Zone C6 (II). The seed is of the relatively smooth type and its identification as *M. fontana* ssp. *fontana* (= *M. fontana* L. *sensu stricto; M. lamprosperma* Chamisso in Clapham, Tutin & Warburg (1952)) has been confirmed by Dr S. M. Walters. Mitchell (1958) recovered a seed of this subspecies from his Zone IV at Ballaugh, Isle of Man, and it is almost certain that the seeds obtained from late-Glacial muds at Hawk's Tor, Cornwall, are referable to it (Conolly, Godwin & Megaw 1950). This is the common subspecies in northern Great Britain. It is aquatic or semi-aquatic, growing in 'trickles of water or very wet places, on acid soil or rock only' (Walters 1953). In its extra-British area in the northern hemisphere it is the most northerly of the British members of the genus. Hulten's map (1950) suggests that in Europe the plant occurs commonly in Scandinavia and is otherwise limited to the coastal belt from Brittany to the Gulf of Bothnia and north-west Russia.

Plantago spp.

Interest in the history of the plantains has largely centred round their value as indicators of open, unforested, conditions, particularly in the late-Glacial, and of the effects of human interference with forest vegetation in the post-Glacial (Iversen 1941, 1949, 1954; Florin 1957; Godwin 1955, 1956). In these diagrams the *Plantago* pollen in the late-Glacial and early post-Glacial is either unidentifiable to a species, *P. maritima* (2 grains C7 Scaleby, 1 grain C9 Scaleby, 1 grain C6 Oulton), or *P. major*. In the later part of the post-Glacial more or less continuous curves for the genus begin late in Zone C18 (VIIb) at Oulton or early in Zone C19 (VIII) at Scaleby. *P. major* and *P. lanceolata* both contribute to these curves. Isolated pollen grains occurring in Zones C13 to C17 (VIIa–VIIb) are identified as follows:

P. coronopus	C15, Scaleby: 1 grain
P. major	C13 and C17, Oulton: 4 grains
P. maritima	C16 and C17, Scaleby: 3 grains
P. lanceolata	C18, Scaleby: 1 grain. C17 and C18, Oulton: 2 grains

These records are entirely consistent with the view that *P. major* and *P. maritima* are plants native to Great Britain, the areas of which were restricted during the post-Glacial expansion of the forests. The record of *P. coronopus* from Zone C15 (VIIa) at Scaleby is the earliest post-Glacial occurrence for the British Isles. All the pollen of *P. lanceolata* is recorded from periods post-dating the possible arrival of Neolithic man in Great Britain.

Polemonium caeruleum

The two pollen grains of *P. caeruleum* from Zone C9 (IV) at Scaleby and what is probably Zone C5 (II) at Oulton corroborate, but do not substantially extend, the late- and early post-Glacial distribution of this species assembled by Pigott (1958).

Salix herbacea

Leaves and twigs of *S. herbacea* were recovered in some quantity from Zone C7 and the base of Zone C8 (III) at Scaleby. The records fall within the known late-Glacial distribution of the species (Godwin 1956).

cf. *Saussurea*

Although pollen of *Saussurea* has sometimes been separately identified, suspect pollen grains of this species have never been certainly distinguished from those of *Arctium* spp. in the deposits now described. In view of the restricted distribution of *S. alpina* in the British Isles at the present day (Clapham *et al.* 1952), the occurrence of pollen thought to belong to this species in Zones C6 (II), and C7 and 8 (III) is of some interest.

Lycopodium spp.

The well-known late-Glacial occurrence of *L. selago* is confirmed by the records of its spores from Zones C5 (Oulton), C6 (Scaleby), C7 and C8 (Oulton) (i.e. Zones II and III). Spores of *L. alpinum* and *L. clavatum* can now be separately and confidently recognized. The former is recorded here from Zone C9 (V) at Scaleby and the latter from Zone C8 (III) at Oulton.

Isoëtes echinospora

A readily identifiable microscopore of *Isoëtes echinospora* was recorded from Zone C9 (IV–V) at Oulton. In Britain today it has a local distribution, mostly in the north and west and usually in acid lakes and tarns. (Clapham *et al.* 1952). In Europe it has a range closely similar to that of *I. lacustris* (Donat 1928), occurring north of 80° N in Scandinavia, and showing a preference for clay soils rich in organic matter along lake margins (Samuellson 1934).

Pilularia globulifera

A microspore of *P. globulifera* was recorded from Zone C9 (IV) at Scaleby. This corresponds well with the Zones III to V occurrence of the species at Moss Lake, Liverpool (Godwin 1959) and is consistent with the present-day distribution of the plant on the 'edges of ponds and lakes...on acid soils'. (Clapham *et al.* 1952).

Ophioglossaceae

In the late-Glacial and early post-Glacial zones, spores of *Botrychium* and *Ophioglossum* are frequently recorded. *Ophioglossum* occurs primarily in Zones C5, C6 and C9 (II and IV), although a single spore is recorded from the later part of Zone C8 (III). *Botrychium*, on the other hand, whilst occurring rarely in Zones C6 (II) and C9 (IV) is most abundant in Zones C7 and C8 (III). Both genera, which are thought to be represented by *B. lunaria* and *O. vulgatum*, have frequently been recorded from British late-Glacial deposits and occasionally also from the post-Glacial (Godwin 1956). At present *B. lunaria* extends farther north (*ca.* 5° farther in Scandinavia) and to greater altitudes (to 500 m in N. Norway) than *O. vulgatum*, which also seems less tolerant of humus-rich soils (Hulten 1950; Polunin 1959).

Ecological development of the mires

Scaleby Moss

The large, shallow, hollow which now contains Scaleby Moss almost certainly held a lake immediately after its formation. Surface ground water would drain into such a lake from a comparatively small area (*ca.* 3 km^2) of sandy boulder clay. There was no well-marked stream draining out of the basin and it seems unlikely that the lake water often became sufficiently deep to overflow northwards into the tributaries of the River Lyne.

The accumulation of organic mud under open water began somewhat before 9000 B.C. and continued through Zones C5 to C8 (II and III) into the early part of Zone C9 (IV), probably until about 8200 B.C. The average accumulation rate at the middle of the lake during these periods was about 1 cm in 13 years, but it is very likely that this rate was exceeded during those periods, viz. C5, C6 and late C8, when inorganic material formed a large proportion of the sediments (figure 7). During Zone C5 (II), the basin must have contained only a rather barren pool with *Myriophyllum alterniflorum* and *Potamogeton* spp., particularly *P. praelongus* and *P. pusillus*. The fringing swamp was probably narrow and, like the plants of the open lake, its species suggest immature, oligotrophic, conditions with local development of rather acid pools over decaying organic matter (*Carex rostrata*, *Menyanthes trifoliata*, *Ranunculus flammula* and *Potentilla palustris*). In the succeeding Zone C6 (II), the aquatic flora seems to have changed little. The reedswamp probably became more extensive, *Equisetum* sp. advancing into the shallow water and replacing *M. alterniflorum* to some extent. Few of these plants are tolerant of very acid conditions on very organic substrata, however, and although stands of sedges, grasses and *Filipendula ulmaria* were common and imply the supply of sand and clay to the lake, it is very unlikely that hydrosere development progressed very far. In Zone C7 (III), whilst the muds became progressively more organic, the aquatic and swamp flora seems to have become even poorer. *Potamogeton* is represented in this zone by a single eroded fruit stone; even the abundance of *Myriophyllum alterniflorum* pollen and seeds and *Equisetum* spores is greatly reduced. *Carex* spp. remain abundant, however (cf. Cyperaceae pollen) and it is likely that they dominated the reedswamp as the water became more acid. Hypnoid mosses and *Sphagnum* spp. began to grow around the margins. In Zone C8 (III), however, this depauperation of the flora was temporarily arrested. The inorganic content of the muds increased very considerably and that this was in fact due to an increased input of inorganic material, rather than a further fall in the productivity of the lake, is proved by the occurrence of coarse sand and pebbles near the middle of the lake. Some of the pebbles are 2 cm in greatest dimension and some were found to be cleanly fractured when removed from the mud. It is difficult to imagine how such pebbles could be borne to the centre of a still lake of this size unless they were floated into position from the shore. This might have been achieved if the surface, frozen during winter, broke into 'ice-floes' in the spring, some of which drifted out into the lake before melting. Such a mechanism might also explain the fractured stones. If a pebble had been split by frost the two halves might well remain together until the pebble was dropped from a melting 'ice-floe', on to the muddy bottom of the lake. Whatever process was actually involved it did not disturb the horizontality of that mud surface. It may have been that the introduction of new inorganic material into the lake ousted the hypnoid mosses and *Sphagnum* and allowed a general increase in *Myriophyllum alterniflorum* and sporadic success of *Filipendula ulmaria*. Even so, by the end of the zone the lake and its surrounding swamp must have been fairly barren.

The opening of Zone C9 witnessed the rapid overgrowth of the whole lake by reedswamp. The pollen diagram does not provide a very consistent index to the floristic composition of this swamp, except in the abundance of Cyperaceae, but it seems likely that it was a 'poor fen' (Du Rietz 1942), for there is an extraordinary absence of base-demanding species. So far as can be judged, the species responsible for this overgrowth were already available in the basin so that a relatively sudden environmental change must be postulated to account for their sudden expansion. It may be that the progressive infilling of the relatively flat-bottomed lake had reduced the depth of water below a threshold, or that an externally controlled fall in water level occurred. It might also be that the environmental change which allowed the rapid expansion of woodland at this stage also removed an inhibition to the extension of the reedswamp. The reedswamp deposit from near the middle of the lake is not mainly detrital but reflects growth of Carices *in situ*. This implies that the water level in the lake could not have been more than about 1 m above the mud surface there, i.e. about 1·5 to 2 m above the base of the hollow. Such a level would also have ensured the preservation of the deposits around the margins of the lake (figure 5). By the end of British Zone IV (mid C9; *ca.* 7700 B.C.) acidification of the reedswamp was quickly taking place. *Menyanthes trifoliata* was temporarily abundant and *Sphagnum* spp. rapidly became dominant, even at the expense of the sedges. This early conversion of such a large lake to a *Sphagnum* bog is probably attributable partly to the shallowness and base deficiency of the water itself and partly to the fixation of the surrounding slopes by woodland and heath vegetation, the ground water draining from which would be acidic. Indeed, the thin uniform layer of compact mud, which seems to be contemporary with the final extermination of the reedswamp, is similar to a 'dy' and may be partly a precipitate from humus rich water draining into the basin. The process of conversion of the lake to a wet, perhaps partially floating, *Sphagnum* bog was complete by about 7500 B.C., i.e. about 700 years after the expansion of the reedswamp. From that time onwards the mire developed as a *Sphagnum* bog which in its earlier stages at least must have been very wet. For this reason it seems unlikely that the *Empetrum nigrum* which was so common during Zone V (C9) was actually growing on the bog surface, whilst there is every reason for supposing that suitable habitats were already available on the surrounding rim of land. The development of the raised bog seems to have been a fairly uniform process in which *Sphagnum* played by far the most important part, although here and there peat layers more than usually rich in *Calluna vulgaris*, *Eriophorum vaginatum* and *Molinia caerulea* fragments were found. The mean accumulation rate at the site of diagram A (boring 6) was about 1 cm in 12 years during Zone VI (C10 to C12) and about 1 cm in 18 years during Zone VIIa (C13 to C16). During Zone C16 (VIIa), when the peat deposits in the central area of the bog had reached a thickness of about 2·5 m, the conditions at the surface evidently changed and thereafter peat accumulation progressed in a less uniform manner, periods of very rapid accumulation alternating with periods when peat formation slowed or even stopped entirely. The evidence for this lies in the recurrence surfaces, about four of which were recorded in the upper 2 m of peat. The stratigraphic clarity of these recurrence surfaces varies along their length, however, and it is difficult to select one for special designation as the 'Grenz-horizont'. The lowest dated recurrence surface (diagram B, 85 cm; Godwin *et al.* 1957) occurs at 3471 ± 130 B.C. in Zone C16 (VIIa) and is unusually early for this kind of feature. The onset of the changed regeneration conditions on the bog surface, which this recurrence surface marks, corresponds roughly with a stage at which the centre of the bog began to grow up above the level of the bog margin. It seems likely that the fluctuations in the curves for *Sphagnum* spores and *Calluna* pollen during Zones C16 to C19 might have some significance in this context but it is not possible accurately to equate any particular trend in these curves with particular ecological stages recorded in the stratigraphy.

The mean accumulation rate at the bog centre during Zones C17 and C18 (VIIb) was about 1 cm in 15 years. In Zone C19 (VIII), which began shortly after the recurrence surface dated at 1936 ± 130 B.C., the accumulation rate is difficult to establish, but if it were of the same order as in the immediately preceding zones, the peat immediately beneath the present surface of the bog must date from about 1000 B.C. Peat cutting and drainage from at least the Medieval period onwards have certainly resulted in compaction and erosion of the uppermost peat, but, although it might not be safe to suppose that accumulation ceased at 1000 B.C., it might be equally fallacious to suppose that it went on well into the Christian era.

Oulton Moss

The relatively small, deep, steep-sided basin which now contains Oulton Moss contained a lake during late-Glacial time; presumably a lake which had its origin at the melting of the ice which occupied and formed the basin. The earliest organic sediments were deposited during Zone C5 (II) but throughout this period clay, silt and sand were still washing in from the margins. In the deep parts of the basin (diagram B) fine detritus muds accumulated to considerable depths and the water evidently contained *Myriophyllum alterniflorum* whilst *Alisma plantago–aquatica* grew in the shallows. In these shallower parts, however, (figure 10) accumulation had hardly begun at that time and the slopes were probably still unconsolidated and the water level fluctuating. Roughly similar conditions pertained during Zone C6 (II) except that accumulation at the margins was slightly greater, inorganic material no longer reached deep water and marginal fens with sedges, *Filipendula ulmaria* and *Thalictrum flavum* became well established. Throughout Zone C6 the values for *M. alterniflorum* pollen fall, more particularly toward the end of the zone when the reappearance of clay and silt in the muds heralds the changed conditions of the subsequent zone. In deep water, clay-mud, almost devoid of organic material and particularly sandy near the base, was laid down throughout the greater part of Zone C7 (III). *M. alterniflorum* was much less common than formerly and the evidence for fringing fens is less strong. More marginally (diagram A), deposits of this period seem hardly to occur and it may be that the water level was particularly low or fluctuating. There is no evidence of solifluction at this time, only of a very unproductive lake with rather bare shores. The later part of Zone C7 and the whole of Zone C8 saw little change in the flowering plants but the higher organic content of the mud suggests improved conditions for the microflora and microfauna of the lake. At the top of the zone, where the inorganic content of the mud begins to fall, *Alisma plantago-aquatica* is again a significant contributor to the pollen diagram and *M. alterniflorum* is temporarily very abundant. In Zone C9 (IV–V) fine detritus mud was being deposited in deep water while the shallows were being overgrown by reedswamp with *Sphagnum* spp. and *Menyanthes trifoliata*. In the intervening regions *Nymphaea* and *Potamogeton* spp. grew, while the high frequencies of fern spores probably derive from drier parts of the marginal fens. These changes imply hydroseral development of a kind which had been inhibited during earlier times. The water level was probably more stable for the time being at about 7 m in the stratigraphic diagram (figure 6). But the lake had a very low base status and the fringing swamps quickly acidified, allowing *Sphagnum* spp. to invade and quickly become the most important plants. This process continued until even in the deeper water acidification had ousted the other plants and *Sphagnum* encroached from the edges. The falling values for fern spores and the appearance of *Calluna* pollen suggest that the marginal fens, too, were converted to bogs at this time.

Toward the end of Zone C9 conditions in the basin changed completely and shortly afterwards the accumulation of consolidated organic deposits ceased. Since sampling of any unconsolidated material was impossible with the equipment used, no data are available about its nature. In boring 11 (diagram A), however, a gap in the samples of only 50 cm covers almost all of Zones C10 to C12 (VI and early VIIa) a period of about 2000 years (cf. Scaleby radiocarbon dates). This suggests that accumulation stopped to all intents and purposes at the end of Zone C9 and did not begin again until the end of Zone C12. In the absence of any evidence for a particularly low water level during this period (e.g. erosion or overgrowth of the mire) it seems that a rising water level must be supposed which successfully inhibited the centripetal spread of the marginal bog until the end of Zone C12 when, presumably, the rate of its rise fell to the point where the bog at boring 11 could regenerate sufficiently fast to keep pace with the rising water. Indeed, the general stratigraphy suggests that, from that time onwards, the bog slowly encroached over the lake surface until the latter was covered by a floating mat of *Sphagnum* peat (cf. Wybunbury Moss, Poore & Walker 1959). The overgrowth in the position of boring 11, and the maintenance of a very actively growing bog there, implies a water level at least as high as 6 m on the stratigraphic scale and possibly one as high as 5 m. The level of the base of the thinnest part of the peat mat (boring 4), however, suggests that by the time of its completion the water level was at about 3 m on the scale. In diagram A this level corresponds with a marked change in the ecology of the mire. Previously the peat had been relatively compact and rich in *Sphagnum cuspidatum* but subsequently it was generally more fibrous in structure, lower in density and composed mainly of *S. imbricatum*. Such a change suggests that this was the time (Zone C18) when the bog had become independent of the lake water at this point and was beginning to grow upwards as an ombrogenous formation. Whatever the conditions during Zones C10 to C12, therefore, Zones C13 to C17 (VIIa and part VIIb) comprised a period of slow centripetal extension of the bog as the water level rose from about 6 m to about 3 m on the stratigraphic scale, a rise of 3 m in about 3000 years. The surface level at boring 11 is estimated (from levelling and bench mark data) to be about 16 m (52 ft.) O.D. and the approximate levels in Zones C9, C12 and C18 were therefore about 9 m (29 ft.), 10 m (32 ft.) and 13 m (42 ft.) O.D. The lowest point in the boulder clay rim surrounding the basin can never have been below 18 m (60 ft.) O.D. and cannot directly have contributed to these changes in level which must, therefore, have been symptoms of general changes in level of the regional ground water table. In a place so close to the present coast-line and only 1 km (½ mile) from the edge of the post-Glacial marine limit it is hardly surprising that the basin proved very sensitive to changes in water level.

The overgrowth of the lake was probably completed early in Zone C18. From then, through Zone C19, the bog continued to grow upwards, probably dominated by *Sphagnum imbricatum* and *Calluna vulgaris*, *Eriophorum angustifolium* and *Molinia caerulea*. Although there is no direct evidence, it seems likely that in such a hollow drainage water from the surrounding slopes would maintain a narrow marginal fen around the bog edge.

The present surface of Oulton Moss is probably secondary, the result of the removal of the surface peat for fuel. There is no reason to suppose that the bog did not continue to grow well into the historic period. By applying the radiocarbon ages in Zones C17 and C18 at Scaleby to the Oulton diagram, and extrapolating upwards from the rates of peat accumulation indicated by them, it seems likely that the top of the Oulton diagram represents the early years of the Christian era.

III. STRATIGRAPHY AND POLLEN ANALYSIS AT MOORTHWAITE MOSS AND ABBOT MOSS

Moorthwaite Moss and Abbot Moss both lie in kettle holes in the Main Glaciation drift outside the limit of the Scottish Readvance Glaciation, south-east of Carlisle in Cumberland. Both bogs have developed over lakes initiated early in the deglaciation of the region and pollen diagrams, zoned according to the standard British and local Cumbrian schemes, indicate accumulation of deposits from a very early stage of the late-Glacial period. The present bog surfaces are secondary and anthropogenic but, in spite of removal or oxidation of the upper peat, undisturbed deposits as young as about 1500 B.C. are thought to be present at both sites. The ecological history of the mires has been reconstructed so far as the stratigraphic and pollen analytical data allow. Among the most interesting subfossil remains recorded are those of *Betula nana*, *Cardaminopsis* cf. *petraea*, *Koenigia islandica*, *Linum usitatissimum*, *Potamogeton filiformis* and *Lycopodium annotinum*.

Introduction

Moorthwaite Moss and Abbot Moss both occupy kettle holes in the drift of the Main Glaciation at about 120 m (400 ft.) O.D. Moorthwaite Moss is 11 km (7 miles) east-south-east of Carlisle on the east bank of the River Eden, and Abbot Moss lies 8 km (5 miles) due south of Moorthwaite on the west bank of the same river (figure 11 *a*). Along this part of its course the River Eden flows northward between steeply sloping banks which rise on each side between 30 m (100 ft.) and 75 m (250 ft.). The bedrock, Penrith Sandstone, is exposed in this gorge but the greater part of the surface is overlaid by thick deposits of glacial drift. 5 km (3 miles) east of Moorthwaite and 10 km (6 miles) east of Abbott Moss, the main slopes of the Cross Fell range begin to rise and peaks almost 600 m (2000 ft.) high lie within 13 km (8 miles) of each site. The narrow strip of land between the river and the foot of the mountains is thickly spread with deposits, mostly sand and gravel, of the Main Glaciation, except where hills of solid rock, sandstones and shales, protrude to heights of about 230 m (750 ft.) O.D. The drift features themselves are very fresh, pocked by kettle holes and cut by overflow channels. Westwards, the valley of the River Eden is divided from that of the River Petteril by a strip of land about 5 km (3 miles) wide in which the sandstone hills again rise to over 210 m (700 ft.) O.D. In this region the overlying drift is predominantly boulder clay, of the Main Glaciation in the south and the Scottish Readvance in the north, and in consequence the features are less steep than those east of the River Eden. The south-eastern limit of the Scottish Readvance Glaciation lies 1 km ($\frac{1}{2}$ mile) from Moorthwaite Moss and 6 km (4 miles) from Abbot Moss (Trotter 1929).

The geological contexts of these two sites are very similar; the basins are of similar size and, although the local topography differs somewhat, they might be expected to contain comparable records of vegetational history. Deposits at a third site, Tarn Wadling, 2 miles north-west of Abbot Moss, have also been investigated (Walker 1964) but the results are not relevant to this discussion.

Geography and stratigraphy

Moorthwaite Moss (Nat. Grid Ref. 510510)

Moorthwaite Moss lies in a hollow on top of a hill at 120 m (400 ft.) O.D., 2 km (1 mile) south-south-east of Cumwhitton village. Westwards, the hill falls fairly evenly to the River Eden, 2 km (1 mile) away at 40 m (120 ft.) O.D. To the south and east it falls within 0·5 km ($\frac{1}{3}$ mile) to the Chapplewell Beck running just below the 120 m (400 ft.) contour. Northward, 0·5 km ($\frac{1}{3}$ mile) from the Moss edge, the hill forms the south-western

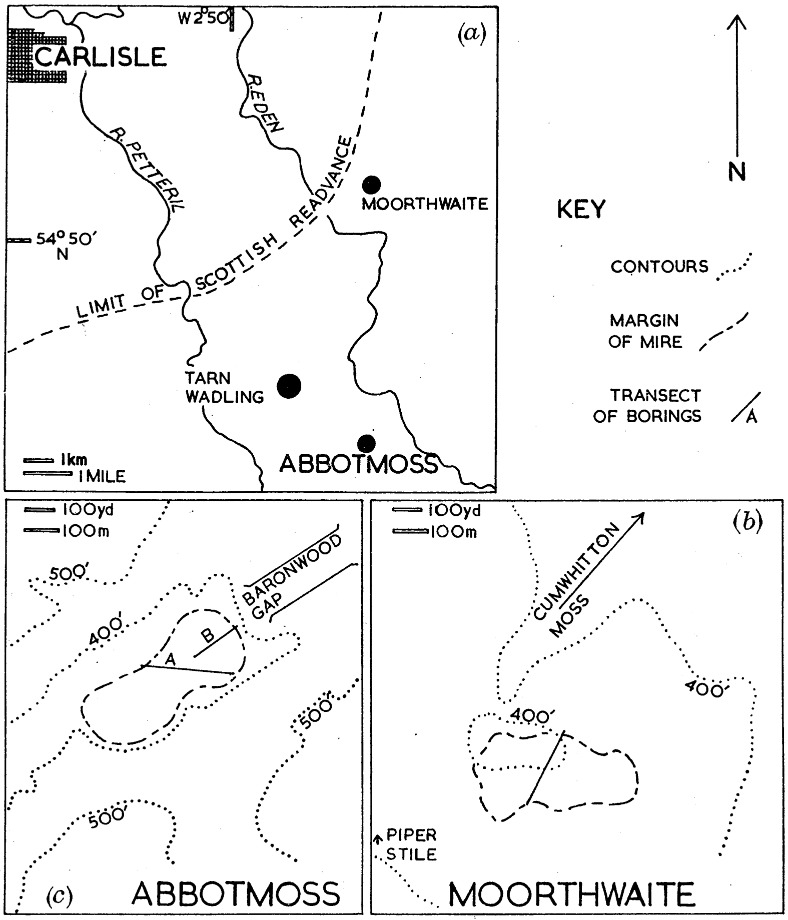


Figure 11. Moorthwaite Moss and Abbot Moss, Cumberland. (*a*) The positions of Moorthwaite Moss and Abbot Moss relative to the main topographic features, the maximum extent of the Scottish Readvance Glaciation, Tarn Wadling and Carlisle. (*b*) Moorthwaite Moss showing its position near to Cumwhitton Moss and the line of a bored section. (*c*) Abbot Moss showing its position in a hollow and the lines of the two bored sections.

edge of a partially enclosed hollow containing a larger bog, Cumwhitton Moss. The crest of the hill surrounding Moorthwaite Moss does not rise more than 9 m (30 ft.) above its surface. The slopes of the hollow are not very steep above the peat surface. There are no natural inflowing streams, but the narrowest and lowest part of the surrounding rim at the north-west corner, across which an artificial drainage ditch has now been dug, probably served intermittently as a natural outflow in the past. The hill is mainly composed of a rather sandy boulder clay, but its eastern flanks are covered by outwash sand of Stages *K* and *M* in the retreat of the Main Glaciation ice, an extension of which drift forms an öse train around the northern edge (Trotter 1929). Deltaic sands of a later stage are banked against the slope of the valley of the River Eden 1 km ($\frac{1}{2}$ mile) west of Moorthwaite and rise to 114 m (375 ft.) O.D. The limit of the Scottish Readvance Glaciation lies immediately west of this accumulation.

The hollow now occupied by Moorthwaite Moss became free of the general ice cover after Stage *M* of the retreat of the Main Glaciation ice. When the delta was formed at 114 m (375 ft.) O.D. the rim of the hill surrounding the hollow must have stood above the waters of the pro-glacial lake and presumably, as the ice retreated farther northward and westward, more and more land emerged as the lake level fell. Subsequently, when the Scottish Readvance ice at its maximum stood across the valley of the River Eden here, its pro-glacial lake stood at 133 m (440 ft.) O.D. completely immersing the Moorthwaite hill. It had emerged again, however, by the first documented retreat stage of the Scottish Readvance (stage *R. A.*, Trotter 1929) when the glacial lake stood at 115 m (380 ft.) O.D. and the hollow on the hill contained an isolated pond.

Moorthwaite Moss is now roughly oval in shape, enclosed by gently rising slopes (figure 11*b*). The surface peat has been cut away for fuel in the past as the old cutting banks and the boundary stones show. It is now covered with a more or less open woodland of *Pinus sylvestris* with some *Betula pubescens*, both of which are regenerating and which might all be subspontaneous from an old plantation, now destroyed, on the southern margin of the bog. The drier areas, particularly the baulks of peat left between the old cuttings, bear a vegetation dominated by *Calluna vulgaris*, but here and there this is replaced by *Vaccinium myrtillus* and *Molinia caerulea*. The cuttings themselves are filled with undulating swards of *Sphagnum*-dominated communities amongst which *S. magellanicum* and *S. papillosum* are particularly abundant. *Oxycoccus palustris*, *Rhyncospora alba*, *Narthecium ossifragum* and *Erica tetralix* are also common in these communities.

The stratigraphy of the deposits was investigated by a single series of borings running across the bog (figure 12), the findings of which were confirmed by six additional borings made near the eastern end of the basin. The boulder-clay slopes fall away very steeply within the limits of the basin and were not proved in the centre where borings did not penetrate more than 9 m from the surface. Lining all but the rim of the basin, and increasing in thickness towards the centre, is a deposit of red sand and gravel, occasionally containing lenses of clay. In the centre, this deposit surrounds a deep pocket of compact, stiff, pink silt with occasional laminae of sand and clay. The maximum depth of this pocket is about 3 m and at the top the silt passes upwards into a grey, silty, clay-mud with rare coarse sand grains. The uppermost layers of this material extend laterally beyond the edges of the silt-filled pocket where they directly overlie the basal sand and gravel fill. A layer, 10 to 15 cm deep, in which the clay-mud is coarsely sandy, marks the top of the silt-filled pocket. The uppermost 15 cm of the clay-mud contains abundant coarse sand and gravel and is difficult to penetrate in some places. Over the greater part of the section this gravelly clay-mud and the sandy gravel into which it passes marginally are overlaid by a layer of brown nekron mud up to 1 m in thickness and containing frequent remains of *Potamogeton* spp. and *Myriophyllum alterniflorum*. Sand and silt are, on the whole, rare in this material except in a rather well marked zone up to 20 cm in thickness where coarse sand occurs commonly in closely spaced horizontal laminae. Except at the extreme edge of the section the nekron mud passes almost insensibly upwards into a mud darker in colour, richer in organic detritus and entirely free of sand or silt. Fragments of sedge leaves are frequent as are seeds of *Nymphaea alba* and fruit-stones of *Potamogeton* spp. Over the greater part of the section this mud becomes more coarsely detrital at the top, remains of *Carex* spp. and *Phragmites communis* becoming very common. *Sphagnum* leaves (mostly *S. cuspidatum*)

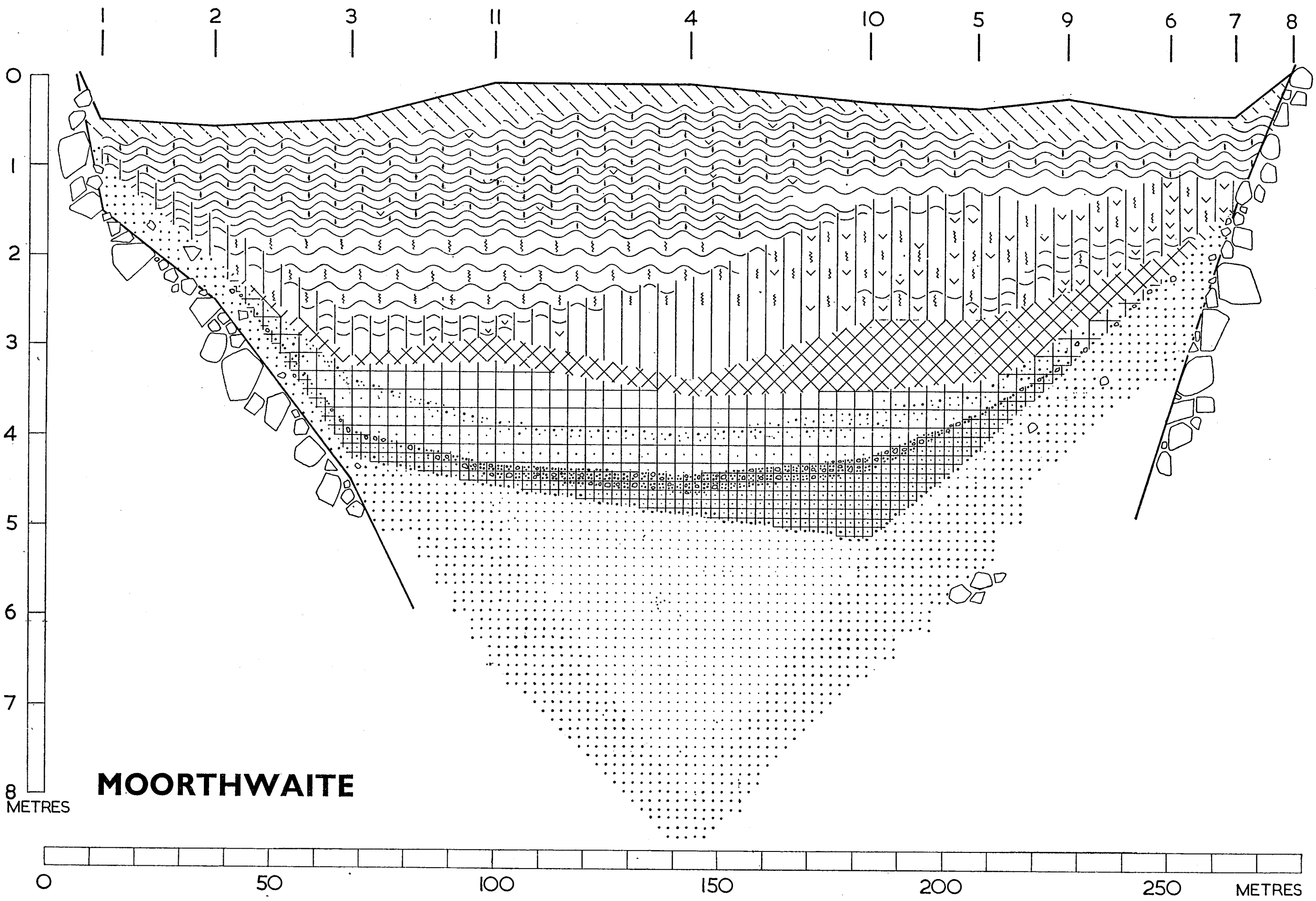


FIGURE 12. Moorthwaite Moss. Stratigraphy of deposits along bored section (cf. figure 11*b*).

are frequently found in this layer and, over the southern half of the section, become progressively more abundant as the mud grades into the *Sphagnum* peat which directly overlies it. At its deepest continuous part this peat is 2·5 m thick, of a slightly varying, deep brown, colour and varying humification (H 5–7). No horizontally consistant changes were traced between borings. Over the northern half of the section the detritus mud is coarser and rich in wood fragments (particularly *Betula* and *Alnus*) and reaches a maximum thickness of 2 m. It is overlain by the northern extension of the *Sphagnum* peat. The interface between the detritus mud and the *Sphagnum* peat rises northward between borings 10 and 11, suggesting that the two deposits were accumulating over the same period whilst the peat-producing communities slowly encroached on those producing the detritus mud. The uppermost layer is composed of the peat, which there contains occasional woody fragments and frequent remains of *Eriophorum vaginatum*. The surface has been cut and the deposits are commonly disturbed to a depth of 30 to 50 cm.

Abbot Moss (Nat. Grid Ref. 511434)

The kettle hole which contains Abbot Moss lies in a deeply incised valley cut through the ridge of Penrith Sandstone on the west bank of the River Eden. To the north of this valley (the Baronwood Gap; Hollingworth 1931) Blaze Fell rises to 240 m (792 ft.) O.D. whilst the southern slopes rise equally steeply to Castlerigg at 190 m (632 ft.) O.D. and Shepherd's Hill at 170 m (565 ft.) O.D. The valley floor lies just below the 120 m (400 ft.) contour except where its eastern end is blocked by a sill of solid rock, the lowest point of which is about 130 m (430 ft.) O.D. The bog itself lies in a basin sunk in this valley floor and receives surface drainage water from all sides. The slopes are covered with boulder clay and sandy drift in which the remnants of marginal glacial drainage channels are still discernible (figure 11*c*).

During the early stages of the retreat of the Main Glaciation this part of the valley of the River Eden became ice-free whilst a thick tongue of ice still protruded through the Baronwood Gap from the west. As that tongue withdrew, the pro-glacial lake overflowed eastwards into the Eden gorge and the Baronwood delta was formed at the eastern debouchment of the Gap. The Gap probably became free of ice rather later than did Moorthwaite Moss and for some time afterwards it must have been under a deep pro-glacial lake which finally drained westwards at a relatively late stage in the deglaciation (Trotter 1929; Hollingworth 1931). At the maximum of the Scottish Readvance Glaciation, Abbot Moss stood 6 km (4 miles) from the ice front but must have been at least temporarily flooded by the pro-glacial lake. It is unlikely, however, that the effects of this glaciation on accumulation would be so drastic in the Abbot Moss hollow as at Moorthwaite Moss.

Abbot Moss itself is roughly oval in shape, about 0·5 km ($\frac{1}{3}$ mile) long and 0·2 km (250 yards) wide, slightly constricted near the middle. All the surface peat has been badly disturbed but the damage seems to have been least at the north-eastern end, now overgrown by birch woodland with an undergrowth of *Calluna vulgaris* and *Molinia caerulea*. The stratigraphic investigations were therefore limited to this area, apart from three borings near the western end made to confirm the apparent distribution of the older deposits.

The stratigraphy was investigated by two intersecting series of borings (figure 11). Section *A* crossed the bog from west to east whilst Section *B* originated at the bog's north-eastern extremity and ran south-westwards toward the middle (figure 13).

Along Section *A* the sides of the hollow fall very steeply to 10 m beneath the bog surface in the middle. At the north-eastern end, crossed by Section *B*, however, the gradient is at first less steep. The material in which the hollow is sunk, and which is impenetrable with a Hiller borer beyond 1 m, is a coarse, unsorted sand and gravel, dark red in colour. It is almost certainly a moraine of the Main Glaciation, perhaps slightly redistributed by melt water immediately after deposition. The bottom of the hollow is filled with pink, silty clay-mud with occasional laminae of coarse sand, which also extends in a layer of varying thickness (20 to 100 cm) up the sides. This clay-mud, which is more than 2 m thick in the

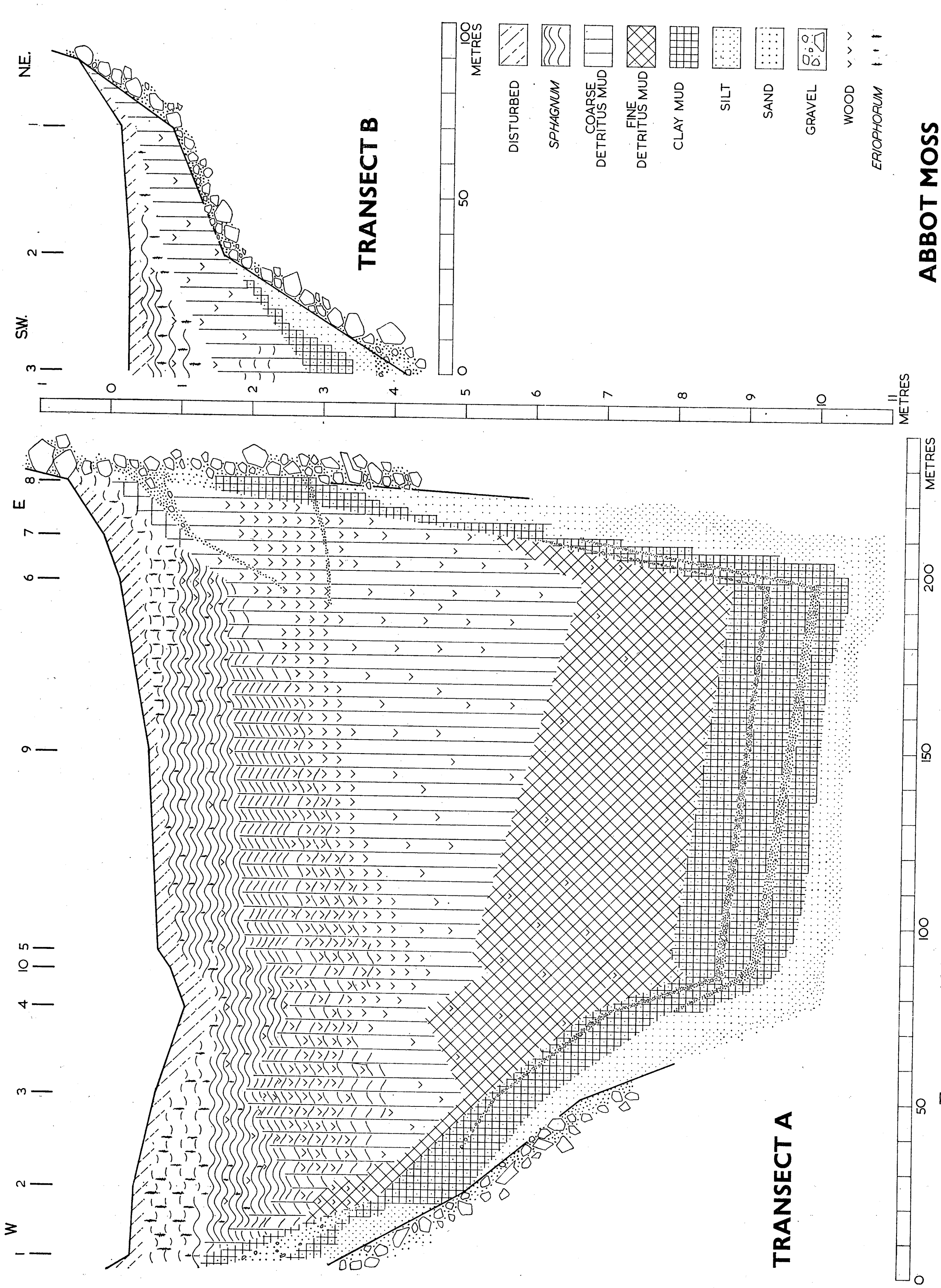


FIGURE 13. Abbot Moss. Stratigraphy of deposits along bored Sections *A* and *B*. (cf. figure 11*c*).

middle of the hollow, is crossed by two well-marked bands of coarsely sandy clay the uppermost of which also contains fine subangular gravel. Each of these bands varies from 5 to 20 cm in thickness. In the middle of Section A they are separated by 10 to 30 cm of clay-mud, whilst another 20 to 50 cm of clay-mud lies between the upper sandy clay and the overlying fine detritus mud. These sandy bands undoubtedly have their origin in the sandy gravel in which the basin is embedded. The upper few centimetres of clay-mud are entirely free of sand and silt and grade upwards into a dark brown, richly organic, nekron mud containing abundant detritus of sedges, *Potamogeton* spp., *Nymphaea alba* and *Potentilla palustris* and less frequent fragments of dicotyledonous leaves and fruits and catkin scales of *Betula* cf. *pubescens*. In the central region this deposit reaches 2 m in thickness but marginally it extends only as a thin layer westwards. The interface between this and the overlying coarse detritus mud is not well marked and transitional muds were recorded in most of the borings. The coarse detritus mud is medium brown in colour and relatively unconsolidated. Like the finer mud beneath it, it contains fruit-stones of *Potamogeton* spp. and *Nymphaea alba*, but sedge remains are much commoner. Fragments of leaves and wood (cf. *Alnus* sp. and cf. *Betula* sp.) are frequent throughout the mud and some of the borings encountered very woody layers and even tree trunks. The greatest depth of this deposit is about 5 m. The uppermost 2 m often contains frequent *Sphagnum* detritus, most of which is identified as *S. cuspidatum* although *S. squamosum* is also present. From the eastern end of Section *A* two layers of sandy mud extend outwards into the upper part of the coarse detritus mud. Above the coarse detritus mud lies a layer of *Sphagnum* peat, 1 to 2 m thick, the cut and oxidized top of which forms the modern surface of the Moss. This peat is medium to dark brown in colour and its humification varies from H 4 to H 7. Amongst the numerous species of *Sphagnum* contributing to it, the remains of *S. cuspidatum*, *S. papillosum* and *S. magellanicum* are most frequently encountered. Fragments of wood (cf. *Betula* sp.), remains of *Eriophorum vaginatum* and seeds of *Menyanthes trifoliata* are rarely found.

The most notable stratigraphic changes in the Abbot Moss deposits are the change from clay-mud to fine detritus nekron mud near the base and the transition from coarse detritus mud to *Sphagnum* peat at the top. In neither case, however, is any discontinuity of deposition suspected, although this may have happened at the times of the deposition of the various sand and gravel layers.

Pollen diagrams and chronology

At Moorthwaite Moss samples for pollen analysis were collected from Boring 10 (figure 12) where the deposits were described in the field as follows:

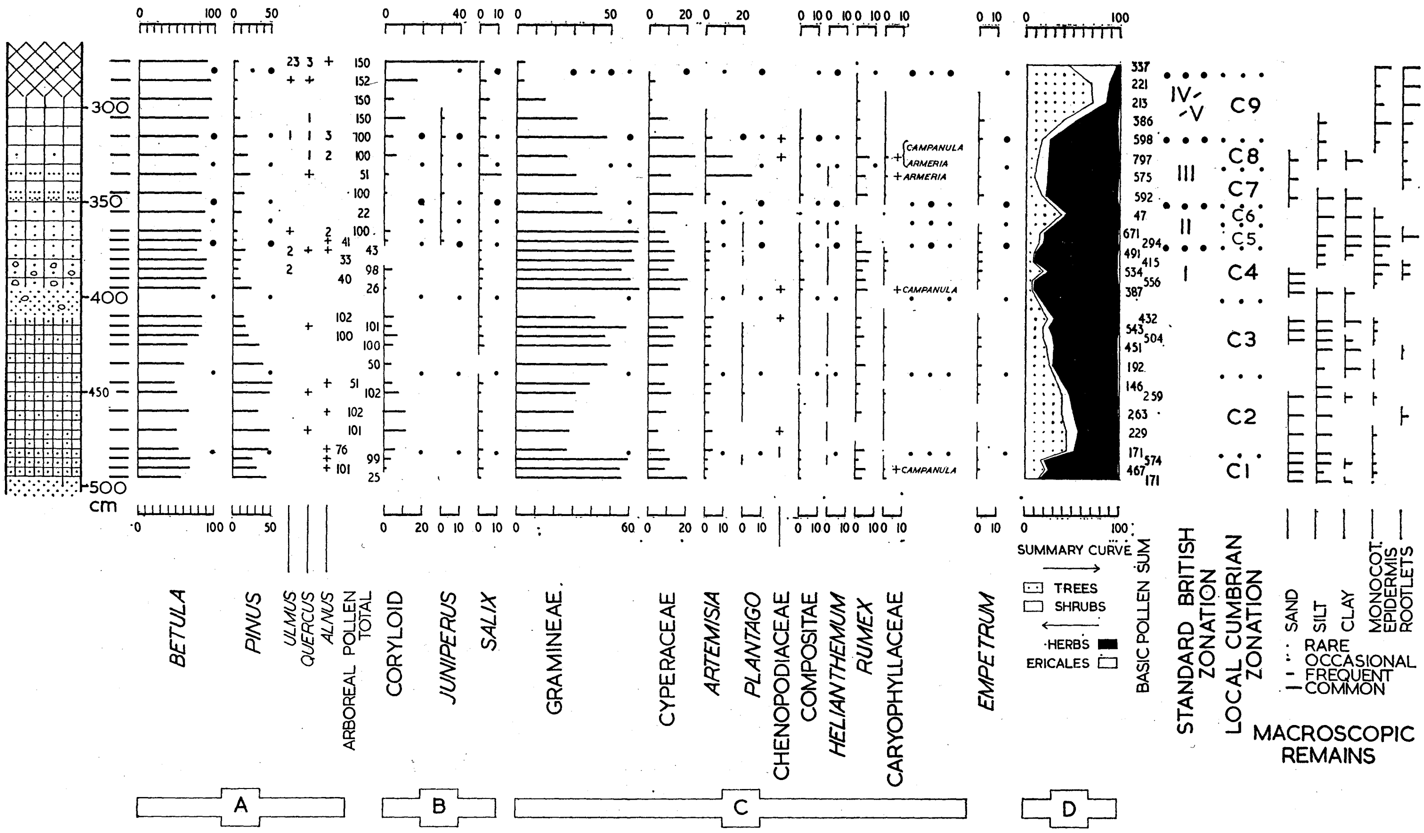
cm	
0–50	disturbed and oxidized peat
50–75	dark brown, coarsely fibrous peat. H 8
75–95	medium brown *Sphagnum* peat with some *Eriophorum vaginatum*. H 5
95–105	unconsolidated, woody, *Sphagnum* peat. H 7
105–120	very woody, medium brown, coarse detritus mud
120–185	medium brown coarse detritus mud with frequent fragments of *Alnus* and *Betula* wood

cm	
185–191	yellow wood in peaty matrix
191–218	dark brown, amorphous, mud with traces of *Sphagnum*
218–240	*Carex–Sphagnum* peat, medium brown, with abundant *Menyanthes* seeds at 225–230 cm
240–250	transitional mud
250–294	moderately fine detritus mud with frequent seeds of *Nymphaea alba* and *Potamogeton natans*
294–320	dark brown nekron mud with occasional laminae of lighter brown mud
320–348	medium brown, slightly sandy, nekron mud with laminae of lighter coloured, more sandy, mud
348–350	abundant sand laminae in buff mud matrix
350–357	slightly sandy, buff, mud with indistinct laminae
357–371	abundant sand in mud
371–377	slightly sandy, dark brown, mud with indistinct laminae
377–395	coarse sand and pebbles in mud matrix
395–411	fine grey sand with occasional pebbles
411–475	grey, silty clay-mud with rare sand
475–482	transition
482–490	pink sandy clay-mud
490–700	coarse red sand

At Abbot Moss samples for pollen analysis were collected from boring *A* 10 (figure 13) where the deposits were described in the field as follows:

cm	
0–50	dark brown oxidized peat
50–150	dark brown *Sphagnum–Eriophorum vaginatum* peat with occasional wood fragments. H 6
150–190	light brown *Sphagnum–Carex* peat
190–200	consolidated *Carex–Sphagnum* mud
200–300	unconsolidated *Sphagnum* peat with very abundant yellow wood and some sedge remains
300–373	very woody, friable, fen peat
373–408	brown, moderately fine detritus mud
408–445	brown, coarse detritus mud with occasional wood fragments and frequent *Potamogeton natans* fruit-stones
445–727	medium brown fine detritus mud
727–742	transitional mud
742–750	light brown nekron mud
750–766	pinkish grey silty clay-mud
766–784	slightly sandy clay-mud
784–796	homogeneous, grey, clayey mud
796–819	coarse red sand and gravel
819–848	slightly pink clay-mud
848–900	stiff sandy silt

MOORTHWAITE MOSS B 1950



MOORTHWAITE MOSS B 1950

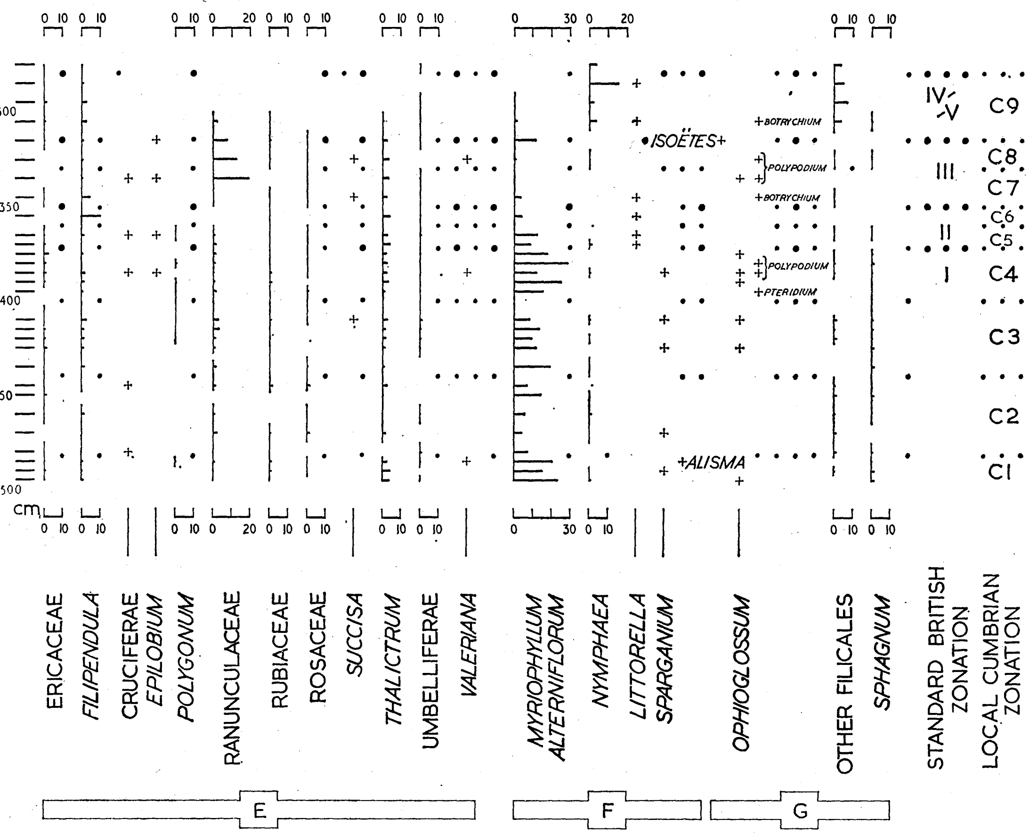


FIGURE 14. Moorthwaite Moss B. Pollen diagram through the late-Glacial and early post-Glacial deposits at boring 10 (cf. figure 12.) Section A: individual trees. Section B: individual shrubs. Section C: individual land herbs. Section D: summary curves for land flora (A+B+C+Ericales). Section E: individual taxa of uncertain ecology. Section F: individual aquatic herbs. Section G: individual Pteridophyta and Bryophyta. The pollen frequencies in Section A are shown as percentages of the sum of Section A pollen (= arboreal pollen total) of the appropriate sample. The pollen and spore frequencies in the other sections are shown as percentages of the basic pollen sum (A+B+C+Ericales) of the appropriate sample.

In the construction of the pollen diagrams the post-Glacial sections (diagrams A) have been separated from the earlier sections (diagrams B) the bottom of the first overlapping with the top of the second. The diagrams from each site were independently zoned but are jointly described. The base of Cumbrian Zone I is defined as the base of the lowest pollen analytical zone identifiable at Moorthwaite Moss.

British Zone I

Cumbrian Zone C1 — Moorthwaite B, 495–482 cm
Abbot Moss, not present

Dry land herb pollen dominates that of trees and shrubs. Amongst the trees *Pinus* pollen represents about 25 % of the total to which *Betula** is the only other substantial contributor. Coryloid* pollen is present in small quantities increasing towards the top. *Salix* is present in low and inconsistent pollen frequencies. Pollen of Gramineae dominates that of all other types and Cyperaceae values rarely exceed 10 %. *Artemisia* values are consistent and low, *Rumex* values inconsistent and higher. *Empetrum* is present but not in significant quantity or distribution through the zone. In addition to Gamineae and Cyperaceae eight pollen types contribute to the dry-land herb pollen curve (Group C). An additional nine types are included amongst the non-aquatic herbs of otherwise uncertain provenance (Group E).

Cumbrian Zone C2 — Moorthwaite B, 482–440 cm
Abbot Moss, not present

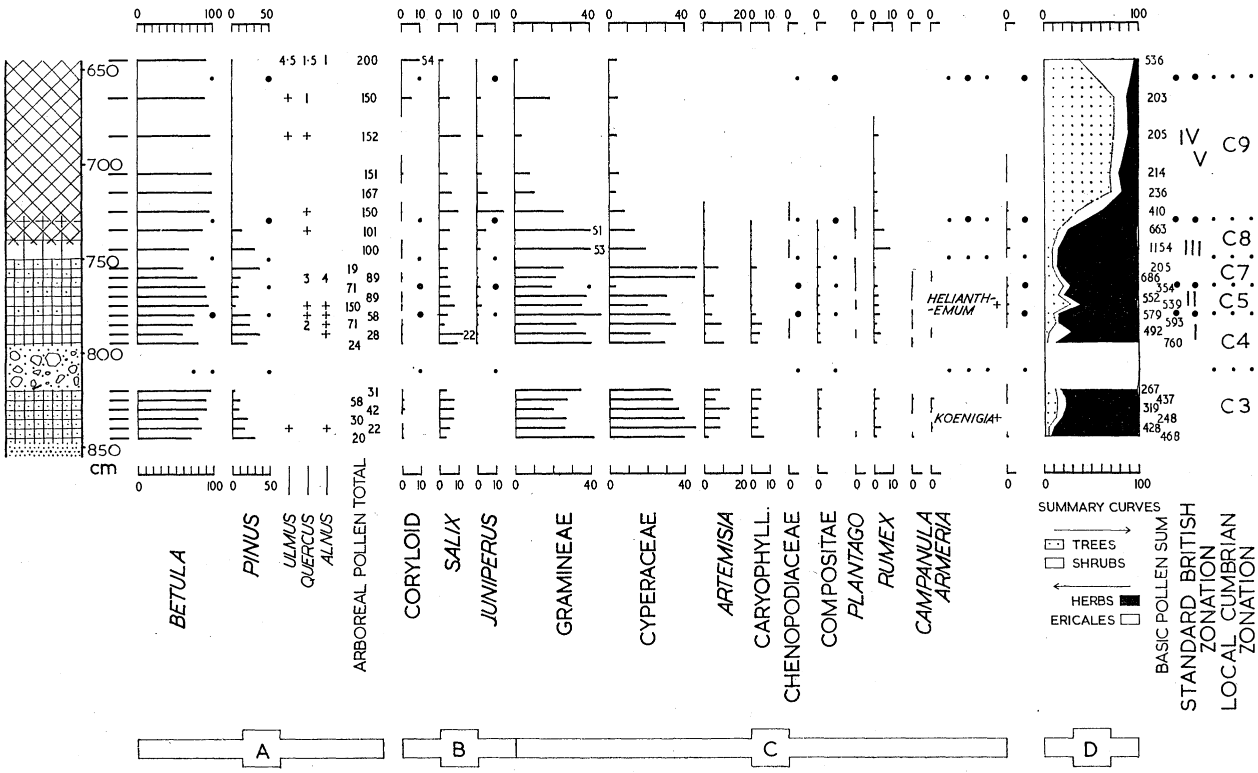
Trees and dry-land herbs are represented by roughly equal pollen frequencies and shrub pollen plays a variable role. Amongst the trees *Pinus* and *Betula* pollen have roughly the same frequencies. Coryloid pollen is present in fair quantity (< 11 %) and *Salix* frequencies are consistently low. Gramineae pollen is less abundant than in neighbouring zones but rises slowly throughout. *Artemisia* pollen is more abundant and *Rumex* pollen less abundant than in Zone C1. Six other dry-land herbs are represented but less abundantly and more spasmodically than in either neighbouring zone. Eight Group E types also occur sporadically through the zone.

Cumbrian Zone C3 — Moorthwaite B, 440–400 cm
Abbot Moss B, 845–810 cm

Dry-land herb pollen dominant over tree and shrub pollen. *Pinus* frequencies, high at the beginning of the zone, decrease to a third of their earlier values through it. Coryloid pollen is low and *Salix*, although low at Moorthwaite, attains frequencies of 8 % at Abbot Moss. Gramineae and Cyperaceae together contribute about 60 % of the pollen sum, but whereas at Moorthwaite grasses are much more abundant than sedges, at Abbot Moss the frequencies are more nearly equal. *Artemisia* values are high at Abbot Moss but no higher than in Zone C2 at Moorthwaite. *Rumex* and *Empetrum* are more consistently frequent at Moorthwaite. At Moorthwaite eight, and at Abbot Moss nine, dry-land herbs contribute to the sum in addition to Gramineae and Cyperaceae and eight and ten types respectively of Group E are also represented.

* Pollen of *Betula nana* was not separately identified during these analyses; it may be that much of the 'Coryloid' pollen derives from this plant.

ABBOT MOSS B 1950



ABBOT MOSS B 1950

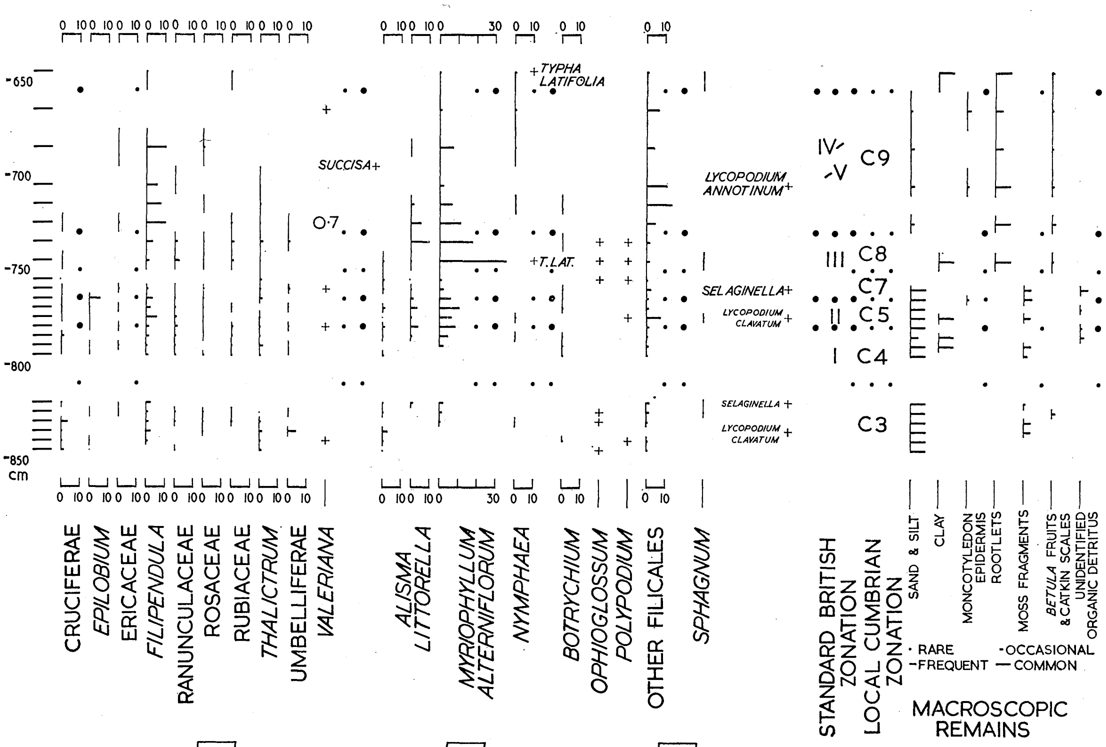


FIGURE 15. Abbot Moss B. Pollen diagram through the late-Glacial and early post-Glacial deposits at boring 10 (cf. figure 13). Section A: individual trees. Section B: individual shrubs. Section C: individual land herbs. Section D: summary curves for land flora (A+B+C+Ericales). Section E: individual taxa of uncertain ecology. Section F: individual aquatic herbs. Section G: individual Pteridophyta and Bryophyta. The pollen frequencies in Section A are shown as percentages of the sum of Section A pollen (= arboreal pollen total) of the appropriate sample. The pollen and spore frequencies in the other sections are shown as percentages of the basic pollen sum (A+B+C+Ericales) of the appropriate sample.

In both diagrams the upper boundary of this zone is drawn at a conveniently chosen level in deposits which are too minerogenic to allow of pollen analysis.

Cumbrian Zone C4 Moorthwaite B, 400–372 cm
Abbot Moss B, 810–780 cm

Dry-land herbs are dominant over trees. *Pinus* is commoner at Abbot Moss than at Moorthwaite, although *Betula* is by far the commoner of the two trees at both sites. Coryloid pollen is variable but low in frequency at Moorthwaite and rare at Abbot Moss. *Juniperus* occurs, sparingly, at both sites for the first time. At Abbot Moss, Gramineae pollen is rather more abundant than that of Cyperaceae and at Moorthwaite this dominance of Gramineae is very well marked. *Artemisia* is relatively low and *Rumex* relatively high at Moorthwaite whilst at Abbot Moss the relative frequencies of these types are reversed. Caryophyllaceae are relatively abundant at both sites as also are Compositae and *Empetrum* at Moorthwaite. In addition to Gramineae and Cyperaceae, nine types contribute to the dry-land herbs at both sites. At Moorthwaite eleven and at Abbot Moss ten pollen types are found in Group E during the zone.

At 385 cm at Moorthwaite the combined tree frequencies rise to double their value in neighbouring samples. Similarly, a superabundance of *Salix* pollen at 790 cm at Abbot Moss depresses the proportion of dry-land herb pollen temporarily. Neither maximum seems seriously or permanently to affect the relative proportions of any other pollen types, however, and they are therefore thought not to have any vegetational significance.

British Zone II

Cumbrian Zone C5 Moorthwaite B, 372–360 cm
Abbot Moss B, 780–765 cm

Dry-land herb pollen is dominant over that of trees and shrubs, although tree pollen frequency does increase slightly through the zone. *Pinus* values are low. *Salix* and *Juniperus* are rather more abundant than at the end of Zone C4. Gramineae attain their absolute late-Glacial maximum at Moorthwaite and are rather high at Abbot Moss. Cyperaceae are lower than in Zone C4 or Zone C6. *Artemisia*, *Rumex*, at Abbot Moss Caryophyllaceae, and at Moorthwaite Compositae, persist in this zone at levels lower than those of Zone C4. *Empetrum* is present at both sites. At Moorthwaite six, and at Abbot Moss eight, pollen types, in addition to Gramineae and Cyperaceae, contribute to the dry-land herb pollen total. Group E types contribute nine records at Abbot Moss and ten records at Moorthwaite in this zone.

Cumbrian Zone C6 Moorthwaite, B, 360–350 cm
Abbot Moss B, not present

The single sample at 355 cm at Moorthwaite has a number of characteristics which distinguish it from the zones above and below it. *Pinus* is more frequent than in Zone C5 whilst *Juniperus* is insignificant and *Salix* entirely absent. Gramineae values are lower whilst Cyperaceae are higher and *Artemisia*, *Rumex* and *Empetrum* are poorly represented.

Only four pollen types, in addition to Gramineae and Cyperaceae, represent Group C, and four, Group E. Although confined to a single sample, these features are characteristic of Zone C6 at other sites and seem to merit recognition at this one. It may be that at Abbot Moss, in which this zone is otherwise unidentifiable, some of these features are to be found in the sample at 765 cm.

British Zone III

Cumbrian Zone C7 Moorthwaite B, 350–330 cm
Abbot Moss B, 765–750 cm

The combined totals of dry-land herb pollen increase their dominance over the trees and shrubs. Amonst the trees, however, *Pinus* is more frequent than formerly. *Salix* is moderately common and *Juniperus* rare. Gramineae values fall through the zone but Cyperaceae are higher than formerly. The initial high value of *Rumex* at the boundary with the preceding zone is followed by low levels for this type. *Artemisia* pollen frequencies are high. Caryophyllaceae values are significantly higher than formerly, as are those of *Empetrum* at Moorthwaite. In addition to Gramineae and Cyperaceae, eight pollen types contribute to Group C at both sites. At Moorthwaite ten types and at Abbot Moss eight types make up Group E.

Cumbrian Zone C8 Moorthwaite B, 330–315 cm
Abbot Moss, 750–730 cm

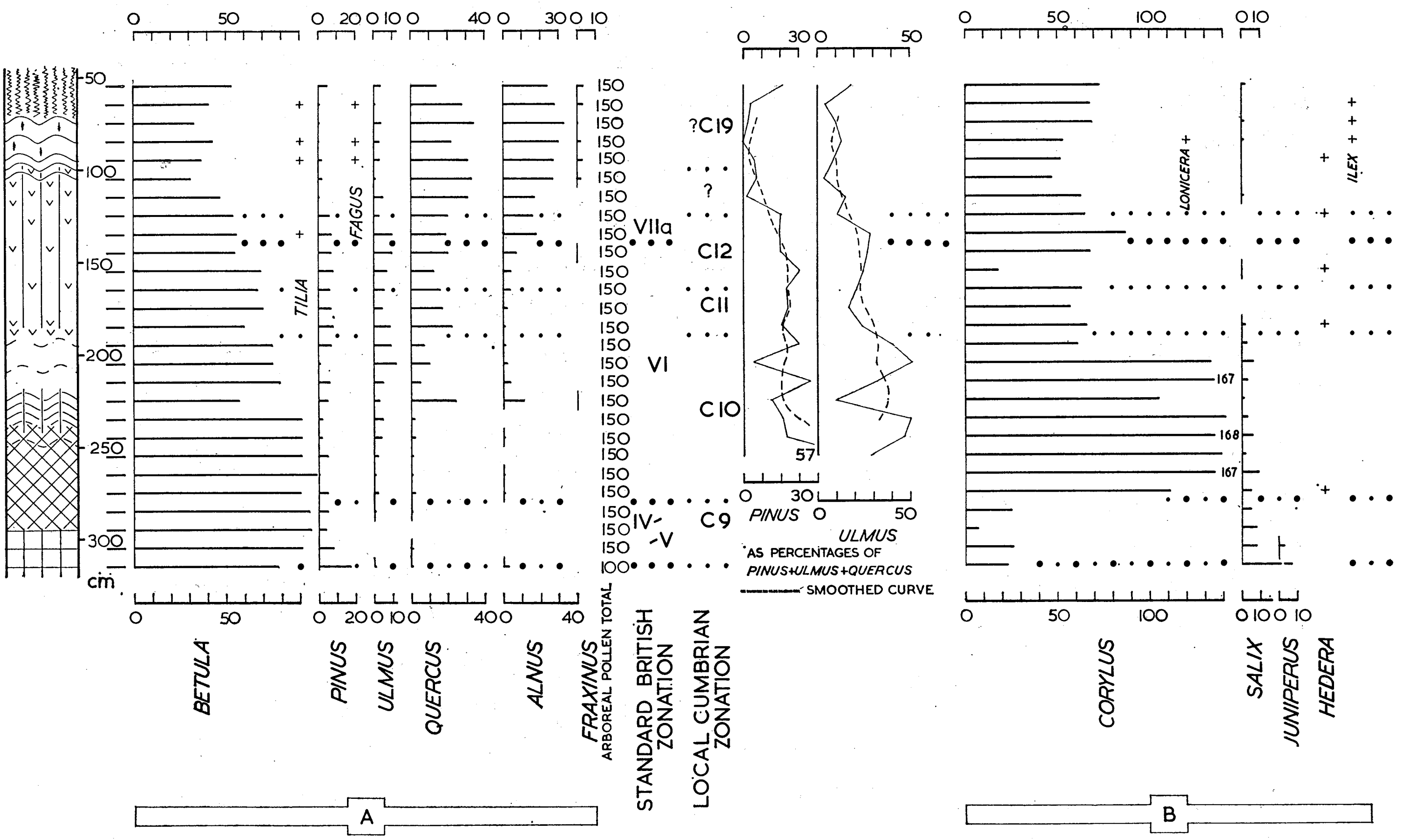
Dry-land herb pollen still retains dominance over that of trees and shrubs, although this dominance decreases through the zone. Amongst the trees at Abbot Moss, *Pinus* values begin to fall, but at Moorthwaite the balance between *Pinus* and *Betula* remains substantially unchanged through the zone. Coryloid pollen values at Moorthwaite, and those of *Salix* at both sites, lie at about the 5% level. *Juniperus* becomes increasingly common at Abbot Moss but is hardly significant at Moorthwaite. Gramineae values are rising and Cyperaceae values falling at Moorthwaite, whilst at Abbot Moss this tendency is even more marked by the high Gramineae and low Cyperaceae values. *Artemisia* frequencies fall steeply at Moorthwaite and are very low throughout at Abbot Moss whilst *Rumex* has a well-marked maximum at both sites. Eight types at Moorthwaite and seven types at Abbot Moss, in addition to Gramineae and Cyperaceae, contribute to the totals for Group C; the corresponding figures for Group E are seven for each site.

British Zones IV and V

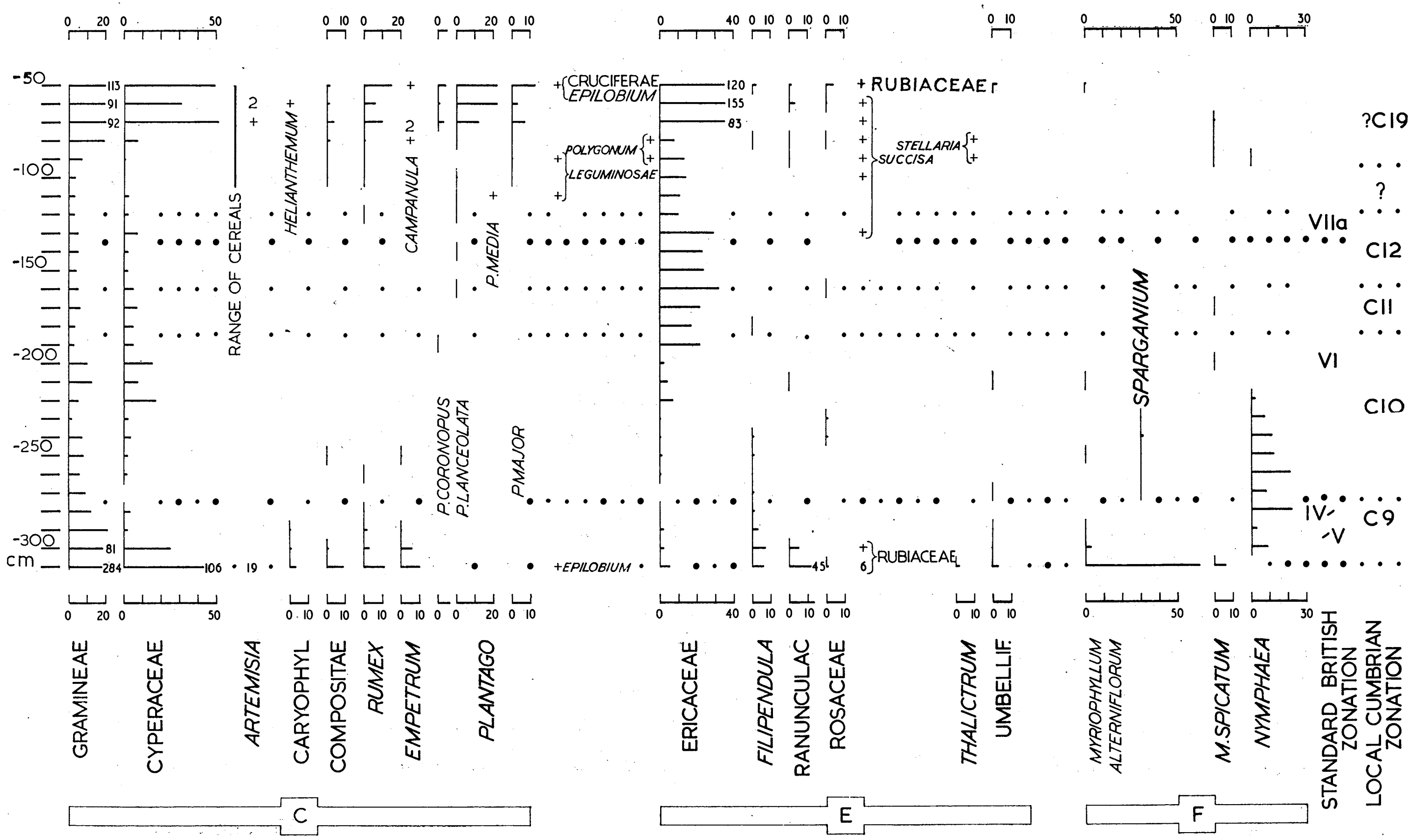
Cumbrian Zone C9 Moorthwaite A+B, 315–280 cm
Abbot Moss A+B, 730–655 cm

Tree and shrub pollen together establish dominance over that of dry land herbs. *Betula* is the dominant tree type; *Pinus* is hardly significant. Coryloid pollen, now almost certainly largely *Corylus* itself, frequent throughout the zone at Moorthwaite but rare for the most part at Abbot Moss, at both sites rises markedly toward the top of the zone. *Salix* is consistently frequent at both sites. *Juniperus* pollen reaches a high maximum early in the zone at Abbot Moss and is present *only* in a similar position at Moorthwaite Moss. The curves for Gramineae, Cyperaceae and the dry-land herbs fall steeply or completely disappear by the middle of the zone at Moorthwaite and even earlier at Abbot Moss,

MOORTHWAITE MOSS A 1950



MOORTHWAITE MOSS A 1950



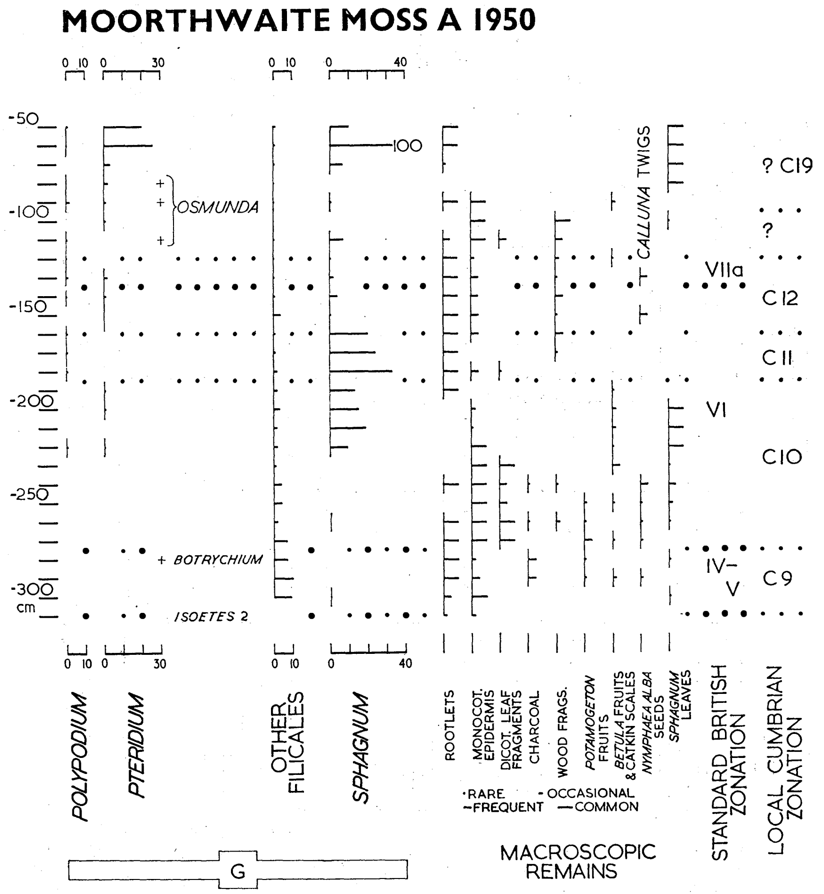


FIGURE 16. Moorthwaite Moss A. Pollen diagram through the post-Glacial deposits at boring 10 (cf. figure 12). Section A: individual trees. Section B: individual shrubs. Section C: individual land herbs. Section E: individual taxa of uncertain ecology. Section F: individual aquatic herbs. Section G: individual Pteridophyta and Bryophyta. The frequencies of pollen or spores of all taxa are shown as percentages of the arboreal pollen total (Section A) of the appropriate sample.

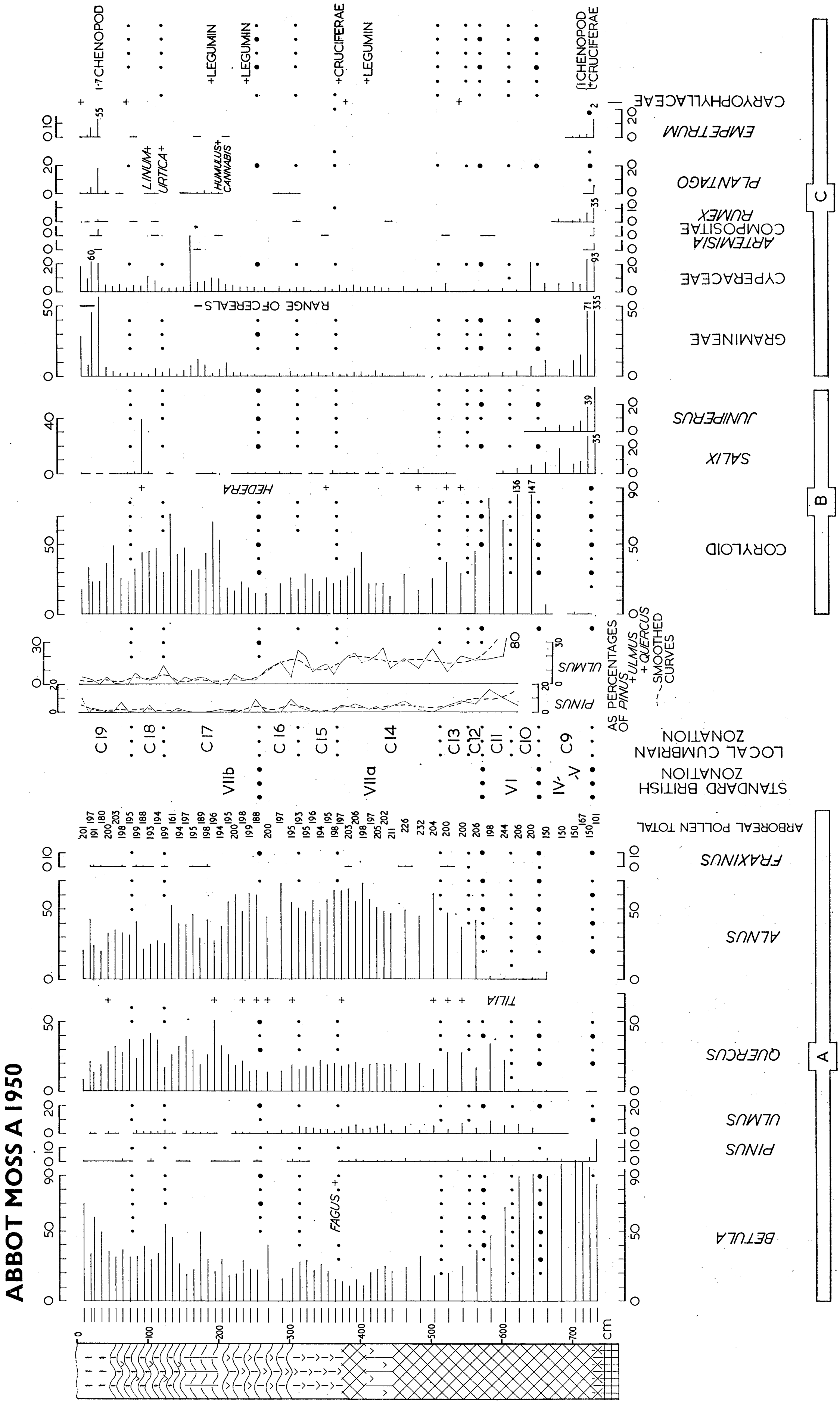
where *Rumex*, however, persists further than other types. *Empetrum* pollen has a temporary maximum early in the zone at Moorthwaite. With the possible exception of Ranunculaceae and *Filipendula* the types of Group E react similarly during the zone. There might be some justification for attempting a subdivision of this zone where *Betula* pollen assumes complete dominance, i.e. where shrubs and herbs alike reach their zonal minima or become extinct. Such a level could perhaps be defined at 290 cm at Moorthwaite and 695 cm at Abbot Moss but wherever it was drawn it would not have equal significance for more than two pollen types. It seems better therefore to accept the transitional nature of this zone rather than to try to subdivide it using extinction as a criterion.

British Zone VI

Cumbrian Zone C10 Moorthwaite A, 280–190 cm

Abbot Moss A, 655–615 cm

Corylus is the most abundant pollen type, its frequencies falling toward the top of the zone. *Betula*, constant in the early stages, falls somewhat later as *Ulmus*, then *Quercus*, begin


ABBOT MOSS A 1950
BETULA
PINUS
ULMUS
QUERCUS
TILIA
ALNUS
FRAXINUS
FAGUS
ARBOREAL POLLEN TOTAL
STANDARD BRITISH ZONATION
LOCAL CUMBRIAN ZONATION
AS PERCENTAGES OF PINUS + ULMUS + QUERCUS
SMOOTHED CURVES
CORYLOID
HEDERA
SALIX
JUNIPERUS
GRAMINEAE
RANGE OF CEREALS
CYPERACEAE
ARTEMISIA
COMPOSITAE
RUMEX
PLANTAGO
LINUM+
URTICA+
HUMULUS+
CANNABIS
EMPETRUM
CARYOPHYLLACEAE
1·7 CHENOPOD
+LEGUMIN
+CRUCIFERAE
CHENOPOD
CRUCIFERAE
A
B
C
cm

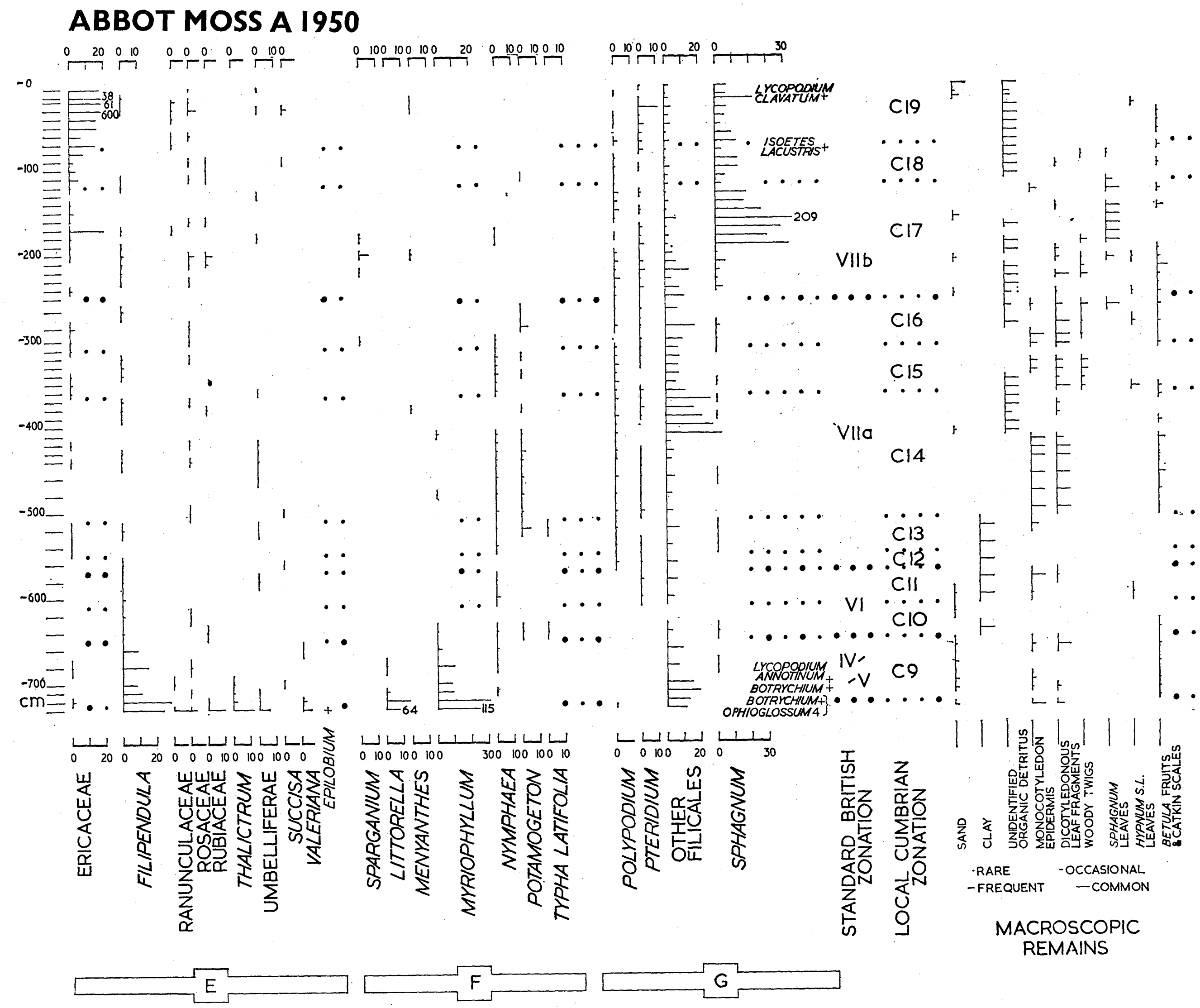


Figure 17. Abbot Moss A. Pollen diagram through the post-Glacial deposits at boring 10 (cf. figure 13). Section A: individual trees. Section B: individual shrubs. Section C: individual land herbs. Section E: individual taxa of uncertain ecology. Section F: individual aquatic herbs. Section G: individual Pteridophyta and Bryophyta. The frequencies of pollen or spores of all taxa are shown as percentages of the arboreal pollen total (Section A) of the appropriate sample.

to rise. *Quercus* seems better represented in the deeper deposits at Moorthwaite but nowhere is it more abundant than *Ulmus* nor does it reach its maximum in this zone. *Alnus* is consistently present, usually in low frequencies but too commonly to be entirely due to contamination. *Salix* persists in variable but significant quantity. A single grain of *Hedera* is recorded at Moorthwaite.

Cumbrian Zone C11 Moorthwaite A, 190–165 cm
Abbot Moss A, 615–575 cm

Ulmus values remain steady at about 8% *A.P.* whilst *Quercus* values continue to rise to a well-marked maximum. *Pinus* values are not substantially changed and though the *Betula* curve continues to fall at Abbot Moss it is maintained at high levels at Moorthwaite probably by a local component. *Alnus* is again significantly present, particularly at Moorthwaite. *Corylus* values remain of the order of 50% *A.P. Salix* persists only into the beginning of the zone. A single grain of *Hedera* is recorded from Moorthwaite.

The 'Boreal-Atlantic transition'

Cumbrian Zone C12 Moorthwaite A, 165–125 cm
Abbot Moss A, 575–555 cm

At Abbot Moss this transitional zone hardly exists, being represented by a single sample at 565 cm. Nevertheless, and because of the high *Alnus* value, *Pinus*, *Ulmus* and *Quercus* levels are not strictly comparable with those in preceding or succeeding zones. At Moorthwaite, on the other hand, the values for *Alnus* rise only slowly through the zone whilst *Betula* remains fairly high. Indeed, there is probably considerable variation in the local components of the tree pollen, for wood of both *Alnus* and *Betula* is recorded from the mud at this level. *Pinus* and *Ulmus* values remain virtually constant and remarkably high, and *Quercus*, although more abundant than either, is not so common as in other Cumbrian sites. *Tilia cordata*, *Fraxinus*, *Salix* and *Hedera* are all sparingly represented at Moorthwaite. The upper boundary of this zone at Moorthwaite is drawn where the rising *Alnus* values approximate to the *Quercus* values at the corresponding level and, but for the local prevalence of *Betula*, would probably considerably exceed them. By this level a pronounced fall in the *Ulmus* curve has begun and it may be that the boundary is drawn too high or that erosion has removed muds formed in the later part of the zone.

The boundary between British Zones VI and VIIa would be drawn at the lower boundary of Zone C12 at Abbot Moss and probably at 140 cm (about half way through that zone) at Moorthwaite.

British Zone VIIa

Cumbrian Zone C13 Moorthwaite A, not present
Abbot Moss A, 555–515 cm

Betula values fall less steeply and *Alnus* continues to rise slightly. *Pinus* falls to zero at the top of the zone and *Ulmus* sustains a temporary fall. *Quercus* values are higher than immediately before or after. *Tilia cordata* and *Hedera* are first represented at Abbot Moss and *Salix* reappears at the top of the zone. Although at Moorthwaite the *Pinus* curve falls markedly from the top of Zone C12, the other pollen curves do not behave in any way consistent with their counterparts at Abbot Moss or elsewhere. No attempt has been made, therefore, to demarcate the zone there.

Cumbrian Zone C14 Moorthwaite A, not present
Abbot Moss A, 515–370 cm

The *Betula* curve lies at its post-Glacial minimum, but its local component still replaces some *Alnus* in the lower half of the zone. Taking this modification into account, *Alnus* values are high and probably steady. *Pinus* recovers uncertainly and the curve becomes discontinuous at the top of the zone, where its smoothed curve (as a percentage of *Pinus*+*Ulmus*+*Quercus*) falls from about 5% to about 1 to 2%. *Ulmus* values are rather irregular but the smoothed curve (cf. above) lies between 15 and 20% until the top of the zone where a diminution smaller than, but parallel with, that of *Pinus* occurs. *Quercus* remains fairly constant at about 20% *A.P.* *Tilia cordata* is rare and the first significant grains of *Fraxinus* appear sporadically. *Corylus* values lie at about 20% *A.P.* in the lower half and 30% *A.P.* in the upper half of the zone. *Salix* is fairly consistently present.

Cumbrian Zone C15 Moorthwaite A, not present
Abbot Moss A, 370–315 cm

Betula values rise, probably owing to a local component in the hydrosere (cf. wood at same level) which might be expected to cause the greatest depression in values for *Alnus*. After adjustment for this, *Alnus* frequencies probably remain high. *Pinus* pollen is negligible. *Ulmus* recovers from low values at the beginning of the zone, its smoothed curve (as a percentage of *Pinus*+*Ulmus*+*Quercus*) never falling below 12%. The upper boundary of the zone is drawn where the *Ulmus* values reach their local maximum. *Tilia* is absent, but *Fagus sylvatica* is represented by a single grain at 365 cm. *Fraxinus* pollen is rare. *Corylus* values, though variable, are relatively low.

Cumbrian Zone C16 Moorthwaite A, probably not present
Abbot Moss A, 315–260 cm

Ulmus values fall almost to zero. *Pinus* recovers slightly and only temporarily at the beginning of the zone. *Quercus* is rather less frequent than in preceding or succeeding zones, but this is probably an effect of local preponderance of *Betula* and *Alnus* which vary dependently, the latter maintaining much the higher values. *Tilia cordata* is present, *Fraxinus* absent, and *Corylus* remains relatively low. The boundary between British Zones VIIa and VIIb (the '*Ulmus* decline') lies at the top of Zone C16. At Moorthwaite, the fall in *Ulmus* which culminates at 105 cm may be in part referable to this zone. There is already some suggestion of a hiatus at the top of Zone C12 however, whilst the pollen curves immediately above 105 cm are not easily recognizable as belonging to any of the Zones C13 to C18 inclusive. No zonation of this part of the Moorthwaite diagram is attempted therefore.

British Zone VIIb

Cumbrian Zone C17 Moorthwaite, not present
Abbot Moss A, 260–125 cm

Ulmus, although not very consistent, recovers somewhat, the top of the zone being defined by its local maximum. The local component of *Betula* again obscures the regional values of the other curves, but *Quercus* on the whole rises slightly whilst *Alnus* falls, the frequencies of both being similar at the top of the zone. *Pinus* is insignificant. *Tilia cordata* is rare at the base and *Fraxinus* is rare at the top of the zone. *Corylus* is considerably higher in the top half of the zone, possibly as a result of the erroneous inclusion of *Myrica* pollen in this category.

Cumbrian Zone C18 Moorthwaite A, not present
Abbot Moss A, 125–80 cm

The *Ulmus* curve remains continuous and significantly high to the top of the zone, where it falls sharply to zero and is insignificant above. *Betula* values are higher than formerly, with less macroscopic evidence of a local *Betula* component. *Quercus* maintains rather high values, but *Alnus* falls to levels between 20 and 30%. *Fraxinus* is present but hardly significant and the pronounced and isolated peak of *Salix* at 95 cm is ascribed to a local component of the pollen rain.

Cumbrian Zone C19 Moorthwaite A, possibly 100–55 cm
Abbot Moss A, 80–10 cm

At Abbot Moss, *Pinus* and *Ulmus* are insignificant and *Quercus* values fall systematically. The general level of *Alnus* is higher in the early part of the zone than in Zone C18 but falls somewhat at the top as *Betula* rises. *Fraxinus* is consistently present in increasing amounts. *Corylus* values are variable and do not differ substantially from those of Zone C18. The abundance of pollen of Gramineae, Cyperaceae and *Plantago* above 45 cm suggests that trees were not everywhere the dominating vegetation throughout this zone. At Moorthwaite, some of these features may be identified near the top of the diagram, particularly the rising *Betula* values, the falling *Quercus* and the presence of *Fraxinus*. *Ulmus* values remain relatively high, however, so that no precise comparison can be made.

The plant list

Macroscopic plant remains were recovered from the pollen analytical samples. Some of these are recorded along with the pollen diagrams, but the less commonly occurring species are listed in table 2. This table also contains the records from a composite sample collected between 766 and 821 cm at Abbot Moss and referable to Zones C3 to C5 (i.e. British Zones II and late I). Some of these records, together with some plants identified only from their pollen, receive special notice below.

Armeria

Pollen of *Armeria maritima* (B type, Iversen 1940) from Zones C7 and C8 (III) at Moorthwaite and Zones C3, C4 and C8 (I and III) at Abbott Moss further confirm the lowland, inland range of this plant during the late-Glacial period (Godwin 1956).

Betula nana

Pollen of *B. nana* was not separately identified in these analyses, although the possibility of its partial inclusion with *Corylus* has already been noted (p. 62). A single fruit of this species from Zone C3 (I) at Abbot Moss is certain indication of the existence of the plant near that site during the late-Glacial (cf. Godwin 1956).

Betula pubescens and *B. verrucosa*

Fruits and catkin scales of *B. pubescens* are recorded from the late-Glacial at Abbot Moss (Zones C3 to C5; I and II) and more abundantly from the post-Glacial at both sites. In spite of the difficulties of identification, however, catkin scales of *B. verrucosa* were certainly recovered from Zone C10 (VI) at Moorthwaite and Zone C14 (VIIa) at Abbot Moss.

TABLE 2

		Moorthwaite Moss						Abbot Moss					
		I	II	III		IV–V	VI	I		II	I–II	IV–V	VIIa
species	remains	C 4	C 5	C 7	C 8	C 9	C 10	C 3	C 4	C 5	C 3+4 +5	C 9	C 14
Betula nana	fr	.	.	.	.	.	.	+	.	.	.	.	.
*B. pubescens**	fr+sc	.	.	.	.	+	+++	+	.	.	++	++	.
B. verrucosa	sc	.	.	.	.	.	+	.	.	.	.	.	+++
Cardaminopsis cf. *petraea*	s	.	.	.	.	.	.	.	.	.	+	.	.
Carex sp.	n	.	.	+	+	.	.	+	.	.	.	.	.
Cirsium cf. *heterophyllum*	fr	.	.	.	.	.	.	.	.	.	+	.	.
Corylus avellana	n	.	.	.	.	.	+	.	.	.	.	.	.
Cyperus sp.	n	.	.	.	.	.	.	.	.	.	+	.	.
Eleocharis palustris	fr	.	.	.	.	.	.	.	.	.	+	.	.
Eleogiton fluitans	fr	.	.	.	.	.	.	.	.	.	+	.	.
Myriophyllum alterniflorum	s	.	.	.	.	.	.	+	.	.	.	.	.
Nymphaea alba	s	.	.	.	.	+	++	.	.	.	.	.	.
Polygonum minus	s	.	.	.	.	.	.	.	.	.	+	.	.
Potamogeton filiformis	f.st	.	.	.	.	.	.	.	.	.	+	.	.
P. natans	f.st	.	.	.	.	+++	++	.	.	.	.	.	.
Ranunculus cf. *flammula*	s	.	.	.	.	.	.	.	.	.	+	.	.
R. sect. *Batrachium*	s	.	++	+++	+++	.	.	.	.	.	.	.	.
Ceratodon purpureus	l	.	.	.	.	.	.	+	.	.	.	.	.
Fissidens osmundoides	l	.	.	.	.	.	.	.	+	.	.	.	.
Hypnum cf. *cuspidatum*	l	++	.	.	.	.	.	.	.	.	.	.	.
H. riparium	l	.	.	.	.	.	.	.	.	.	+	.	.
Polytrichum cf. *juniperinum*	l	.	.	.	.	.	.	.	.	+	.	.	.
P. piliferum	l	.	.	.	.	.	.	+	+	.	+	.	.
Polytrichum sp.	l	.	.	.	.	.	.	+	.	.	.	.	.

Fr = fruits; f.st = fruit stones; l = leaves; n = nutlets or nuts; s = seeds; sc = catkin scales. + = rare; ++ = occasional; +++ = frequent.
* Full records for *B. pubescens* accompany the pollen diagrams.

Cardaminopsis cf. *petraea*

A single seed, probably of this species, from the late-Glacial at Abbot Moss accords well with the records from Zone III at Neasham (Blackburn 1952) and at three Irish sites (Mitchell 1954). In Great Britain at present this species is restricted to high, rocky habitats in North Wales and similar places in Scotland where, however, it is also recorded only 50 ft. above sea level (Clapham *et al.* 1952; Wilson 1956). In the Arctic the plant grows 'in gravelly situations among rocks' (Polunin 1959) and in the Alps on most, but particularly on rich, soils in the grasslands and open woodlands of the montane and subalpine zones (Hegi 1919). In Scandinavia it is a mountain plant in S.W. Norway, but grows near to sea level on the west coast of the Gulf of Bothnia at about 63° N. (Hulten 1950).

Gramineae: cereal type

Grass pollen has only been recorded as of 'cereal-type' when the diameter of the grain exceeded 40 μm and the pore was protuberant and ringed. Even so, it seems possible that some wild grasses may have been included in this category whilst some cereal grains have been excluded. The diagrams therefore show the range of samples over which grains of cereal-type, as defined above, occur and no attempt is made to assess variations in frequency of occurrence. All cereal-type grains are also included in the curve for Gramineae; at Abbot Moss they occur in Zones C17 and C19 (VIIb and VIII) and at Moorthwaite in Zone C19 and below (VIII and earlier).

cf. *Humulus*

The single grain at 205 cm (Zone C17, VIIb) at Abbot Moss may represent *H. lupulus* or *Cannabis sativa* (Walker 1955*a*). The stratigraphy suggests that fen woodlands were only just being replaced by *Sphagnum* bog at that stage so that natural habitats for *H. lupulus* would probably have been available.

Koenigia islandica

Another find of the pollen of this species from Zone C3 (I) at Abbot Moss confirms, but does not extend, the known late-Glacial range of this plant now restricted in the British Isles to Skye (Raven 1952; see paper II of this series).

Linum usitatissimum

This species is represented by a single pollen grain from 105 cm (Zone C18; VIIb) at Abbot Moss. The grain is tricolpate, 58 μm in diameter, with verrucae of two sizes. It is distinguished from the closely related *L. bienne* by the greater relative abundance of large verrucae and the distinctly striate endexine pattern of the latter. Pollen of *L. usitatissimum* is easily distinguished from that of *L. anglicum* as described by Godwin (1959). Although the seeds of cultivated flax are frequently recorded in archaeological contexts from the Neolithic onwards (Helbaek 1959; Godwin 1956) the pollen seems not to have been found before in the British Isles (cf. Hafsten 1958).

Plantago spp.

In the late-Glacial samples from both sites *P. major* is represented in all available zones, except for Zones C1 and C6 at Moorthwaite and Zone C4 at Abbot Moss. *P. lanceolata* and *P. maritima* are each represented by a single grain from Zone C3 (I) at Moorthwaite and Zone C8 (III) at Abbot Moss respectively. Grains unidentifiable beyond the genus are distributed through all the late-Glacial zones except C6 (II) at both sites. Zone C8 (III) at Moorthwaite has one grain of *P. coronopus*. Apart from a single grain of *P. major* in Zone C9 (IV–V) at Abbot Moss, and two grains of *P. lanceolata* and one of *P. coronopus* in Zone C12 (B.A.T.) at Moorthwaite, the post-Glacial occurrence of the genus is restricted to the upper four zones. At Moorthwaite *P. major* and *P. lanceolata* are present in the hiatus between Zones C12 and C19 but expand together at the top of Zone C19 where they are joined by *P. coronopus*. At Abbot Moss Zones C15 and C16 (VIIa) each contain a single grain of *P. major*, which is more or less continuously represented between

205 and 155 cm (C17; VIIb), 115 and 105 cm (C18; VIIb) and 45 and 10 cm (C19; VIII) where it reaches a peak of 9·5% *A.P.* at 35 cm. *P. lanceolata*, on the other hand, runs from 185 to 135 cm (C17; VIIb), is absent from Zone C18, and appears again from 65 to 25 cm (C19; VIII) also reaching a maximum of 8·5% *A.P.* at 35 cm. This pattern of occurrence of the species of *Plantago* in the late- and post-Glacial periods is generally well known (Godwin 1956). *P. coronopus* has not hitherto been recorded for the late-Glacial in the British Isles but its history may now be closely compared with that of *P. maritima*, restricted by the post-Glacial spread of forests to the coasts and only a few inland habitats, unsuitable for tree growth.

Polygonum spp.

A seed of *P. minus* was recovered from late-Glacial mud at Abbot Moss (Zone C3+4+5 sample; I+II) and pollen referred to *P. amphibium* type (which is only slightly different from *P. persicaria*, *P. minus* and *P. hydropiper* (Hedberg 1946)) occurs in Zones C1 and C3 to C5 (I and II) at Abbot Moss. Pollen of this type, as well as a fruit of *P. amphibium* itself (Mitchell 1953) and seeds and fruits of *P. nodosum* (Godwin 1956) have already been recorded from late-Glacial deposits in the British Isles, but *P. minus* has hitherto been recorded only from post-Atlantic time (Godwin 1956). All are plants of waste places, damp ground or shallow water, habitats which might have been least frequent during the post-Glacial forest period of relatively stable soil.

Potamogeton filiformis

The fruit-stone of *P. filiformis* from the late-Glacial at Abbot Moss (Zones C3+4+5 sample; I+II) confirms but does not extend the known late-Glacial range of this species south of its present southern limit in Scotland (Godwin 1956).

Isoëtes lacustris

Two microspores of this plant, one from Zone C9 (IV–V) at Moorthwaite and the other from Zone C18 (VIIb) at Abbot Moss confirm its long history in the north of England.

Lycopodium spp.

The record of *L. selago* from Zone C19 (VIII) at Moorthwaite is unusually late for such a lowland region, as is that of *L. clavatum* from the same zone at Abbot Moss. The late-Glacial occurrence (Zone C5; II) of this species at Abbot Moss fits well with the accumulating evidence for the genus as a whole. *L. annotinum* has only previously been recorded from late-Glacial deposits at Liverpool and in North Wales (Godwin 1959), although it occurs in post-Glacial deposits at Malham (Pigott & Pigott 1959), and in the interstadial at Chelford (Simpson & West 1958). Although in this country it is a rare plant of hills and mountains, its presence in the early post-Glacial forest communities is perhaps comparable to its habitation of the rather open, high level pine woods of the Black Forest, Germany, at the present day.

Ophioglossaceae

Spores of both *Botrychium* and *Ophioglossum* are recorded from both sites and together provide records for late-Glacial Zones C1 C3 and C4 (I), C5 (II) and C7 and C8 (III) as well as for the early post-Glacial Zone C9 (IV to V). Whilst *Botrychium* occurs in all these except C1, *Ophioglossum* is restricted to Zones C1, C3 and C4 (I) and C7 and C8 (III), exactly the converse of their distribution through the same general period at Scaleby and Oulton Mosses (part II of this series) and less suggestive of a differential climatic control comparable with that indicated by their distribution at the present day.

Fissidens osmundoides

A small tuft of leaves from Zone C4 (I) at Abbot Moss was identified to this species. At present the moss is not common in Great Britain, but is found in damp, often rocky, situations on hillsides.

Polytrichum spp.

Numerous tufts of moss with the characteristic hair-pointed leaves, many of them still intact, of *P. piliferum* were recovered from late-Glacial samples (Zones C3 to C5; I–II) at Abbot Moss. In another sample from Zone C5 (II) at the same site a few leaves more closely resembling *P. juniperinum*, more evenly tapering to a shorter point, were found. Both are species of open heath-land and sandy soils, widely distributed in the British Isles and Europe.

Ecological development of the mires

Moorthwaite Moss

The deep, steep-sided, basin now occupied by Moorthwaite Moss is almost certainly a kettle hole created by the melting of a residual ice block left behind after the general retreat from the locality of the ice cover of the Main Glaciation. There is no way of knowing at what stage in the general deglaciation this block finally melted, except that it must have post-dated Stage *M* of the retreat and is unlikely to have persisted very long under climatic conditions which resulted in the general deglaciation of the Carlisle Plain. It is very likely that the red sand and gravel lining the hollow is morainic material which melted out of the isolated ice block itself. By that time, the hollow containing a lake was probably isolated from the pro-glacial lake between the ice front to the north-west and the Pennine foothills and Penrith Sandstone ridge to the east. Much of the surrounding countryside would still have been flooded and only hills rising above 150 m (500 ft.) O.D. are likely to have been entirely free of the effects of a high water-table. The Moorthwaite hollow itself can never have received very much drainage water, the area of land from which it could possibly do so being rather less than 1 km^2. The only outlet, however, was across the watershed northward into the Cumwhitton Moss basin, but this could only have functioned if the water level had stood above 120 m (400 ft.) O.D., an order of level for which there is no evidence in the stratigraphy.

The melting of the ice block was followed by the accumulation of a sandy silt which became progressively more muddy as time went on but never became very organic. This deposit (figure 12) might represent only a remnant of a formerly greater extension, removed from the edges of the basin by subsequent erosion. Above it, silty clay-mud was laid down during Zones C1, C2 and early C3 (I). The pollen diagram indicates how barren was the vegetation of this period. Only *Myriophyllum alterniflorum* could really flourish in such oligotrophic conditions, although *Alisma plantago-aquatica*, *Sparganium* sp. and *Nymphaea* cf. *alba* were sparsely represented whilst grasses, sedges, *Thalictrum* sp. and *Filipendula ulmaria* formed poor fringing fens, probably incompletely covering the ground and hardly distinguishable from the communities occupying the drier and higher land. The later half of Zone C3 (I) witnessed the deposition first of fine sand and then (in Zone C4) of coarse sand and gravel which can only have resulted from the redistribution of earlier-deposited material from the upper slopes of the basin. A pronounced change in water-table may have been sufficient to account for this, but the upper parts of the deposit are very mixed, suggesting the downslope solifluction movement of unsorted material under freeze-thaw conditions. The pollen analytical data do not indicate any major ecological change in the basin during this period. The consistent presence of *Sphagnum* spores (*ca.* 20% *A.P.*) is perhaps of interest, but might be due to their secondary incorporation with soliflucted material.

After this episode the formation of truly organic deposits in the basin began. The first stage, covering Zones C5, C6 and early C7 (II and early III) resulted in up to 40 cm of nekron mud being deposited beneath the lake up to a maximum height of 3·5 m below site datum, i.e. about 117 m (386 ft.) O.D. The pollen diagram is rather uninformative about the lake vegetation during this period. It is evident that *Myriophyllum alterniflorum* was much less important than formerly but there is no indication of what replaced it. It may be that the more stable conditions around the margins, resulting in a diminution in the quantity of inorganic material supplied to the lake, thereby rendered the lake water intolerably poor in nutrients to anything other than micro-organisms. Apart from an isolated maximum of *Filipendula ulmaria* pollen and the persisting *Thalictrum* sp. the fringing fens must have been largely dominated by grasses.

During the latter part of Zone C7 and Zone C8 (III) sand was once again washed into the lake, although not on the scale of Zones C3 and C4. Indeed, no more rigorous conditions than a change in water table, or the slight exposure of surrounding slopes to water erosion, seem necessary to explain this change, particularly as the deposition of nekron mud continued throughout. The only recorded floristic change of any substance was the continued diminution of *M. alterniflorum*, punctuated at the top of Zone C8 (III) by a temporary maximum, perhaps only at the site of the pollen diagram, and the sudden abundance of *Ranunculus* sect. *Batrachium*. In the fringing fens, as in the dry-land vegetation, sedges perhaps replaced grasses in part, but there is no other indication of change there.

With the opening of Zone C9 (IV–V), allochthonous material became very rare in the lake mud, whilst in the latter part of the zone the muds became finely detrital, suggesting overgrowth and the initiation of a hydrosere, at least at the edges. During Zone C9 at least half a metre of organic mud accumulated and the water level cannot have been more than 2·5 m below site datum, i.e. below 118 m (389 ft.) O.D. As the curves for *M. alterniflorum* and *R.* sect. *Batrachium* fall in the pollen diagrams, that of *Nymphaea* rises to take their place whilst abundant macroscopic remains near the top of the zone indicate the presence of *N. alba* and *Potamogeton natans* in quantity. Marginally grass and sedge fens undoubtedly began to encroach on the lake; *Thalictrum* first and then *Filipendula ulmaria* diminished in importance, presumably as organic accumulations reduced the accessibility of mineral soil. During this zone, therefore, the organic productivity of the lake and the surrounding mires was evidently much increased. There is no stratigraphic evidence of enrichment by the inflow of new materials from the surroundings, nor was the nature of the sediment on the lake bottom markedly different from that which had been available since the end of Zone C4 (I). It seems probable, therefore, that this marked, and fairly rapid, change was largely the result of the climatic amelioration at the beginning of the post-Glacial period (*sensustricto*).

During Zone C10 (VI) the overgrowth of the lake by mire communities continued. The stratigraphy is confusing but there seems little doubt that fens encroached from the northern margin, through the deposits of which the pollen diagram passes. By the middle of Zone C10 these fens had replaced the aquatic communities of *N. alba* and *P. natans*, which had been joined at the beginning of the zone by aquatic species of *Sphagnum*, suggesting the beginning of acidification of the lake. The fen deposits of this period still contain a large sedimentary fraction indicating that they were still being laid down below water level, which cannot have stood more than 2 m below the site datum, i.e. 118 m (390 ft.) O.D., at the end of Zone C10. The abundant remains of trees in the mud, particularly those of *Betula pubescens*, suggest that the initial colonizing communities were of the swamp-carr type (Lambert 1951). At the south side of the basin, however, *Sphagnum* peat, at first with a few sedges, directly overlays the lake muds attributable to Zone C9. Moreover, unless their origin be ascribed to the neighbouring Cumwhitton Moss, the high values of *Sphagnum* spores and *Calluna* pollen in the diagram from late in Zone C10 onwards must indicate the active growth of bogs in the basin. It therefore seems necessary to suppose that, whilst swamp-carr occupied the northern part of the basin, a *Sphagnum* bog was developing on the southern banks and aquatic Sphagna were invading the water surface of the lake itself. (It may be significant in this connexion that the field immediately to the south of the basin until very recently contained a woodland growing over a *Calluna* heath on shallow peat over a very well-developed podzol profile.) This pattern persisted throughout Zones C10, C11 and C12 (VI), the bog steadily encroaching on the swamp-carr and finally replacing it. This replacement was probably not a very regular process and its uncertainties account for the chronological hiatus in the pollen diagram between the top of Zone C12 and the base of Zone C19, an interval represented by only 25 cm of deposits.

Early in Zone C19, *Sphagnum* bog extended as far northward as the site of the pollen diagram and probably rapidly covered the rest of the mire thereafter. It is difficult to determine when, if ever, this bog became independent of topogenous water. The high *Calluna* values at the top of the pollen diagram might indicate this change, with which an increased frequency of drier habitats would probably have been associated, but they might equally well derive from vegetation on heaths outside the basin itself. It is evident from historical records and microtopographic evidence, however, that Moorthwaite Moss had grown up to considerably above its present surface level by the Middle Ages, presumably as an ombrogenous raised bog.

The most notable ecological changes at Moorthwaite Moss with which stratigraphic breaks are associated are: (i) the accumulation of sandy clay mud in an oligotrophic lake during Zones C1 and C2 leading, in Zone C3, to the deposition of what is probably a solifluction deposit; (ii) the beginning of organic accumulation immediately after this event; (iii) the overgrowth of the lake by swamp-carr from the north and *Sphagnum* from the south, beginning in Zone C10; and (iv) the final overgrowth of the whole basin by *Sphagnum*-dominated bog communities. There is no strong evidence for major changes in water level at any time, although the *lowest* water level compatible with accumulation of the deposits naturally rises as the basin fills.

Abbot Moss

Abbot Moss also lies in a deep, steep-sided, kettle hole in sandy drift but in the bottom of a narrow valley, the drift-plastered slopes of which rise steeply to north and south and more gently to the east. Even though the basin might have been created by the melting of an isolated ice block shortly after a similar event at Moorthwaite, the whole valley at Abbot Moss remained part of the lake pro-glacial to the melting Main Glaciation ice for some considerable time. On the other hand, in the immediate vicinity a large proportion of the land would be above water; indeed high enough to be substantially unaffected by the high water table from an early stage of deglaciation.

The basal deposit of the hollow, the red sand and gravel, not reached across the middle of Section *A*, is thought to be the moraine dropped from the melting ice block during the creation of the kettle hole. There then followed the accumulation of an unknown depth of pink silty clay-mud, an upper part of which dates from Zones C3 and C4 (I). A layer of sandy, gravelly, clay was laid down at about the C3 and C4 boundary. During Zone C3 (I), *Alisma plantago-aquatica* and *Myriophyllum alterniflorum* seem to have been the only frequent aquatic plants, both of them suggestive of pronounced oligotrophy. Lake-edge communities seem to have been dominated by sedges with grasses, some *Filipendula ulmaria*, *Thalictrum* sp. and *Epilobium* sp. There is no pollen analytical indication of the vegetation during the deposition of the gravelly, sandy, clay. Subsequently, in Zone C4 (I) and continuing into Zone C5 (II), *M. alterniflorum* seems to have become much the commonest water plant, whilst the pollen of *Nymphaea* perhaps suggests the development of organically richer bays. The fringing communities changed hardly perceptibly, except for the apparent increase of *F. ulmaria* and the success of *Littorella uniflora* during Zone C5 (II). The macroscopic remains from these lower zones (C3 to C5) on the whole confirm the impression gained from the pollen diagram of a fairly barren, oligotrophic, lake with a disturbed gravelly shore and intermittent fringing fens of sedges and grasses.

Zone C6 (II) is not represented in the pollen diagram probably because of erosion during the deposition of sandy clay in the subsequent Zone C7 (III). At the western end of Section *A*, if the stratigraphical correlation is correct, clay-mud continued to accumulate throughout this zone to levels demanding a water level at least as high as 3·5 m below the site datum, i.e. not below 112 m (370 ft.) O.D. During Zone C7 (III) sand was once again washed into the lake in some quantity and the pollen diagram suggests that both lake and banks became even poorer in vegetation. Toward the end of the zone, however, more organic material had begun to accumulate along with the clay and in Zone C8 an organic mud with only a little included sand was accumulating. *M. alterniflorum* again luxuriated in the water and *Littorella uniflora* became rather abundant around the edges.

It seems likely, too, that grasses became more important than sedges in the fringing fens.

The reworking and deposition of the sand and gravel at the C3 to C4 boundary (I) almost certainly required solifluction movement of the soil on the slopes surrounding the lake, as well as disturbance of the shore. The sandy clay of Zone C7 (III), however, suggests much less rigorous conditions, although, in the absence of any indication of water level change, slight solifluction was probably involved. The decrease in the inorganic content and the increase in organic content of the mud during Zone C8 (III) are coincident with the appearance of detrital rootlets in the mud. This suggests that the lake edges were becoming completely vegetated and fixed for the first time and that the new conditions favoured the organic development in the lake itself.

In Zone C9 (IV–V) the accumulation of a richly organic fine detritus mud began in the deep parts of the basin and continued until Zone C14. This almost certainly implies the initiation and development of hydroseres, particularly on the more gently sloping margins. *M. alterniflorum* and *L. uniflora* became very rare in the pollen diagram where, however, the expansion of *F. ulmaria* pollen and fern spores probably reflects the development of fens. The presence of fruits and catkin scales of *Betula pubescens* in the muds of C9 indicates the close proximity of this tree to the lake during that period.

Fine detritus mud accumulated at the middle of the basin through Zones C9 to C13 and at least to the middle of C14 (IV–V to VII a). At some time during this period the lake level must have stood at least as high as 1·5 m below local datum, i.e. not below 114 m (376 ft.) O.D., and for the greater part of the time it cannot have been below 5 m below local datum, i.e. not below 111 m (365 ft.) O.D. The deep water conditions at the centre of the lake prevented the rapid extension of the fens from the edges, and the zone of *Nymphaea* and *Potamogeton* (represented pollen analytically in Zones C13 and C14) was probably very narrow. From the middle of Zone C14 (VII a) through Zones C15 and C16 the mud in the middle of the basin, although still containing a substantial microscopic sedimentary fraction, became very coarsely detrital and particularly rich in remains of sedges, *Phragmites communis*, leaves, wood and fruits of *Betula* spp. and more rarely of *Alnus glutinosa*. This, and the abundance of fern spores in the pollen diagram, indicates the establishment of fen woodlands and reedswamps in the shallower parts of the lake, such as that crossed by Section *B*, possibly as a result of a fall in water table or as a result of normal hydroseral development there.

Sphagnum spores first become a significant feature of the pollen diagram in Zone C16 at about the level at which *Sphagnum* leaves first occur in the muds at the site of the diagram. These are the first indications of the acidification of the basin and with them the pollen of *Nymphaea* and *Potamogeton* virtually disappear. It is evident from Section *A* that this event took place at about the same time all over the deeper part of the basin, and it was probably the result of depauperation of the soils of the surrounding hill slopes and the high organic content and low mineral status of the water draining into the lake. Not all the slopes were irretrievably fixed, however, for at about this time a layer of sand was deposited off the eastern shore, followed some time later (probably near the end of Zone C17) by a second, more extensive band. The cause of the erosion which must have first made this sand available from the banks is difficult to imagine, since no change in water level is otherwise evidenced, but the possibility of local interference by human beings cannot be ruled out.

By the middle of Zone C17, *Sphagnum* had become very abundant in the basin where accumulation of mud had by this time so shallowed the free water that sedge swamp, rich in aquatic Sphagna, had spread all over the basin. By the end of Zone C17 (VIIb) fen plants hardly persisted in the hollow which was by then occupied by a *Sphagnum*-dominated bog with *Eriophorum vaginatum*, *Calluna vulgaris* and *Menyanthes trifoliata* and dry enough in some places to support trees of *Betula* sp. It seems very likely that accumulation of sediments in the basin had now reached up to about the topogenous water level in the basin of that time (i.e. about 1·5 m below local datum; 114 m (376 ft.) O.D.) and that thereafter mire growth was largely under the control of direct precipitation except for the marginal areas which must still have received some drainage water from surrounding slopes and which might even then have harboured narrow fens.

During Zones C18 and C19 (VIIb and VIII), the bog continued to grow upwards and although, in some places (e.g. the site of the pollen diagram), evidence of a slowing of accumulation was found in the upper peat this was not sufficiently consistent over the deposit as a whole to suggest the operation of a general controlling factor. There is no evidence of the length of the period during which bog growth continued and although peat cutting, afforestation and other disturbances of the surface have undoubtedly taken place no historical records of these are known.

The most significant ecological changes during the history of Abbot Moss mire were the change from oligotrophy to eutrophy during Zone C8 (III) and the acidification of the basin, beginning in Zone C16 (VIIa) and completed by the beginning of Zone C18 (VIIb), as a result of which a continuous, ombrogenous, *Sphagnum*-dominated bog was established.

IV. STRATIGRAPHY AND POLLEN ANALYSIS AT ST BEES AND EHENSIDE TARN

A late-Glacial pollen diagram from a deposit of organic mud at St Bees, has been re-drawn and described according to the standard British zonation and the local Cumbrian zonation.

The small lake basin at Ehenside Tarn contains organic deposits extending from late-Glacial time until about A.D. 1869 when the tarn was drained and the surface covered with boulder clay. The general stratigraphy and the stratigraphy exposed in a marginal trench, together with pollen diagrams from both localities zoned according to standard British and local Cumbrian schemes, allow the reconstruction of the ecological history of the mire and provide data for the study of more general problems of post-Glacial vegetational history, notably the clearance of the forests. The cause of a long discontinuity in the deposition of mud marginally in the lake is tentatively attributed to human interference. Amongst the more interesting plants recorded are *Chrysanthemum segetum*, *Gentianella* cf. *campestris*, *Humulus* or *Cannabis*, *Linum usitatissimum*, *Potentilla* cf. *crantzii*, *Trifolium scabrum*, *Isoëtes echinospora* and *Pilularia globulifera*.

Introduction

The sites of St Bees (Nat. Grid Ref. 962116) and Ehenside Tarn (Nat. Grid Ref. 003071) lie 7 km (4 miles) apart on the coastal lowland fringe of West Cumberland, 7 km (4 miles) and 13 km (8 miles) south of Whitehaven respectively (figure 18*a*). Both sites have been investigated before and the periods covered by their deposits do not substantially overlap. Together, however, they provide a complete late- and post-Glacial record for their part of the county, for which reason they are included together here. Since the sites themselves are so different, however, the results from each will be separately described.

ST BEES

Geography and stratigraphy

The layers of mud and peat exposed in the sea-eroded, glacial drift, cliff at St Bees at 20 m (70 ft.) O.D., were first investigated by Smith (in Eastwood *et al.* 1931) and assigned to an inter-Glacial period between the Main Glaciation and the Scottish Readvance Glaciation. Walker (1956) showed that the main organic deposit now exposed in the cliff ('Site 6'), and to which all future discussion applies, is of late-Glacial, rather than inter-Glacial age and probably the equivalent of the Allerød oscillation. Moreover, the stratigraphy of the cliff deposits does not indicate that this mud was formed before the Scottish Readvance Glaciation and there is some circumstantial evidence for supposing that it accumulated later. More recent observations and pollen analytical investigations (Pearson 1962) have substantially confirmed the earlier findings, although further erosion has now exposed a thicker section of these muds. Finally, radiocarbon assay of wood contained in the mud gave ages of 8390 ± 200 B.C. and 8550 ± 200 B.C. for Zone γ of Walker's (1956) provisional zonation, confirming the general equivalence of the interstadial with the Allerød oscillation (Godwin 1960).

Details of the stratigraphy of this deposit have already been published (Walker 1956). As then described, erosion had exposed a section of a basin in Main Glaciation drift, about 4 m wide at the top and about 0·8 m deep at the middle, filled with organic detritus muds covered at the top by a thin layer of grey clay with sand and rounded pebbles. There is no evidence for any comparison between the ages of this deposit and of the boulder clay of the Scottish Readvance which caps a low hill 0·5 km south-eastward.

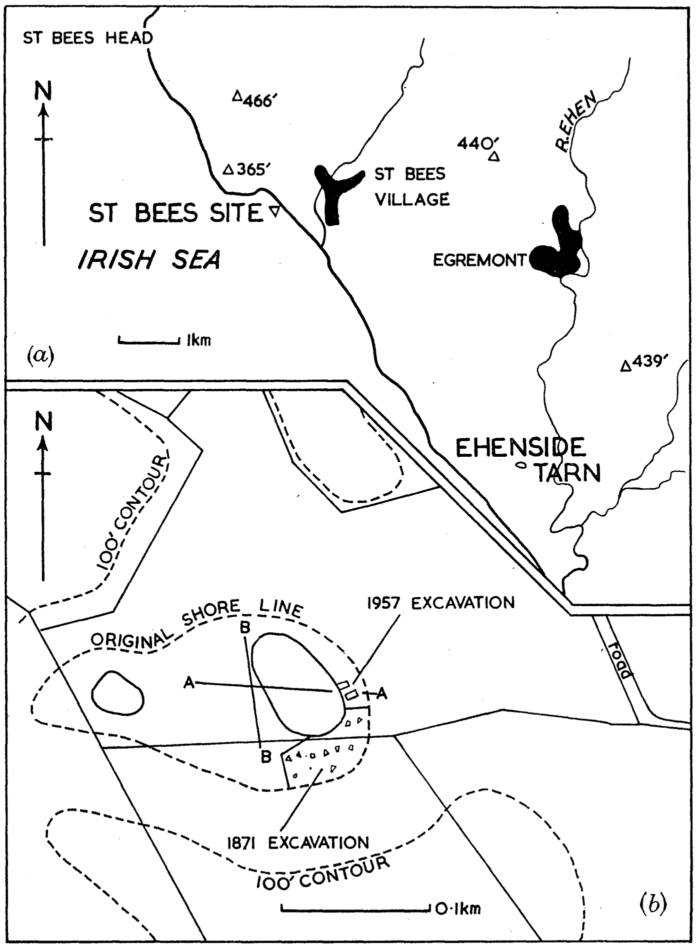


FIGURE 18. St Bees and Ehenside Tarn, Cumberland. (*a*) General map showing positions of the two sites relative to the sea coast, the nearby towns, and the main topographic features. (*b*) Map of Ehenside Tarn, showing the location of the two modern ponds within the old (pre-1869) shoreline, and the positions of old and new archaeological excavations and the lines of the transects of borings A–A and B–B.

POLLEN DIAGRAM AND CHRONOLOGY

The pollen diagram (figure 19) is constructed from the same analyses as those previously reported, after re-examination of the slides for *Juniperus* pollen and recalculation of frequencies on a basic sum including trees, shrubs, shade-intolerant, dry-land, herbs, grasses, sedges and *Empetrum* (see part I). The diagram is zoned according to the provisional non-commital zonation first attributed to it (Walker 1956), the standard British and the local Cumbrian schemes. In parts of the diagram *Salix* and Cyperaceae pollen are particularly abundant at levels where the mud contains macroscopic remains of these plants, indicating their close proximity to the site and their probable over-representation in the local component of the pollen rain. In zoning the diagram an attempt has been made to allow for the more obvious cases of this over-representation.

British Zone I

Cumbrian Zone C4. 0 to $6\frac{3}{4}$ in.

Pollen of dry-land herbs dominant over that of trees. Amongst the trees *Betula* is overwhelmingly dominant over *Pinus*, although these frequencies are thought to contain a large, but falling, contribution from the shrub *B. nana*. *Salix* pollen, abundant at first, is

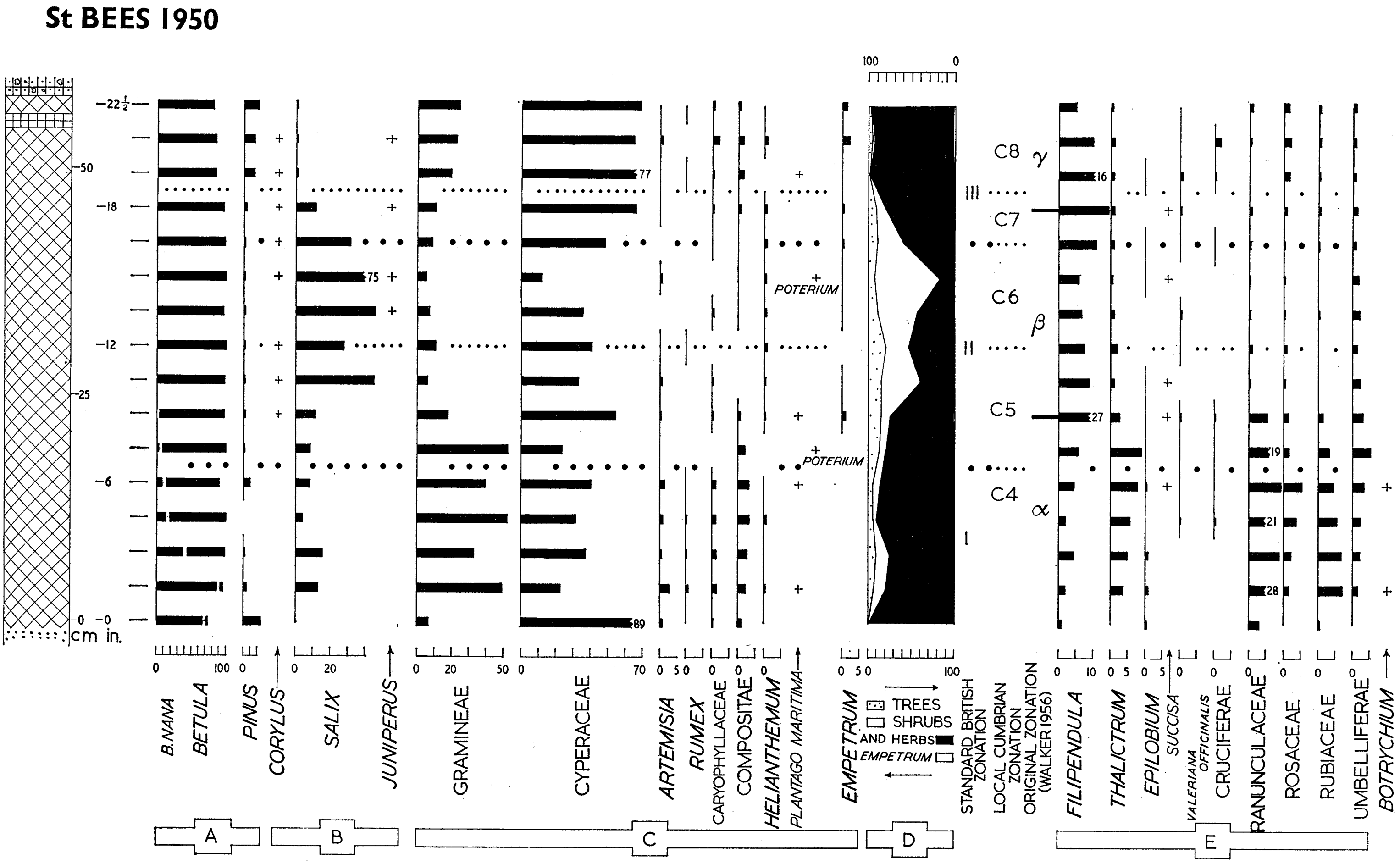


FIGURE 19. Pollen diagram from late-Glacial deposits at St Bees, re-presented in the standard form, excluding aquatic plants and most Pteridophyta. Section A: individual trees. Section B: individual shrubs. Section C: individual land herbs. Section D: summary curves for land flora (A + B + C + Ericales). Section E: individual taxa of uncertain ecology. The pollen frequencies in Section A are shown as percentages of the sum of Section A pollen (= arobreal pollen total) of the appropriate sample. The pollen and spore frequencies in the other sections are shown as percentages of the basic pollen sum (A + B + C + Ericales) of the appropriate sample.

less common in the upper half of the zone. Gramineae pollen is rather more abundant than that of Cyperaceae, and *Artemisia*, Caryophyllaceae and Compositae are frequent throughout. These pollen analytical features are all comparable with those of Zone C4 elsewhere. The apparent division of the zone at $3\frac{3}{4}$ in. is entirely the effect of the rising *Salix* curve, almost certainly a local component. Accordingly only Zone C4 is recognized at St Bees.

British Zone II

Cumbrian Zone C5. $6\frac{3}{4}$ to 12 in.

Pollen of dry-land herbs remains dominant over that of trees, but the frequency of *Betula*, which now includes only negligible amounts of *B. nana*, increases to 20% of the pollen sum at the top of the zone. Locally produced pollen of *Salix* is abundant in the upper half of the zone. Frequencies of Gramineae pollen fall through the zone but those of Cyperaceae, although fluctuating, are on the whole higher than formerly. *Artemisia* and Caryophyllaceae are insignificantly represented and Compositae values fall. *Empetrum* is infrequently present.

Cumbrian Zone C6. 12 to $16\frac{1}{2}$ in.

Dry-land herb pollen slightly increases its dominance over tree pollen through the zone. *Salix* pollen is even more abundant than in the preceding zone. *Juniperus* is first recorded. Amongst the herbs, *Helianthemum* is more consistently represented than hitherto. The top of this zone is drawn where there is a marked increase in the ratio of herb pollen to that of the trees disregarding the values for *Salix* which do not fit an otherwise consistent scheme.

British Zone III

Cumbrian Zone C7 $16\frac{1}{2}$ to $18\frac{3}{4}$ in.

Pollen of herbaceous plants increases dominance over that of trees. *Pinus* pollen, though low in frequency, is a significant contributor for the first time. Gramineae values increase slightly and those for Cyperaceae more positively. *Helianthemum*, Compositae and Caryophyllaceae and *Empetrum* are slightly more frequent than they were.

Cumbrian Zone C8. $18\frac{3}{4}$ to $22\frac{1}{2}$ in.

Tree and shrub pollen very rare. Amongst the trees, however, *Pinus* is represented by up to 20% of the total pollen. Frequencies of Gramineae, Caryophyllaceae, Compositae and *Empetrum* are substantially higher than in Zone C7 and *Artemisia* and *Rumex* are more frequently represented.

Conclusion

When presented on the same basis, therefore, the pollen analytical results from St Bees record vegetational changes very similar to those discovered elsewhere in Cumberland during the later part of the late-Glacial period. The solifluction which evidently took place during Zone C8 (III) and the subsequent inwash of sand from the hillsides inhibited the further accumulation of organic deposits in the lakelet. Nevertheless, the St Bees diagram provides a useful record of the vegetation of the area during a period which was not investigated at Ehenside Tarn.

EHENSIDE TARN

Geography and stratigraphy

Ehenside Tarn (otherwise known as Gibb Tarn) is a steep-sided hollow in the sandy boulder clay of the Scottish Readvance Glaciation lying just below 30 m (100 ft.) O.D.

near the ill-defined crest of a ridge of lowland between the Irish Sea to the west and the River Ehen to the east. The site is 1 km ($\frac{1}{2}$ mile) from the modern sea cliffs and about 8 km (3 miles) to the east the high hills of the Lake District rise steeply. Ehenside Tarn is one of many mire- or lake-filled hollows in the region (e.g. Braystones' Tarn, Hollas Moss), most of which are undoubtedly the result of the flooding of kettle holes and similar basins and channels of glacial origin. The local topography is low and undulating, peaks more than 45 m (150 ft.) O.D. being very rare, and slopes are usually gentle, except where the River Ehen and its tributary, the Kirk Beck, have incised narrow, deep, valleys. The ground surface is almost everywhere formed of glacial drift (figure 18*a*, *b* and A, plate 1).

The tarn was drained in 1869 (Darbishire 1874) and the wet surface spread with boulder clay in an attempt at reclamation for farming. Until then the hollow had had no natural outlet and received surface drainage water from an area of about 0·2 km^2. The drain was not effective for long, however, and the basin partially reflooded creating two ponds with a dryer area between which had formerly been partly occupied by an island. The bank of the original hollow can easily be seen on the ground and the margin of the historical lake within it can also be discerned (figure A, plate 1). The hollow is roughly oval in shape, elongated in the east-west direction, 180 m (600 ft.) by 90 m (300 ft.) at its widest point. Before the drainage in 1869 all but a marginal beach about 6 m (20 ft.) wide was flooded but a crescentic island almost divided the basin about 60 m (200 ft.) from the eastern end. One of the two ponds now occupies the space between this island and the eastern end of the hollow and the other, smaller, one occupies the far western end. The intervening ground is now rough pasture with *Holcus mollis* and tufts of *Juncus effusus*, *Eriophorum vaginatum* and *Deschampsia flexuosa*. The larger, eastern, pond is partially fringed with willows and alders growing in a *Juncus effusus* swamp, the greater part of the central area being occupied by a reedswamp of *Carex rostrata*, *Equisetum fluviatile* and *Typha latifolia* with *Potentilla palustris*, *Hydrocotyle vulgaris*, *Lemna minor*, *Galium uliginosum* and, here and there, *Sphagnum squarosum*, growing in 30 to 90 cm of water. The smaller pond contains a larger area of open water with a narrow fringing reed swamp.

The stratigraphic investigations were limited to the eastern half of the basin. A group of trenches was dug for archaeological purposes on the eastern bank of the larger pond (figure 18*b*) and the stratigraphy of the muds exposed on their walls was recorded (figure 21). A line of borings was made (Transect *A*) from the datum post of these excavations across the pond and on to the land beyond in a direction W 5° N. A second line of borings (Transect *B*) crossed this in the region of the old island, originating at the northern edge of the basin and intersecting Transect *A* at boring 7 in a direction S 5° E (figures 18*b*, 20).

Around the edges of the mire a bouldery grey-brown sandy clay, stoneless and rather silty near its surface, underlies the organic deposits. It is probable that this, the glacial drift, forms the bottom of the basin everywhere, but over the greater part of the two bored transects (figure 20) it was not proved. Instead, borings were stopped when a well-marked layer of grey sandy clay mud with occasional pebbles was encountered. This is undoubtedly redistributed material from the banks of the hollow and, in the middle of the basin at least, overlies a medium brown, slightly clayey, nekron mud the total depth and extent of which is unknown. The grey sandy clay mud extends right across the basin, its surface

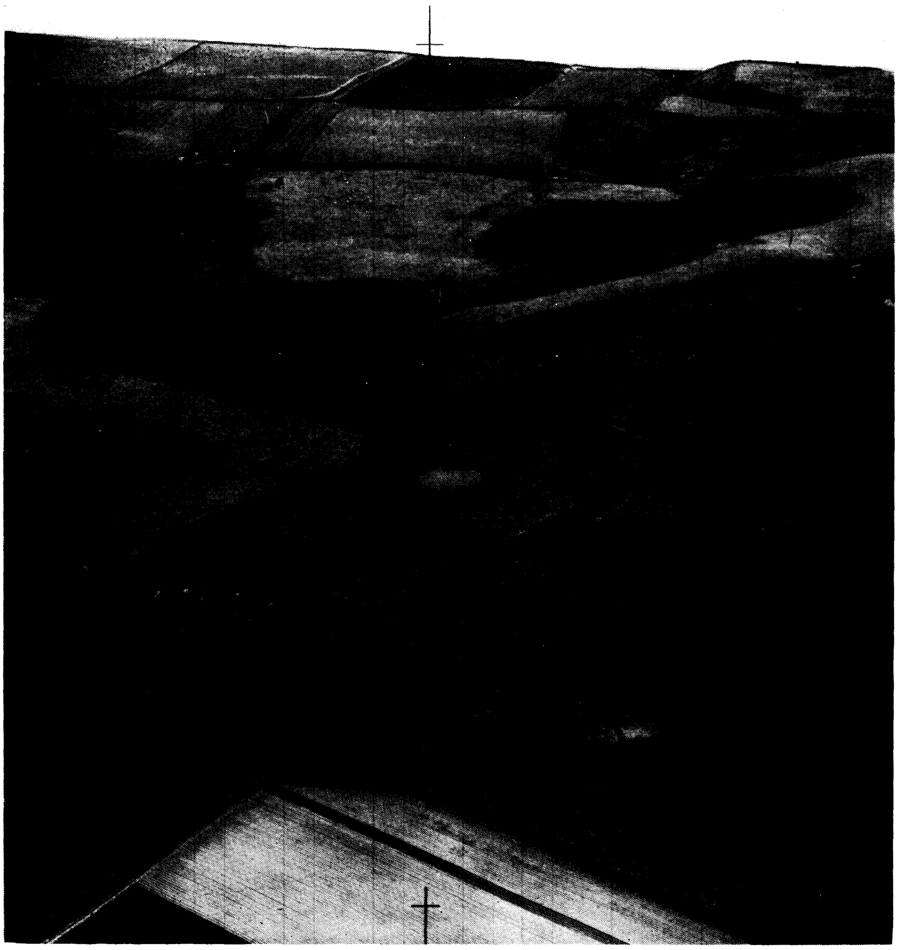


FIGURE A. Aerial photograph of the Ehenside Tarn region viewed from the north-east. The old tarn basin, with its two ponds, is in the left fore-ground. Similar features, Hollas Moss and Silver Tarn occupy the middle-right of the picture, and the coast is in the background. The distance from the immediate foreground to the coast on this line is 1 km. (*Phot.* J. K. St Joseph. Crown Copyright Reserved.)

(*Facing p.* 86)

FIGURE B. Archaeological excavation trench 1 at Ehenside Tarn, photographed from the south-western (lakeward) end. The upper surface of the timber and boulder layer has been cleaned of mud but other, underlying, timbers are not yet exposed. The surveying pole is graduated in feet. (*Phot.* B. Blake. Copyright.)

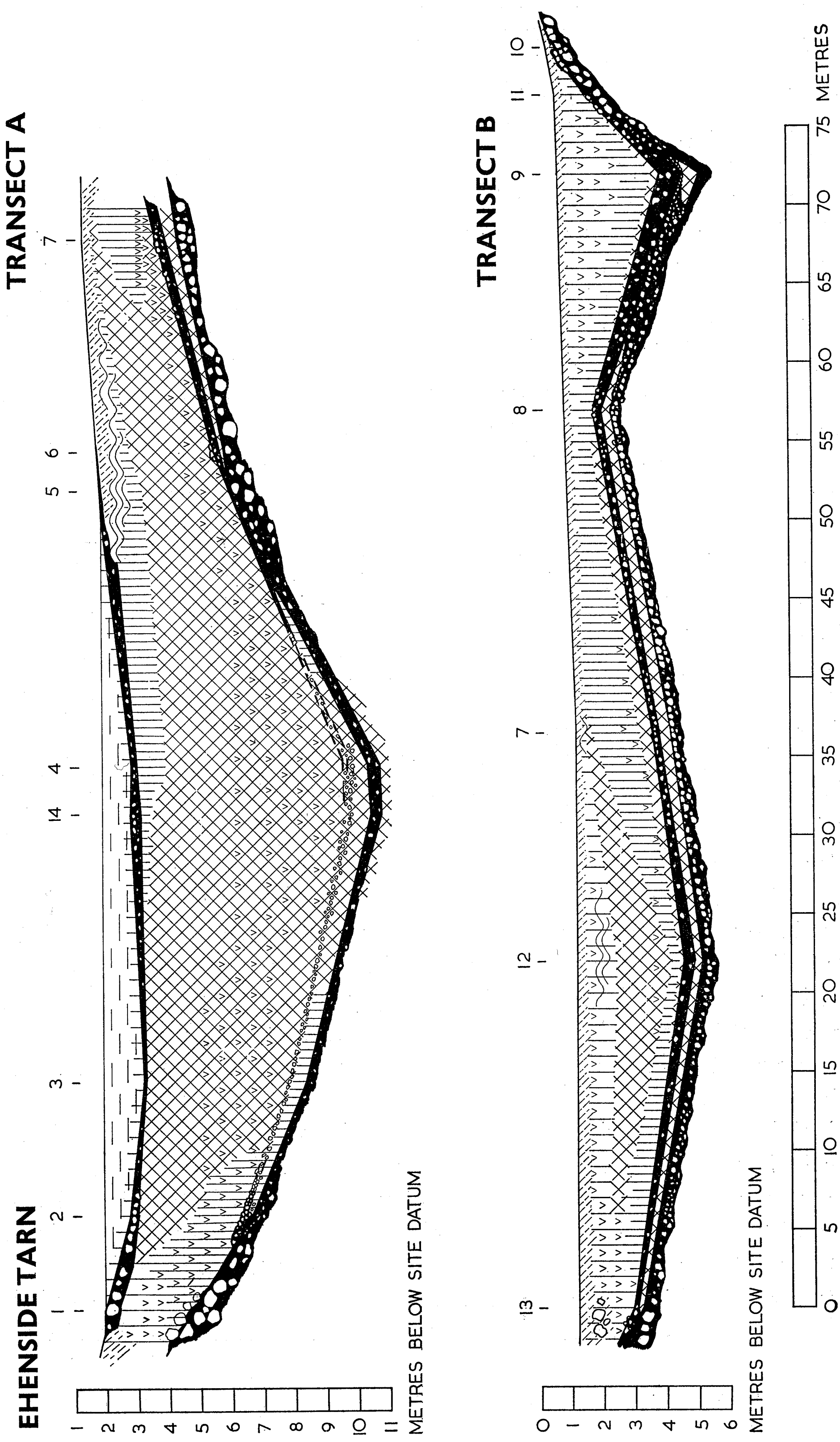


Figure 20. Stratigraphy of deposits at Ehenside Tarn as revealed by two transects of borings (cf. figure 18*b*). Levels are to site datum.

at the deepest point lying about 8·5 m below the level of the water in the modern pond. Over much of the lake, this clay-mud passes upwards into a dark brown fine detritus mud with occasional moss stems, small wood fragments and pieces of the nuts of *Corylus avellana*. Marginally, this layer of mud is very detrital, rich in sedge remains. It nowhere attains a thickness of more than 50 cm and is absent over the steeper slopes of the underlying sandy clay. Above it, a similar brown fine detritus mud, about 30 cm in thickness, contains a large admixture of grey sand and silt with rare pebbles but frequent fragments of wood charcoal. Marginally, and in the generally shallower region crossed by Transect *B*, the equivalent layer is very clayey and considerably richer in coarse sand and fine gravel.

In the deeper parts of the basin fine detritus mud, particularly rich in twig fragments in the lower 3·5 m and with *Potamogeton natans* and *P. pusillus* throughout, directly overlies the sandy mud. In shallower regions, however, the stratigraphically equivalent position is occupied by coarser detritus mud, with sedge and *Phragmites* remains but fewer and larger pieces of wood. At the south-western end of the area investigated (Transect *B*, figure 20) a lens of fine detritus mud included in the coarse is at such a level and of such a nature as to suggest that it is a lateral extension of the upper part of the fine detritus mud crossed by Transect *A*. At the deepest point in the basin the fine detritus mud reaches a thickness of 6 m above the sandy mud layer. Except for the region crossed by the eastern end of Transect A, the fine detritus mud is covered by a relatively thin layer of very coarse brown detritus mud occasionally containing wood fragments and *Menyanthes trifoliata* seeds and in some places composed mainly of sedge detritus (Transect *A*), in others of *Phragmites communis* (Transect *B*). Around the western edge of the present pond, this mud is also rich in remains of *Sphagnum* spp.

In the shallower parts of the basin this coarse detritus mud, mixed with bouldery sand and clay, forms the ground surface. Below the water of the present pond, however, up to 30 cm of mixed mud, clay, sand and pebbles, overlies the organic mud, and is interpreted as the boulder clay spread over the basin after drainage in 1869. Above this rests a thin layer of unconsolidated detritus in which the modern water plants find root. The greatest depth of organic deposits above the continuous layer of sandy clay with gravel is 7·5 m. The deposits indicate continuous deposition in and around a small lake, except perhaps during the period represented by the sandy or clayey mud when some sort of disturbance, and perhaps even erosion, must have taken place. It is evident that the crescentic 'island' was indeed an area of higher land, perhaps occasionally flooded but for the most part dry or swampy.

The marginal deposits were examined in greater detail on the south-east face of trench 1 of the archaeological excavation (figure 21). In a horizontal distance of 6 m, the level of the basal grey silty clay (the top of the boulder clay) fell 5 m vertically. The thickness of more or less undisturbed deposits between this clay and the overlying mixed soil increases from about 1 m at the north-east end to 6 m at the south-west, lakeward, end.

Over the lower part of its slope, the surface of the silty clay is evidently eroded and disturbed. 'Flames' of clay rise into the mud above, where lenses of sand and clay can often be traced, by excavation, to contact with the underlying material. The lowermost band of very fine, brown, detritus mud which contains these intrusions itself shows signs of brecciation, and where lamination is discernible it is always contorted. The top of these

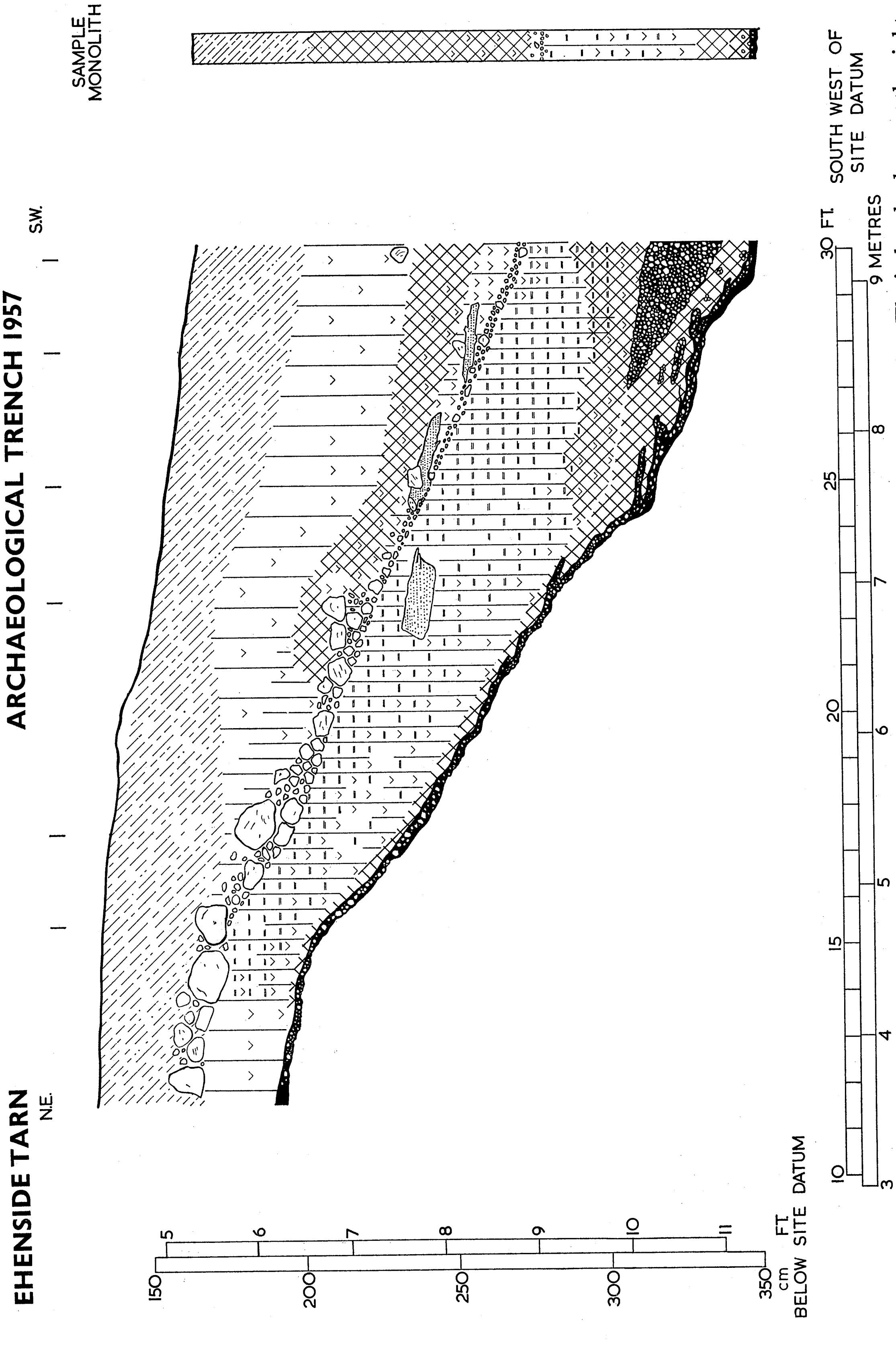


Figure 21. Stratigraphy of marginal deposits at Ehenside Tarn as revealed in archaeological trench 1. The isolated column at the right is the stratigraphic record at the point from which the pollen-analytical monolith was taken (cf. figure 23).

mixed deposits slopes gently lakeward at about 1·1 m above the base of organic material measured at the south-west end of the section. The contact with the overlying woody detritus mud is very sharp and easily discernible in the field. The latter deposit is a matrix of medium brown nekron mud containing abundant twigs and small branches, mostly of tree birches, most of them lying horizontally. At its thickest, near the south-west end, it may reach 0·5 m but even well up the slope, where it contains much more sedge and *Phragmites* detritus and is very narrow, this woody layer is still distinguishable. It is overlain by, and apparently passes gradually into, a coarser detritus mud in which wood fragments are rare except near the landward edge but which is very rich in horizontally bedded dicotyledonous leaves, the most frequent amongst them being those of *Quercus petraea*, *Corylus avellana* and *Betula pubescens*. Sedge and grass remains are not infrequent and fruit stones of *Potamogeton* spp. and seeds of *Nymphaea alba* occasionally occur. The surface of this leafy mud is distinct and falls 3·3 m in a horizontal distance of 5 m in a lakeward direction. At the landward end of the section large boulders lie on the surface, but lakeward these are replaced by smaller stones and finally by a layer of coarse sand and fine gravel. During excavation of the trench this gravel and sand were found to be intimately associated with a mass of tree-trunks (up to 20 cm in largest diameter) and brushwood, on and amongst which the larger stones lay (figure B, plate 2). Most of the wood was of *Betula pubescens* but a few pieces of *Quercus* cf. *petraea* were also found. Some of the butts were tapered, as if the trees had been purposely felled, but no axe marks were identified on them. Most of the timbers, and all the larger ones, lay roughly parallel with the surface of the leafy mud but a few smaller ones passed, peg-like, at a steep angle into the mud below. The mud in which this wood was embedded contains very large quantities of twig fragments, minute particles of charcoal and, at the lakeward end of the section, frequent remains of *Phragmites communis*. It may be that these timbers are part of a humanly constructed platform on the edge of the lake, but there is, as yet, no irrefutable evidence of this. It is certain, however, that the trees did not grow *in situ* but it is just possible that they grew sufficiently close by to have fallen naturally into the lake-edge mire, particularly at a time when the soil of the surrounding slopes was disturbed, as is evidenced by the spread of boulders, gravel and sand.

Along the lakeward half of the section the timber layer is covered by a very fine detritus mud, about 70 cm thick, with frequent twigs of *Betula* sp. and occasional fruit stones of *Potamogeton* spp. and seeds of *Carex* spp. and of *Nymphaea alba*. Above this, coarse detritus mud containing abundant stems and rootlets of *Phragmites communis* and *Carex* sp. together with fruit stones of *Potamogeton* spp. extends horizontally along most of the section forming an undisturbed layer up to 130 cm deep. The oxidized surface of this material, mixed with sand and clay, forms the surface soil around the margin of the modern pond and is continuous with the spread of gravelly clay sealing in the organic deposits there (cf. figure 20).

The stratigraphy on the south-west face of trench 1 is strictly comparable with that described above except that the deposits seem to reflect a slightly deeper water facies throughout. A single profile from this face is described in detail from the monolith collected for pollen analytical and radiocarbon sampling (page 96 and figure 21).

On stratigraphical grounds alone, it is concluded that the disturbed basal mud with sand and clay intrusions is equivalent to the layer of sandy mud (clayey in shallow regions) near the bottom of the deposits described in the general stratigraphy of the basin (Tran sects A and B; figure 20). The layer of large timbers, gravel and sand seems only to be represented in the strictly marginal deposits but it may be that the fine, relatively wood-free, mud above it is roughly equivalent to the upper part of the main spread of fine detritus mud in which wood fragments are also very rare. The boulder-clay layer, re-deposited shortly after 1869, is more or less continuous across the basin, although best preserved where it is flooded.

Archaeology

Shortly after the drainage of the tarn in 1869, Darbishire (1874) recorded hearths and a 'large earthenware vessel' lying on the newly exposed shore amongst a lot of other fragmentary archaeological material of differing ages. In 1871 he also had 'a fair amount of the tarn bottom turned over' (roughly the area shown in figure 18*b*) and recorded the general stratigraphy, which, apart from the lowermost '*Sphagnum*' layer, can be correlated with the stratigraphy in the modern archaeological trenches as follows:

Darbishire (1874)	Walker
(*a*) Bed of boggy soil with roots and leaves of water plants..., about 1 ft. thick	(*a*) Coarse detritus mud with wood fragments, 25–35 cm thick
(*b*) Forest-bed, earthy bog with rotten leaves, branches etc...., about 3–4 ft.	(*b*) Woody detritus mud, up to 100 cm thick
(*c*) Bed of leaves, without twigs or branches; about 3–4 ft. thick	(*c*) Leafy detritus mud, up to 50 cm thick

Fair (1932) separated from the whole assemblage of artifacts a few which she supposed to be Romano-British in age (e.g. a beehive rotary quern and a fragment of Crambeck ware), but the rest has usually been considered as of a single culture amongst which the 'stone celts' are undoubtedly of Great Langdale origin and typologically of the Secondary Neolithic (Piggott 1954). Of the archaeological objects recovered from the mud, Darbishire localized ten stratigraphically. One 'unpolished stone celt' and a 'bow-shaped oak object' came from the surface of the 'leaf bed' and two grinding stones came from the base of the 'forest bed'. A second 'unpolished stone celt', two wooden clubs, a fragment of a wooden bowl, a 'pot-boiler' and the horn and metacarpal of *Bos longifrons* were reported from the 'forest bed' generally. The 'leaf bed' itself was archaeologically barren.

The excavation of 1957 revealed, in addition to the tree-trunk 'platform' described in the stratigraphy, the following stratified objects:

1. An unidentified wooden object, possibly carved, lying in the south-west face of trench 1, 1 m north-west of the sampled monolith, just above the sand layer, 112 cm below the ground surface. Two mud samples were scraped from the faces of this object for pollen analysis (Samples EA1 and EA2; Appendix, part 1).

2. A second, possibly shaped, piece of wood, lying in the south-west face of trench 1, 1·5 m north-west of the sample monolith, just above the sand layer, and 2 cm vertically lower than the first wood object. A sample of mud for pollen analysis was taken from the hollow left after the removal of this object (Sample EA3; Appendix, part 1).

3. A flint flake in the sand and gravel layer above the leafy detritus mud in the south-west face of trench 1. A sample of adhering mud was collected for pollen analysis (Sample EA 4; Appendix, part 1).

4. A second flint flake from woody mud in the south-east face of trench 1 was included in a narrow monolith of mud collected vertically beneath a surface point 22 ft. 6 in. (7 m) from the site datum. The level of the flint corresponds with 23 cm in the short pollen analytical series from this monolith (see Appendix, part 2) and is in a sandy layer immediately above the large timber layer.

5. A fragment of Medieval pottery from the north-west face of trench 1, 1 m below ground surface. A sample of mud in contact with the sherd was collected for pollen analysis (Sample EA 5; Appendix, part 1).

No prehistoric artifacts of any typological value were found in these excavations. The correlation of archaeological stage with stratigraphy and pollen analysis must therefore rest on the ten stratified objects of the 1871 excavations. The consistency with which the fragments excavated in 1957 were found in the sand and gravel layer immediately above the leafy detritus mud and the certain correlation of this level with the 'surface of the leaf bed' on which Darbishire found two Neolithic axes, strongly suggests that this is a major level of occupation, probably the Neolithic occupation, and that the closely associated layer of large timbers also has archaeological significance. However tentative these correlations must be, however, there can be no doubt that Neolithic and later settlements existed on the shores of Ehenside Tarn.

Pollen analysis and chronology

Two main pollen diagrams have been produced, the first (diagram A, figure 22) to investigate the vegetational history of the area as completely as possible from a long and continuous sequence of samples and the second (diagram B, figure 23) to correlate the stratigraphy of the marginal deposits, with their archaeological significance and their rich content of macroscopic plant remains, with the chronology developed from the first diagram.

The samples from which diagram A (figure 22) was prepared were collected in glass tubes from the boring at point 14 (figure 20). The stratigraphy there was recorded as follows:

cm	
0–100	surface water of reedswamp
100–104	gravel in red clay
104–124	disturbed, gravelly, mud
124–150	medium brown, fairly fine, detritus mud with occasional sedge remains and common rootlets
150–170	medium brown coarse detritus mud with abundant sedge and *Phragmites* remains
170–620	medium brown, very fine detritus mud
620–765	Fairly compact, medium brown, fine detritus mud. Large yellow wood fragments at 634–639 cm. cf. *Hypnum* stems at 680–700 cm. Horizontal band of coarse sand at 717·5 cm

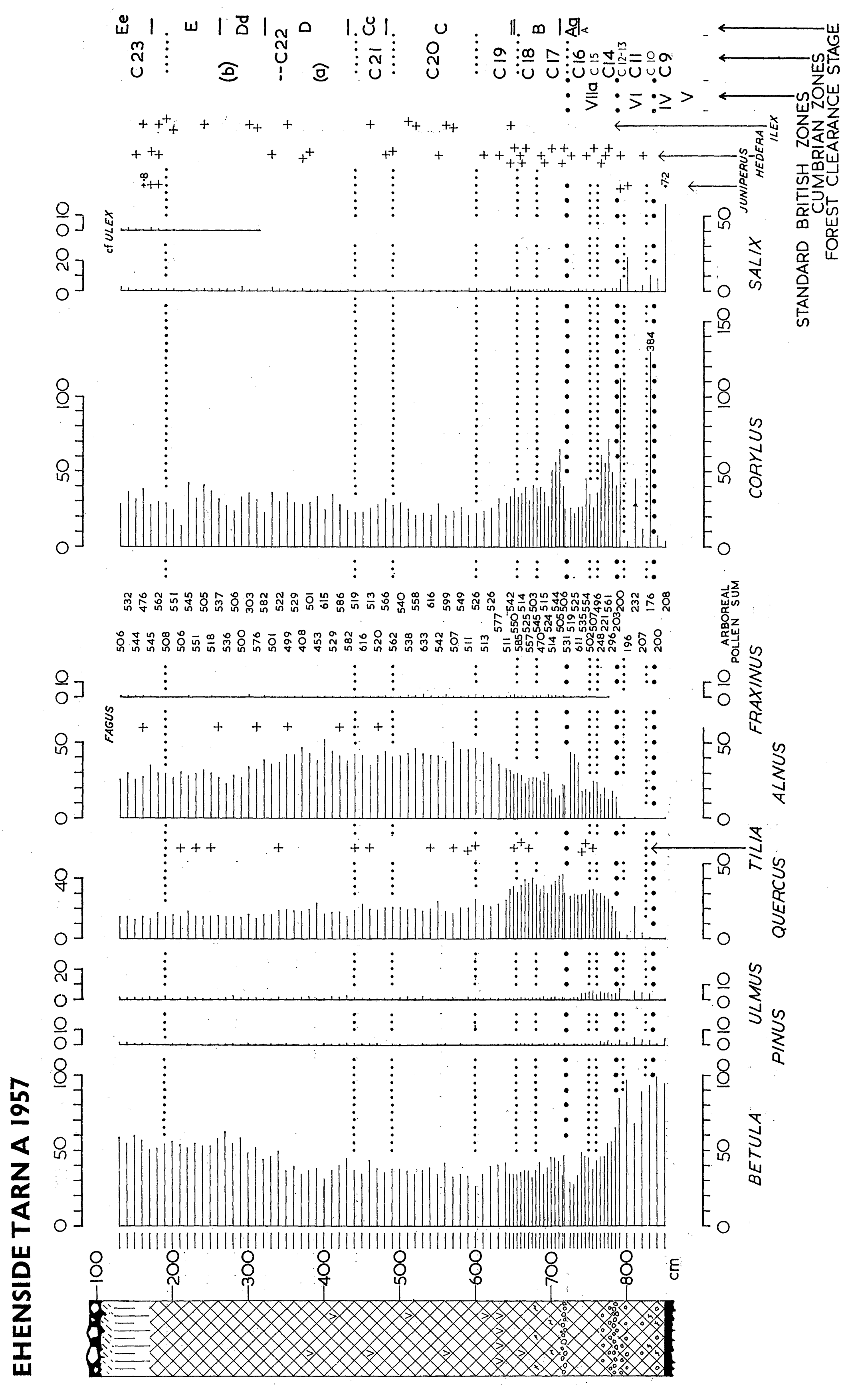
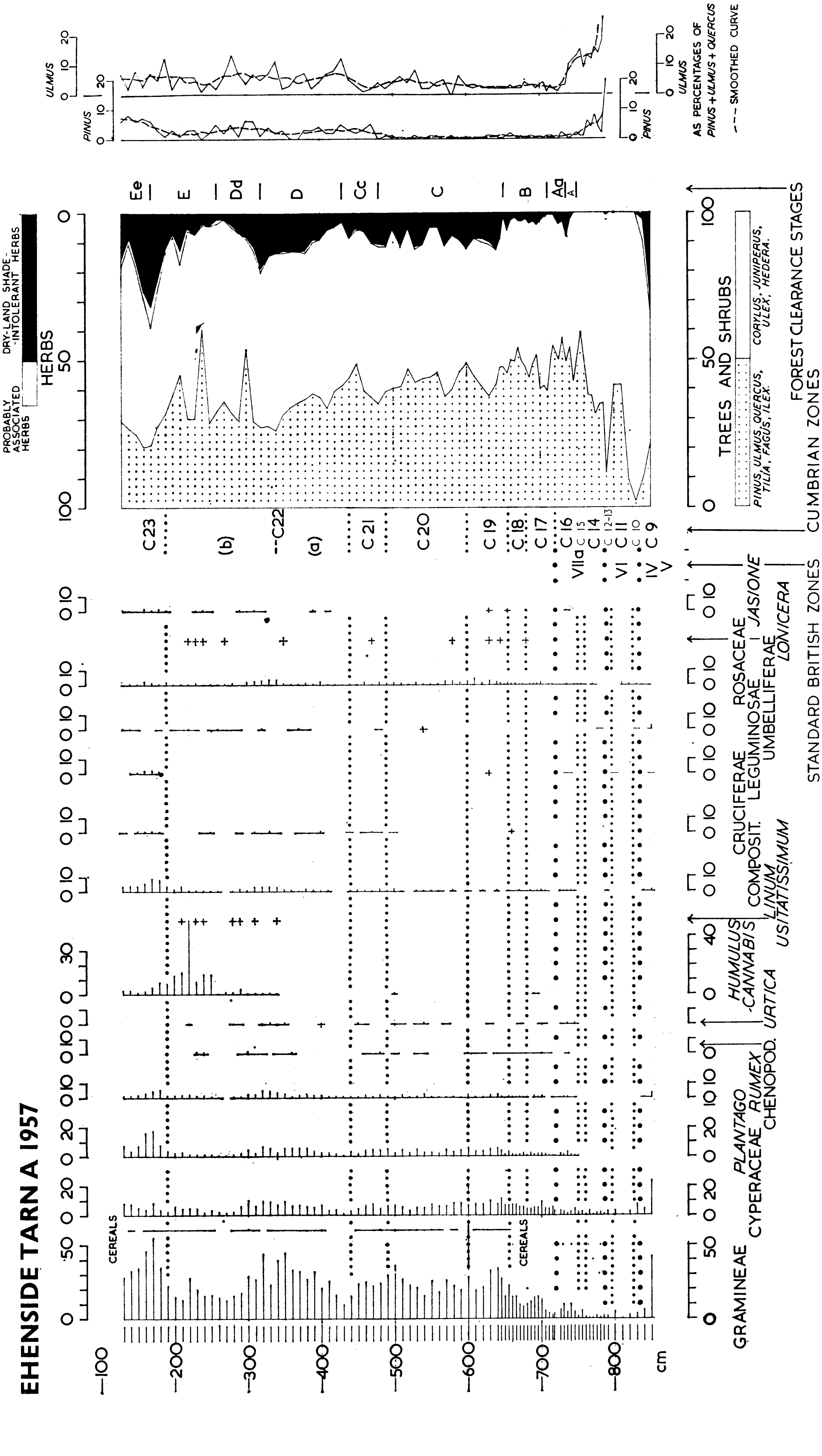


FIGURE 22 (for legend see p. 95)


EHENSIDE TARN A 1957
GRAMINEAE
CYPERACEAE
PLANTAGO
RUMEX
CHENOPOD.
URTICA
HUMULUS -CANNABIS
LINUM USITATISSIMUM
COMPOSIT.
CRUCIFERAE
LEGUMINOSAE
UMBELLIFERAE
ROSACEAE
JASIONE
LONICERA
CEREALS
STANDARD BRITISH ZONES
CUMBRIAN ZONES
FOREST CLEARANCE STAGES
TREES AND SHRUBS
PINUS, ULMUS, QUERCUS, TILIA, FAGUS, ILEX.
CORYLUS, JUNIPERUS, ULEX, HEDERA.
HERBS
PROBABLY ASSOCIATED HERBS
DRY-LAND SHADE-INTOLERANT HERBS
PINUS
ULMUS
AS PERCENTAGES OF PINUS + ULMUS + QUERCUS
SMOOTHED CURVE
cm

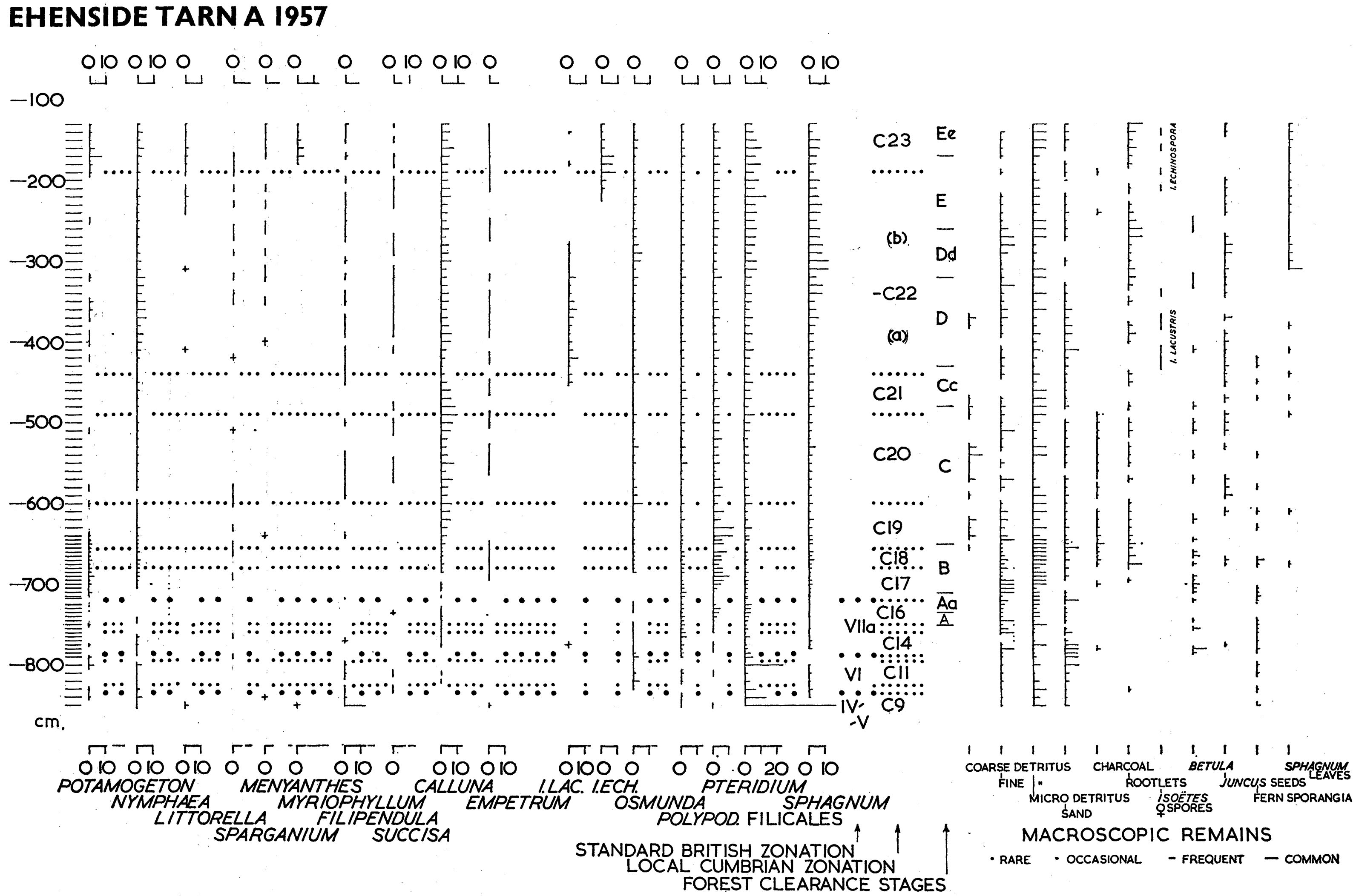


FIGURE 22. Pollen diagram through the deep post-Glacial lake deposits at Ehenside Tarn, Boring 14. Levels are to water surface in pond. The frequencies of pollen or spores of all taxa are shown as percentages of the arboreal pollen total of the appropriate sample.

cm	
765–781	grey sand in indistinctly laminated fine detritus mud
781–787	muddy grey sand
787–800	medium brown fine detritus mud with frequent horizontal laminae of coarse sand
800–850	medium brown fine detritus mud. cf. *Hypnum* remains become common at base
850–855+	grey clay-mud with abundant coarse sand and occasional pebbles

The samples from which diagram B was prepared were cut in the laboratory from a column of mud collected in boxes from the south-west face of archaeological excavation trench 1. The stratigraphy of the column as recorded in the field is shown in figure 21, where its relationship to the section along the south-east face of the trench is shown. The field record reads:

cm	
0–38	mineral soil and oxidized, disturbed, mud
38–115	medium brown fine detritus mud with a few twigs near base. 113 to 115 cm is the approximate level of rounded boulders elsewhere in trench
115	coarse sand and fine gravel
115–164	warm brown detritus mud with abundant dicotyledonous leaf fragments. Below 132 cm twigs and branches of cf. *Betula* are common, lying horizontally or slightly sloping
164–175	medium brown very fine detritus mud with occasional small twigs, rare leaf fragments and rare sand grains
175–182	compact, dark brown, slightly sandy, fine detritus mud with abundant moss stems
182+	grey-brown sand and occasional gravel

In order to obtain an indisputably valid basis for the calculation of small frequencies, as well as to allow the exclusion of some of the probably over-represented local components e.g. *Betula* and *Alnus*) from some calculations without reducing the remainder to insignificance, a total of about 500 tree pollen grains was usually counted from each sample. The formal description of the zonation of both diagrams together is followed by a comment on the apparent anomalies between them. The abundance of *Betula* pollen throughout both diagrams, doubtless the result of a local component of the vegetation, and the fluctuations it apparently induces in the other curves, particularly that of *Alnus*, has demanded greater dependence than usual on the values of *Pinus*, *Ulmus* and *Quercus* calculated as percentages of their combined totals.

British Zones I to III

Cumbrian Zones C1 to C8

Not represented in these diagrams, except that the sample at 850 cm in diagram A may fall on the C8 and C9 (III–IV) boundary.

British Zones IV and V

Cumbrian Zone C9 — Ehenside A, 850–835 cm
Ehenside B, not represented

Betula is the dominant pollen type with a very little *Pinus*. *Salix*, high at the base (with *Juniperus*), falls steeply, as do Gramineae, Cyperaceae and *Rumex*.

British Zone VI

Cumbrian Zone C10 — Ehenside A, 835–825 cm
Ehenside B, not represented

In the single sample from this zone the *Corylus* value is very high. *Betula* has started to fall slightly as *Ulmus* rises and *Quercus* first appears.

Cumbrian Zone C11 — Ehenside A, 825–795 cm
Ehenside B, not represented

Betula values continue to fall (except at 800 cm where the high value is probably due to local over-representation as it depresses all other types). *Pinus* and *Ulmus* rise only slightly, but *Quercus* values climb steeply and then fall again. *Corylus* and *Salix* values are very variable. The first *Hedera helix* grain is recorded as well as a single grain of *Juniperus* (which, like the one in the sample immediately above, might be derived from older deposits).

The Boreal-Atlantic Transition

Cumbrian Zone C12 — Ehenside A, not describable
Ehenside B, 180–174 cm

In diagram B the zone is confused by the fact that it covers the lowest organic layers, in which there is considerable stratigraphic evidence of mixing. In diagram A there is similar evidence of possible erosion and non-sequence restricting Zones C12 and C13 jointly to one sample. Diagram B suggests, however, that *Alnus* values rise slowly at first, then steeply at the end of the zone. *Betula* values fall and *Quercus* remains fairly low. The boundary between British Zones IV and VIIa lies at 174 cm (the upper limit of Zone C12) in diagram B and at 788 cm (the upper limit of the C12 and C13 region) in diagram A.

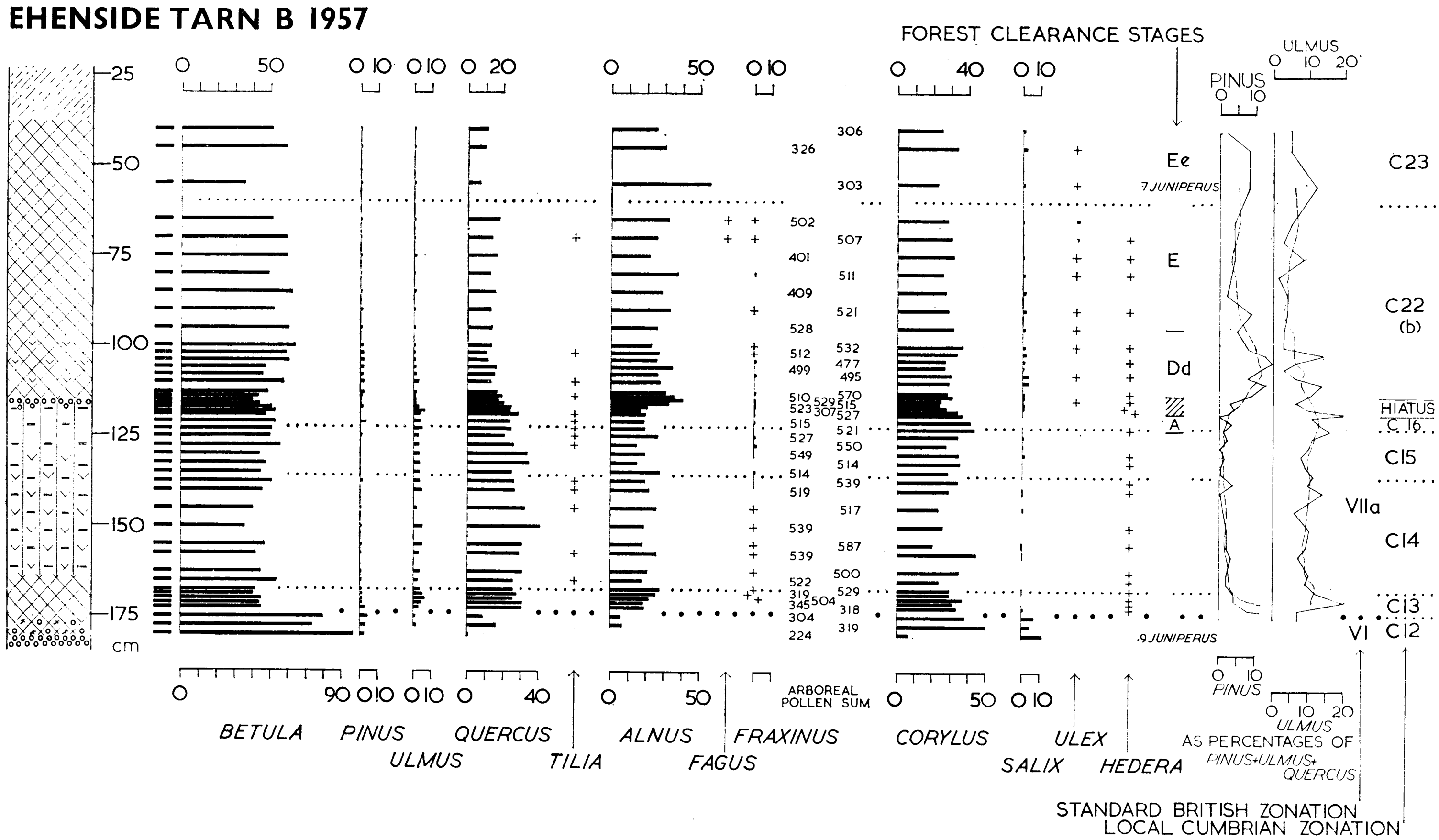
British Zone VIIa

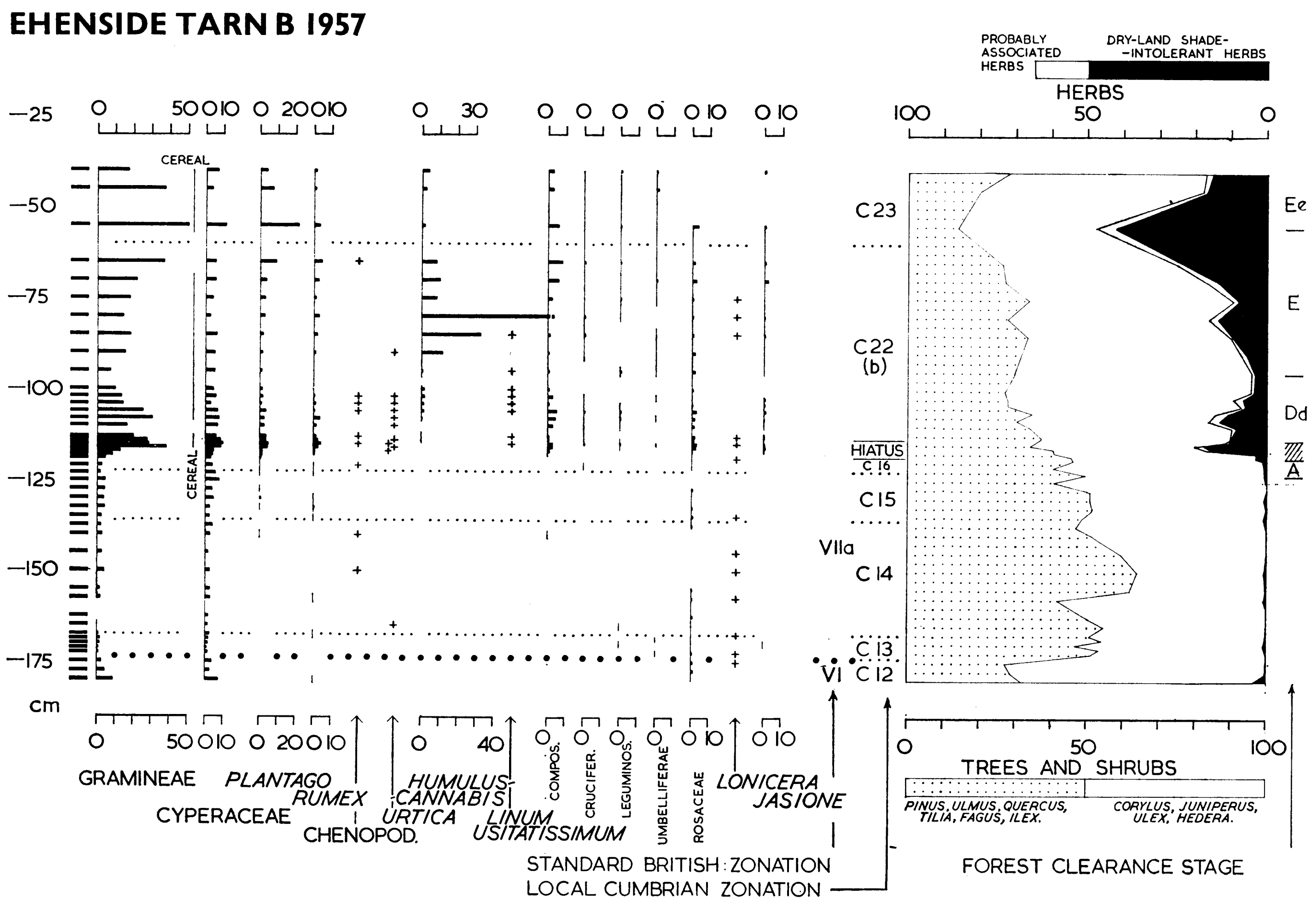
Cumbrian Zone C13 — Ehenside A, not describable
Ehenside B, 174–167·5 cm

Betula values are relatively low (*ca.* 45 %) and *Pinus* values fall to a well-marked minimum (as a percentage of *Pinus* + *Ulmus* + *Quercus*). *Alnus* rises and *Ulmus* and *Quercus* fall slightly. *Corylus* frequencies are lower than formerly and *Salix* is insignificant. *Fraxinus* pollen first occurs at the top of the zone and *Hedera* is consistently present throughout.

Cumbrian Zone C14 — Ehenside A, 788–760 cm
Ehenside B, 167·5–136 cm

The smoothed curve for *Pinus* (as a percentage of *Pinus* + *Ulmus* + *Quercus*) falls to new low values and *Ulmus* sustains a minor, temporary, fall. *Quercus* values climb slightly and fall again in diagram B. *Tilia cordata* pollen is occasional throughout the zone in diagram B, but does not occur in diagram A (probably a result of the relatively small number of samples in the latter). Similarly, *Fraxinus*, although common in neither diagram, is more frequent in B than in A. *Hedera helix* pollen occurs throughout the zone.


EHENSIDE TARN B 1957
FOREST CLEARANCE STAGES
ULMUS
PINUS
BETULA
PINUS
ULMUS
QUERCUS
TILIA
ALNUS
FAGUS
FRAXINUS
ARBOREAL POLLEN SUM
CORYLUS
SALIX
ULEX
HEDERA
?JUNIPERUS
·9 JUNIPERUS
HIATUS
PINUS
ULMUS
AS PERCENTAGES OF PINUS+ULMUS+QUERCUS
STANDARD BRITISH ZONATION
LOCAL CUMBRIAN ZONATION
cm


EHENSIDE TARN B 1957
CEREAL
PROBABLY ASSOCIATED HERBS
DRY-LAND SHADE-INTOLERANT HERBS
HERBS
GRAMINEAE
CYPERACEAE
PLANTAGO
RUMEX
CHENOPOD.
HUMULUS-CANNABIS
URTICA
LINUM USITATISSIMUM
COMPOS.
CRUCIFER.
LEGUMINOS.
UMBELLIFERAE
ROSACEAE
LONICERA
JASIONE
STANDARD BRITISH ZONATION
LOCAL CUMBRIAN ZONATION
TREES AND SHRUBS
PINUS, ULMUS, QUERCUS, TILIA, FAGUS, ILEX.
CORYLUS, JUNIPERUS, ULEX, HEDERA.
FOREST CLEARANCE STAGE
HIATUS
cm

EHENSIDE TARN B 1957

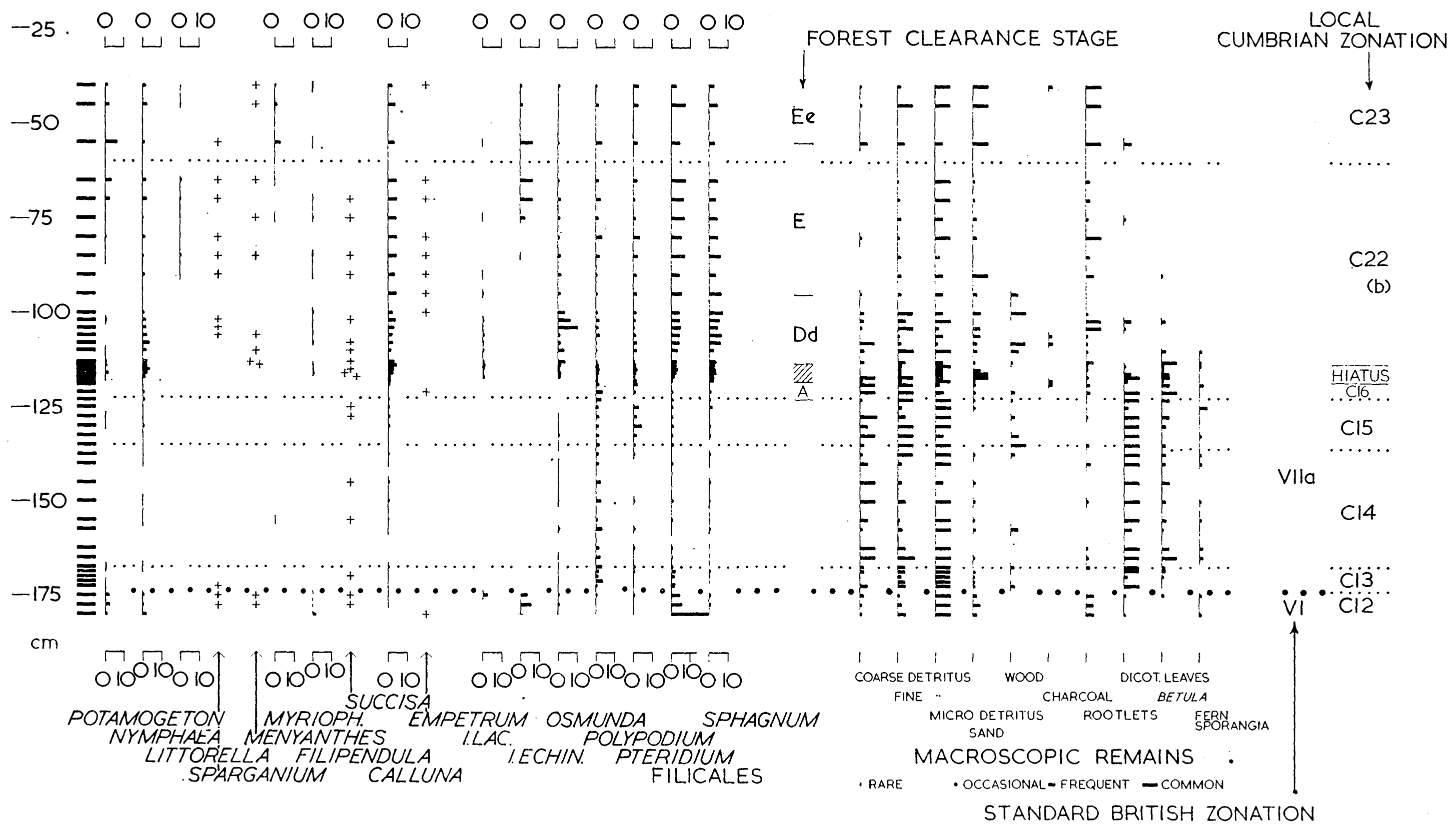


FIGURE 23. Pollen diagram through the marginal deposits at Ehenside Tarn, sampled by a monolith from archaeological trench 1. Levels are to ground surface above sampled points. The frequencies of pollen or spores of all taxa are shown as percentages of the arboreal pollen total of the appropriate sample.

Cumbrian Zone C15 Ehenside A, 760–750 cm
Ehenside B, 136–122·5 cm

Ulmus values (as indicated by their percentages of *Pinus* + *Ulmus* + *Quercus*) recover to a maximum which defines the top of the zone. In diagram B, *Quercus* is higher at first but falls to about its former level in the upper half of the zone. *Alnus* is not consistent. *Tilia cordata* is most frequent at the top of the zone, a distribution shown even more strongly by the *Fraxinus* curve. *Hedera helix* occurs throughout. (The continuous curve for *Plantago* spp begins at the top of the zone, and higher values for Gramineae and Cyperaceae are also recorded.)

Cumbrian Zone C16 Ehenside A, 750–720 cm
Ehenside B, 122·5 to *ca.* 118·5 cm

Ulmus frequencies fall steeply, almost to zero. *Pinus* at first rises steadily but quickly falls again. *Quercus* levels are fairly steady. *Tilia* and *Fraxinus* are present as is *Hedera helix* and *Salix*. In diagram A, *Corylus* reaches its consistently lowest values (*ca.* 25 %) since Zone C9 (IV–V). *Betula* and *Alnus* values vary markedly and dependently. The top of this zone is clearly recognizable in diagram A but in diagram B the early part of the *Ulmus* decline is punctuated by an isolated maximum for this type after which its renewed fall is accompanied by a marked fall in *Quercus* and a corresponding rise in *Alnus*. In diagram B *Ulmus* does not reach the very low level which defines the top of the zone elsewhere and the pollen analytical pattern, between about 118·5 cm and about 112·5 cm, is not easily reconciled with that of any zone whilst above 112·5 cm a much later period is indicated (see below).

British Zone VIIb

Cumbrian Zone C17 — Ehenside A, 720–680 cm; Ehenside B, not represented

Ulmus values (as percentages of *Pinus* + *Ulmus* + *Quercus*) rise somewhat, the maximum, although rather ill-defined, marking the top of the zone. *Quercus* frequencies reach their post-Glacial maximum although there is strong evidence of the dependent interplay of the *Betula*, *Quercus* and *Alnus* curves probably due to local factors. *Tilia cordata* is absent but *Fraxinus* is more frequent than formerly. *Corylus* at first markedly higher than before, falls again to about 30% *A.P.* *Hedera helix* is present throughout.

Cumbrian Zone C18 — Ehenside A, 680–652·5 cm; Ehenside B, not represented

The *Ulmus* curve falls and continues at a low level into the next zone. *Quercus* values are rather higher than before. The upper boundary of the zone is drawn where the *Quercus* curve begins to fall and the *Alnus* curve begins to rise. *Tilia cordata* and *Hedera helix* are present.

Cumbrian Zone C19 — Ehenside A, 652·5–600 cm; Ehenside B, not represented

Quercus values fall, although this is very probably enhanced by the high *Betula* values in the upper part of the zone, the product of a local component of which there is certain stratigraphic evidence. The definition of the upper limit of the zone attempts to allow for this and corresponds, too, with the top of a rising *Alnus* curve. *Ulmus* is beginning to recover slightly. *Tilia cordata* is rather rare but *Hedera helix* is frequent. A grain of *Ilex aquifolium* is recorded.

Cumbrian Zone C20 — Ehenside A, 600–490 cm; Ehenside B, not represented

A period of little pollen-analytical change, the main tree curves remaining at levels established during the last zone. *Ulmus* (as a percentage of *Pinus* + *Ulmus* + *Quercus*) rises fairly steadily. *Tilia cordata* pollen is present. *Corylus* values stand consistently at about their post-Boreal minimum (*ca.* 20% *A.P.*). *Hedera helix* is rare but *Ilex aquifolium* more common.

Cumbrian Zone C21 — Ehenside A, 490–440 cm; Ehenside B, not represented

The main tree-pollen types have values to all intents and purposes as in C20, but *Ulmus* (as a percentage of *Pinus* + *Ulmus* + *Quercus*) sustains temporarily low levels and *Pinus* values begin to rise considerably. *Tilia cordata* is present together with a single grain of *Fagus sylvatica*. *Corylus* values rise slightly. *Hedera helix* and *Ilex aquifolium* grains are rare.

Cumbrian Zone C22 Ehenside A, 440–190 cm
Ehenside B, *ca.* 114–60 cm

The smoothed curves indicate fairly high levels of *Ulmus* and *Quercus*, the actual frequencies of which show occasional but unsustained minima and peaks. *Fagus sylvatica* and *Tilia cordata*, though rare, are present throughout. *Hedera* is present, though not common. *Ilex aquifolium* is fairly frequent in diagram A. *Corylus* values are fairly consistent and lie slightly higher (*ca.* 30% *A.P.*) than in the preceding zone. Between 114 and 100 cm in diagram B, *Pinus* values are higher than in any part of the zone in diagram A. No really adequate explanation of this can be offered, although similar over-representation of *Pinus* in marginal sites has been encountered before (cf. Walker & Godwin 1954). At 340 cm in diagram A, *Quercus* and *Alnus* levels fall somewhat in the main diagram, as a result of a rise in *Betula* frequencies. Since the rise in *Betula* is clearly the cause of these changes and since it may be either local and hydroseral or more general and anthropogenic it is not proposed as a zone boundary. For descriptive purposes, however, it may be convenient to subdivide Zone C22 at 340 cm, thus separating a lower sub-Zone C22a from an upper C22b, which would also be distinguished by a continuous curve for *Ulex* sp. By comparison of the major curves it would then seem that only sub-Zone C22b is represented in diagram B.

Cumbrian Zone C23 Ehenside A, 190–130 cm
Ehenside B, 60–40 cm

Whilst the levels of the other curves hardly change significantly, *Pinus* values (as a percentage of *Pinus*+*Ulmus*+*Quercus*) rise considerably. *Tilia* is absent and *Fagus sylvatica* is represented by one grain. In diagram A, *Ulex*, *Hedera helix* and *Ilex aquifolium* are more abundant than formerly and *Juniperus* is recorded in both diagrams.

The common zonation of the two pollen diagrams introduces a number of problems which are best explicitly stated at this juncture. Accumulation in the centre of the lake before the end of Zone C11 (VI) seems to have been very slow. If it took place at all around the margins, the deposits there were subsequently mixed and eroded during the early part of C12 when the stratigraphic evidence suggests considerable disturbance. In view of this marginal disturbance, and the evidence of the distribution of clay, sand and gravel across the basin at that time, it is scarcely surprising that Zones C12 and C13 cannot be separately identified in diagram A with a vertical interval of 10 cm between samples. The hiatus between about 118·5 cm and about 114 cm in diagram B, covering Zones C17 to C21 and parts of C16 and C22 is less easily explained. Although the limits of the hiatus have been satisfactorily defined in the general zonation, a closer study of the details of the diagrams defines them even more closely. In this examination the pollen curves are used as 'markers', all of similar validity, since the sites are very close together and real vegetational changes are not under discussion. In diagram B, 118·5 cm cannot represent the top of Zone C16 (VIIa) as the *Ulmus* values are insufficiently low and there is no comparable fall in *Quercus* and *Corylus* or a rise in *Alnus* and *Betula* in diagram A. Some stability of the curves seems to be re-established by about 114 cm, immediately above which level (i) *Betula* values rise from *ca.* 45% to about 60%, (ii) *Quercus* values lie at about 15%, (iii) *Alnus* values lie at *ca.* 25% and (iv) *Corylus* values rarely exceed 30%. In diagram A, above the base of Zone C16, this combination of phenomena is not found below 330 cm. In diagram B, the values of *Ulmus* above the hiatus are at about 1·5 to 2·5% *A.P.* In diagram A above 330 cm, such frequencies are first attained between 310 and 300 cm. It seems very likely, therefore, that 114 cm in diagram B corresponds with about 310 cm in diagram A. This bears out the correlation already suggested and is further confirmed if the evidence of herbaceous, and almost certainly archaeologically significant, pollen grains is allowed. In diagram A, pollen of *Humulus–Cannabis* type and of *Linum usitatissimum* occur together from 340 to 210 cm, the former type reaching frequencies of 10% *A.P.* and more above 250 cm. In diagram B the same relationship exists, beginning at 115 cm with the rise in *Humulus–Cannabis* occurring at 90 cm. Therefore, pollen types which are most unlikely to have occurred in the vicinity before the time indicated in diagram A at 340 cm (i.e. the boundary between the subdivisions of Zone C22) are represented *in* the hiatus in diagram B. Moreover, the pattern of their distribution above these levels is strictly comparable in the two diagrams. It seems very likely, therefore, that the correlation suggested above is entirely valid. The nature of the hiatus will be discussed elsewhere, but it might be noted here that it corresponds with the level of the sand and fine gravel in the mud and the associated, and possibly humanly deposited, timbers and boulders. A layer of coarse sand was detected in the stratigraphy of diagram A which corresponds with the top of Zone C16 there and might possibly indicate a correlated disturbance of normal mud deposition.

Four radiocarbon age determinations are available from materials from Ehenside Tarn. One of these (C462, Arnold & Libby 1951) was carried out on charred wood of such uncertain provenance that its result, 4964 ± 300 B.P., cannot be associated with the sequence described here and is better not used in discussions of the Ehenside Tarn chronology.

A second determination (BM68, Barker & Mackey 1961) gave a date of 3530 ± 150 B.P. for a piece of a wooden implement collected during the investigations of 1871 (Darbishire 1874) and gives a certain date for some stage in the occupation at least. Two assays were carried out on a piece of branch penetrating the timbers of the hiatus layer at a steep angle, and thought to have been used as a stake, unearthed during the 1957 excavations. These yielded dates (Q303, Godwin & Willis 1960) of 4051 ± 115 B.P. and 4125 ± 115 B.P. If the 'platform' is truly man-made, these dates also indicate a time of human occupation of the tarn shores. In view of the long period of time represented by the hiatus there is nothing contradictory in the different ages obtained from samples BM68 and Q303.

The forest clearance stages

The long sequence of deposits younger than the Boreal-Atlantic Transition, which probably extends almost to the drainage of the tarn in A.D. 1869, offers an unusual opportunity for the detailed study of vegetational change during this period. The site is particularly suitable because of the positive evidence of human settlement in its immediate vicinity, since many changes in post-Boreal vegetation are probably rightly attributed to human activity. It is evident from diagram A (figure 22) that from Zone C16 onwards shade-intolerant herbs, e.g. *Plantago* spp, *Rumex* cf. *acetosella*, have been important constituents of the land vegetation. In order to examine the changes in the balance between the different types of plant community certainly on the land and not contributing to a hydrosere, four groups of pollen types have been selected and the sum of each group expressed as a percentage of the total of the four. The dry-land tree group includes the following pollen types: *Pinus*, *Quercus*, *Fagus*, *Ulmus*, *Tilia*, *Ilex*. The corresponding group of shrubs includes: *Corylus*, *Ulex*, *Juniperus*, *Hedera*.

The group of dry-land shade-intolerant herbs excludes grasses and sedges as well as plants which were almost certainly grown as crops (e.g. cereals, *Linum usitatissimum*). This group comprises: *Artemisia* spp., *Armeria maritima*, *Centaurea* cf. *nigra* and *scabiosa*, Chenopodiaceae (cf. *Chenopodium*), *Jasione montana*, *Pastinaca sativa*, *Plantago* spp., *Polygonum* cf. *bistorta* and *convolvulus*, *Poterium sanguisorba*, *Rumex* cf. *acetosella*, *Trifolium scabrum*.

A fourth group of pollen types which probably, but not certainly, represent plants of shadeless habitats on dry land includes: Caryophyllaceae (most recorded pollen is of *Cerastium* type; none is of *Myosoton* or *Stellaria* type), Compositae *sect.* Tubuliflorae (of the 14 British species of ponds, fens or woods, 10 are certainly not represented by the recorded pollen although the remaining four might be; the remaining 63 British species are more likely contributors however). Leguminosae (of the 11 British species of ponds and mires, six are certainly not represented by the recorded pollen although the other five may be; the remaining 54 British species are more likely contributors however). Families, the ecology of the species of which is more varied and which cannot be more closely characterized pollen analytically (e.g. Compositae *sect.* Ligulaeflorae, Rubiaceae) are excluded from this group. It is notable that the curve for the fourth group of pollen types is usually low and follows that of the third group very closely. This is circumstantial evidence for supposing that the selection of its components was more or less correctly made.

The expansion of the curve for dry land, shade-intolerant, herbs at the expense of the dry-land trees or shrubs is taken as evidence of forest clearance by some means or other, whilst intervening periods when the curve is descending or low are thought to indicate periods of woodland regeneration. Using this curve as a criterion, the diagram Ehenside A can be divided into five stages of clearance and five stages of regeneration since the end of Zone C15 (VIIa). The selection of the components of these groups very probably excludes a number of pollen types which have some significance in terms of forest clearance and regeneration. The curve for Gramineae runs roughly parallel with that for shade-intolerant herbs and undoubtedly largely represents shade-intolerant grasses which may, in fact, have dominated the clearings. But this significant component cannot be separated from the insignificant component from the hydrosere in the tarn itself and therefore the Gramineae curve cannot be used as *primary* evidence for clearance, useful though it may be in developing hypotheses about the nature of the clearing communities. Similarly, birch trees were very probably a most important factor in forest regeneration but the contribution of such trees to the pollen rain cannot be separated from that of the birches of the hydrosere. The *Betula* curve cannot be included in this first analysis, therefore, although its indications may subsequently be of value in reconstructing the possible course of the regeneration succession. Each stage of expansion of the curve and its subsequent maintenance at a fairly high level is designated by a capital letter, e.g. *C*, and the subsequent stage during which the curve falls and remains at a low level is designated by the capital and the corresponding small letter, e.g. *Cc*. The limits of these stages are shown on the diagram (figure 22) and are correlated with depth and zonation as shown in table 3.

Some of these stages are more positively marked than others. A stage *Bb* does not exist but there can be little doubt that Stages *B* and *C* are distinct. The relative general levels of the curve for shade-intolerant herbs in the different stages may be indications of the relative intensity of clearance but they may also indicate the relative proximity of the cleared areas to the site of the pollen diagram.

TABLE 3

level (cm)	clearance or regeneration stage	Cumbrian zone
130–170	*Ee*	C23
170–260	*E*	C22b–23
260–320	*Dd*	C22b
320–430	*D*	C22a–22b
430–480	*Cc*	C21–22a
480–650	*C*	C19–20–21
650–710	*B*	C17–18–19
710–735	*Aa*	C16–17
735–750	*A*	C16

In diagram B (figure 23), Stages *Aa* to *D* are unlikely to be represented, since Zones C17 to C22a inclusive are absent. Isolated occurrences of shade-intolerant herb pollen below Zone C15 can probably safely be attributed to very small clearings catastrophically, or serally, produced very close to this marginal site. The first traces of clearance (Stage *A*) are recognizable in Zone C16 in diagram B but it is unlikely that this reaches its full extent before the beginning of the hiatus. Above the hiatus, in Zone C 22b, the descending curve for the shade-intolerant herbs is probably the equivalent of the latter part of Stage *Dd*. Subsequent stages are clearly discernible and are correlated with depth and zonation as shown in table 4.

TABLE 4

level (cm)	clearance or regeneration stage	Cumbrian zone
35–55	*Ee*	C23
55–95	*E*	C22b–23
95–114	*Dd*	C22b
114–118·5	hiatus	—
118·5–123	*A*	C15–16

The forest clearance stages are of unequal length and intensity of indication by the pollen curves, and the components of the clearing vegetation, although including some types in common, are not identical. The stages of clearance, whilst too long to represent only natural regeneration seres in climax forest, are too short to be explained as the results of long term climatic change. These facts, together with the importance in the clearance phases of plants now commonly known as weeds of farm land (e.g. *Plantago* spp., *Trifolium scabrum*), strongly suggest that they are anthropogenic phenomena. Even so, they are not the only pollen analytical indicators of human activity for the range of pollen of *Linum usitatissimum*, surely grown as a crop, extends from Stage *D* to Stage *E through* the intervening regeneration Stage *Dd*. Similarly, cereal pollen is not restricted to the clearance stages. The details of the 'ethnobotany' (Helbaek 1959) of this post-Boreal period are described and discussed below (part VIII).

The plant list

Table 5 shows the distribution through the deposits of plants not recorded in the pollen diagrams and the correlation of the various samples with the two pollen diagrams. The identifications are based on pollen grains encountered in the routine analyses or on macroscopically identified remains extracted from the samples for pollen analysis, or from samples specially collected for this purpose in the field from the same borings or monolith from which the pollen analytical samples were taken.

Table 6 is a recapitulation of Darbishire's (1874) finds of organic material attributed to his description of the stratigraphy. A very tentative pollen analytical correlation has been applied by comparing this stratigraphy with that recorded from the marginal deposits in the current investigations.

Armeria maritima

Records of the pollen of this species from the later part of the post-Glacial period are unusual but the presence of the plant in Zones C22b and C23 (Types A and BII, Iversen 1940) need be explained by nothing more than the proximity of the site to the sea coast.

Centaurea nigra

Pollen of *C. nigra* is certainly recorded from Zones C14, C15, C22a and C22b (VIIa–VIIb), where it is sometimes associated with other shade-intolerant plants, although not necessarily in a forest clearance stage. The early isolated occurrences may derive from coastal plants or plants in natural clearings in the regenerating woodland.

Chrysanthemum segetum

A single fruit of *C. segetum* was recovered from each of two samples, one from immediately above the hiatus in diagram B (113 cm, C22b, Stage *Dd*), the other from between 83 and 95 cm in diagram B (C22b, Stage *E*). These are the earliest certain records of this weed in the British Isles (Godwin 1956) and, if it is still not to be considered a native, demand its introduction, presumably with cereal seed, in a pre-historic period (Clapham *et al.* 1952).

Descurainia sophia

A single seed of this species, recovered from between 300 and 350 cm in diagram A (C22a to 22b, Stage *D* to *Dd*), seems to represent the first certain record for the British Isles. It is not now a common plant in the north of England and is 'undoubtedly native' (Clapham *et al.* 1952). Like the last plant, its presence strongly suggests the availability of tilled and waste land.

Table 5

standard British Pollen Zone ...		IV–V	IV–VI	VI	VIIa													Post VIIa							
local Cumbrian Pollen Zone ...		9	9–11	11	13		13–14	14				15			12–15	16		17	18	19		20			21
correlated Pollen Diagram ...		A	A	A	B	B	B	A	B	B	B	A	B	B	A	A	A	A	A	A	A	A	A	A	A
vertical limits of sample in cm	Remains	850–835	850–800	825–795	174–167	175–170	140–135	760–788	140–150	150–158	167–136	760–750	135–123	136–122	800–750	750–700	750–720	720–680	680–652	650–600	652–600	600–650	550–500	600–490	490–440
Alnus glutinosa	fr	.	.	.	.	.	++	.	+++	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.
Apium inundatum	s	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.
Armeria maritima	p	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.
Artemisia sp.	p	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	++	.	.	.	++	.	.	+	++
Betula pubescens	fr+sc	.	.	.	.	+++	++	.	+++	+++	.	.	+++	.	.	.	.	.	.	.	.	.	.	.	.
B. verrucosa	fr+sc	.	.	.	.	.	+++	.	.	.	.	.	++	.	.	.	.	.	.	.	.	.	.	.	.
Betula sp.	fr+sc	.	+++	.	.	++	+++	.	.	++	.	.	+	.	+++	+++	.	.	.	+++	.	+++	+++	.	.
Calluna vulgaris	tw+lvs	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.
Campanula cf. *rotundifolia*	p	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.
Carex rostrata	fr	.	.	.	.	.	.	.	.	.	.	.	.	.	+	.	.	.	.	.	.	+	.	.	.
C. cf. *echinata*	fr	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	+	.	.	.
C. cf. *vulpina*	fr	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.
Carex sp.	fr	.	.	.	.	.	.	.	+	.	.	.	.	.	.	.	.	.	.	+	.	+	.	.	.
Centaurea cf. *nigra*	p	.	.	.	.	.	.	.	.	.	++	.	.	+	.	.	.	.	.	.	.	.	.	.	.
Chrysanthemum segetum	fr	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.
Corylus avellana	n	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.
Descurainia sophia	s	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.
Drosera sp.	p	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	+	.	.	.	.
Eleocharis sp.	n	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.
Erica tetralix	lvs	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.
Gentianella cf. *campestris*	s	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	++	.	.	.	.	.
Hydrocotyle vulgaris	p	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	+	.	.	++	.	.	++	.
Juncus sp.	s	.	.	.	.	.	.	.	.	.	.	.	.	.	.	+	.	.	.	+++	.	+++	.	.	+
Linum catharticum	s	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.
L. usitatissimum	s	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.
Littorella uniflora	s	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.
Lysimachia sp.	p	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.
Menyanthes trifoliata	s	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.
Myriophyllum alterniflorum	p	+	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.
M. spicatum	s	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.
M. spicatum	p	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	+	.	.	.	.
M. verticillatum	p	.	.	.	.	.	.	.	.	.	+	.	.	.	.	.	.	.	.	.	.	.	.	.	.
Nuphar lutea	p	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.
Nymphaea alba	s	.	.	.	.	++	+	+	+	.	.	.	.	.	.	+	.	.	.	+	.	.	.	.	.
Origanum vulgare	s	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.
Pastinaca sativa	p	.	.	.	+	.	.	.	.	.	++	.	.	+	.	.	.	+	+	.	+	.	.	+	+
Petroselinum segetum	s	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.
Plantago lanceolata	p	.	.	.	.	.	.	.	.	.	.	.	.	+	.	.	+++	+++	++	.	+++	.	.	+++	+++
P. major	p	.	.	.	.	.	.	++	.	.	+	+	.	++	.	.	+++	++	++	.	+++	.	.	+++	+++
P. maritima	p	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	+++	.	.	++	+++
Plantago sp.	p	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.
Polygonum convolvulus	fr	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.
P. mite	fr	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	+	.	.
P. persicaria	fr	.	.	.	.	.	.	.	.	.	.	.	.	.	.	+	.	.	.	.	.	.	+	.	.
P. cf. *lapathifolium*	s	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	+	.	+	.	.	.
P. amphibium type	p	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	+	.	.	+	.	.	+	.
P. bistorta type	p	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.
P. persicaria type	p	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.
Polygonum sp.	s+p	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	+	.	.	.	.	.	.	.
Potamogeton berchtoldii	f.st	.	.	.	.	.	.	.	+	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.

TABLE 5 (*cont.*)

standard British Pollen Zone ...		IV–V	IV–VI	VI	VIIa													Post VIIa							
local Cumbrian Pollen Zone ...		9	9–11	11	13		13–14	14				15			12–15	16		17	18	19		20			21
correlated Pollen Diagram ...		A	A	A	B	B	B	A	B	B	B	A	B	B	A	A	A	A	A	A	A	A	A	A	A
vertical limits of sample in cm	Remains	850–835	850–800	825–795	174–167	175–170	140–135	760–788	140–150	150–158	167–136	760–750	135–123	136–122	800–750	750–700	750–720	720–680	680–652	650–600	652–600	600–650	550–500	600–490	490–440
Potamogeton natans	f.st	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·
P. perfoliatus	f.st	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·
P. trichoides	f.st	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·
P. cf. *alpinus*	f.st	·	·	·	·	++	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·
Potamogeton sp.	f.st	·	·	·	·	·	·	·	·	·	·	·	·	·	+	·	·	·	·	·	·	·	+	·	·
Potentilla palustris	s	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	+	·	·	·
P. procumbens	s	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	+	·	·	·
P. cf. *crantzii*	s	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	+	·	+	·	·	·
P. cf. *erecta*	s	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·
P. cf. *sterilis*	s	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·
Potentilla sp.	s	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	+	·	·	·	·
Poterium sanguisorba	p	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·
Prunella vulgaris	s	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·
Quercus sp.	fr	·	·	·	·	·	·	·	·	·	·	·	+	·	·	·	·	·	·	·	·	·	·	·	·
Ranunculus acris	s	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·
R. flammula	s	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·
R. sect. *Batrachium*	s	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	+	·
Ranunculus sp.	s	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	+	·	·
Rubus subgenus *Rubus*	s	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·
R. idaeus	s	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	+	·	·
Schoenoplectus lacustris	s	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·
Sieglingia decumbens	fr	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·
Sparganium ramosum	fr	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·
S. cf. *angustifolium*	fr	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·
S. cf. *simplex*	fr	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·
Sparganium sp.	s	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·
Stellaria graminea	s	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·
S. neglecta	s	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·
cf. *Thalictrum flavum*	s	·	·	·	·	·	·	·	+	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·
Trifolium scabrum	p	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·
Ulex cf. *europaeus*	tw	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·
Urtica dioica	s	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·
cf. *Vaccinium* sp.	s+p	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	+	+	·	·	++	·	·	+++	++
Valeriana dioica	p	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·
V. officinalis	p	+	·	+	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·
cf. *Vicia* sp.	p	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·
Lycopodium clavatum	sp	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·
L. selago	sp	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	+	·
Osmunda regalis	sp	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	+	·
Pilularia globulifera	sp	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·
Pteridium aquilinum	lvs	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·
Eurhynchium spp.	lvs	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	+	·	·	·
Hypnum cf. *molluscum*	lvs	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·
Polytrichum commune	lvs	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·
Sphagnum spp.	lvs	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·
Musci	lvs	·	·	·	·	++	·	·	·	++	+	·	+	++	·	·	·	+	+	·	++	·	·	+++	++
Chara sp.	oosp	·	·		·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·
Nitella sp.	oosp	·	·		·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·

TABLE 5 (*cont.*)

standard British Pollen Zone ...		Post-VIIa																						
local Cumbrian Pollen Zone ...		21	21–22a	22a		22a–22b	22b			Hiatus		22b						22b–23	23					
correlated Pollen Diagram ...		A	A	A	A	A	A	A	A	B	B	B	B	B	B	B	B	A	A	A	B	B	B	B
vertical limits of sample in cm	Remains	480–450	450–400	400–350	440–340	350–300	300–250	250–200	340–190	119–115	119–114	81–79	107–105	105–101	77–65	95–83	60–114	200–170	170–150	190–130	62–58	52–45	60–40	45–40
Alnus glutinosa	fr	·	·	·	·	·	·	·	·	+++	·	·	·	·	·	·	·	·	·	·	·	·	·	++
Apium inundatum	s	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	++	++	·	·
Armeria maritima	p	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	++	·	·	+	·	·	·	·
Artemisia sp.	p	·	·	·	++	·	·	·	++	·	++	·	·	·	·	·	·	·	·	++	·	·	·	·
Betula pubescens	fr+sc	·	·	·	·	·	·	·	·	+++	·	·	·	+++	·	+++	·	·	·	·	++	·	·	+++
B. verrucosa	fr+sc	·	·	·	·	·	·	·	·	+++	·	·	·	·	·	·	·	·	·	·	·	·	·	·
Betula sp.	fr+sc	+++	+++	++	·	+++	+++	++	·	·	·	·	++	·	+	·	·	+	·	·	·	·	·	+
Calluna vulgaris	tw+lvs	·	+	·	·	·	·	·	·	·	·	·	·	·	+	·	·	·	·	·	·	·	·	·
Campanula cf. *rotundifolia*	p	·	·	·	++	·	·	·	++	·	·	·	·	·	·	·	++	·	·	·	·	·	·	·
Carex rostrata	fr	++	+	++	·	·	·	·	·	·	·	·	·	·	·	·	·	+	·	·	·	·	·	·
C. cf. *echinata*	fr	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·
C. cf. *vulpina*	fr	·	·	·	·	·	·	·	·	·	·	·	·	·	++	·	·	·	·	·	·	·	·	·
Carex sp.	fr	++	·	·	·	·	·	·	·	+++	·	+	++	·	·	++	++	·	++	·	·	+++	·	++
Centaurea cf. *nigra*	p	·	·	·	+	·	·	·	+	·	++	·	·	·	·	·	+	·	·	·	·	·	·	·
Chrysanthemum segetum	fr	·	·	·	·	·	·	·	·	·	·	·	·	·	·	+	+	·	·	·	·	·	·	·
Corylus avellana	n	·	·	·	·	·	·	·	·	+	·	·	·	·	·	·	·	·	·	·	·	·	·	·
Descurainia sophia	s	·	·	·	·	+	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·
Drosera sp.	p	·	·	·	·	·	·	·	+	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·
Eleocharis sp.	n	·	·	·	·	·	·	·	·	·	·	·	+	·	·	·	·	·	·	·	·	·	·	·
Erica tetralix	lvs	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	++	·	·
Gentianella cf. *campestris*	s	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·
Hydrocotyle vulgaris	p	·	·	·	·	·	·	·	++	·	·	·	·	·	·	·	+	·	·	·	·	·	·	·
Juncus sp.	s	·	·	++	·	·	·	+	·	·	·	+	·	·	·	+++	+++	+	·	·	·	+++	·	·
Linum catharticum	s	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	+	·	·
L. usitatissimum	s	·	·	·	·	·	+	·	·	·	·	+	·	++	+	++	·	·	·	·	·	+++	·	·
Littorella uniflora	s	·	·	·	·	·	·	·	+	·	·	·	·	·	·	·	·	·	·	·	·	+	·	·
Lysimachia sp.	p	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·
Menyanthes trifoliata	s	·	·	·	·	·	·	·	·	·	·	·	·	++	++	++	·	·	·	·	·	++	·	·
Myriophyllum alterniflorum	p	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	+	·	·	+++	·	·	+++	·
M. spicatum	s	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	++	·	·
M. spicatum	p	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·
M. verticillatum	p	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·
Nuphar lutea	p	·	·	·	·	·	·	·	+	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·
Nymphaea alba	s	·	·	++	+	++	+	·	·	++	·	+++	++	++	++	++	++	·	+	·	·	++	·	++
Origanum vulgare	s	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	+	·	+	·
Pastinaca sativa	p	·	·	·	+	·	·	·	++	·	·	·	·	·	·	·	++	·	·	·	·	·	·	·
Petroselinum segetum	s	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	+	·	·	·	·	·	·
Plantago lanceolata	p	·	·	·	+++	·	·	·	+++	·	+++	·	·	·	·	·	+++	·	·	+++	·	·	+++	·
P. major	p	·	·	·	+++	·	·	·	+++	·	+++	·	·	·	·	·	+++	·	·	+++	·	·	+++	·
P. maritima	p	·	·	·	++	·	·	·	+++	·	+	·	·	·	·	·	++	·	·	++	·	·	·	·
Plantago sp.	p	·	·	·	+++	·	·	·	+++	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·
Polygonum convolvulus	fr	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	+	·	·
P. mite	fr	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·
P. persicaria	fr	·	·	+	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·
P. cf. *lapathifolium*	s	+	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·
P. amphibium type	p	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	+	·	·	+	·	·	·	·
P. bistorta type	p	·	·	·	+	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·
P. persicaria type	p	·	·	·	·	·	·	·	·	·	+	·	·	·	·	·	+	·	·	·	·	·	·	·
Polygonum sp.	s+p	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	+	·	·	·
Potamogeton berchtoldii	f.st	·	·	·	·	·	·	+	·	·	·	·	·	·	·	++	·	·	·	·	+++	+++	·	·

TABLE 5 (*cont.*)

standard British Pollen Zone ...		Post-VIIa																						
local Cumbrian Pollen Zone ...		21	21–22a	22a		22a–22b	22b			Hiatus		22b						22b–23	23					
correlated Pollen Diagram ...		A	A	A	A	A	A	A	A	B	B	B	B	B	B	B	B	A	A	A	B	B	B	B
vertical limits of sample in cm	Remains	480–450	450–400	400–350	440–340	350–300	300–250	250–200	340–190	119–115	119–114	81–79	107–105	105–101	77–65	95–83	60–114	200–170	170–150	190–130	62–58	52–45	60–40	45–40
Potamogeton natans	f.st	.	.	.	.	.	.	.	.	.	.	+++	+	+	.	.	.	+	.	.	.	.	.	.
P. perfoliatus	f.st	.	.	.	.	.	.	.	.	.	.	.	.	.	.	+	.	.	.	.	.	.	.	.
P. trichoides	f.st	.	.	.	.	.	.	.	.	.	.	.	.	.	+++	.	.	+	+++	.	.	.	.	.
P. cf. *alpinus*	f.st	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.
Potamogeton sp.	f.st	.	.	.	+	.	.	.	.	.	.	.	+	++	++	.	.	.	.	.	.	.	.	.
Potentilla palustris	s	.	+	++	.	+	.	.	.	++	.	+	++	.	++	++	.	.	+	.	.	+	.	.
P. procumbens	s	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.
P. cf. *crantzii*	s	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.
P. cf. *erecta*	s	.	.	.	.	.	.	.	.	.	.	.	.	.	++	.	.	.	.	.	.	.	.	.
P. cf. *sterilis*	s	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	++	.	.
Potentilla sp.	s	.	+	.	++	.	.	.	.	.	.	.	.	.	.	++	.	.	.	.	.	.	.	.
Poterium sanguisorba	p	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	+	.	.	.	.	.	.	.
Prunella vulgaris	s	.	.	.	.	.	.	.	.	.	.	.	.	.	.	+	.	.	.	.	.	.	.	.
Quercus sp.	fr	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.
Ranunculus acris	s	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	+	.	.	.
R. flammula	s	.	.	.	.	.	.	.	.	.	.	.	.	.	.	++	.	.	.	.	.	++	.	.
R. sect. *Batrachium*	s	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.
Ranunculus sp.	s	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.
Rubus subgenus *Rubus*	s	.	.	.	.	.	.	.	.	+	.	.	.	.	.	.	.	.	.	.	.	++	.	.
R. idaeus	s	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.
Schoenoplectus lacustris	s	.	+	.	.	.	.	.	.	.	.	.	.	.	.	.	.	+	.	.	.	.	.	.
Sieglingia decumbens	fr	.	.	.	.	.	.	.	.	.	.	.	.	.	+	.	.	.	.	.	.	.	.	.
Sparganium ramosum	fr	.	.	.	.	.	.	.	.	.	.	.	.	+++	.	.	.	.	.	.	.	.	.	.
S. cf. *angustifolium*	fr	.	.	.	.	.	.	.	.	.	.	.	.	.	.	+++	.	.	.	.	.	+	.	.
S. cf. *simplex*	fr	.	.	.	.	++	.	.	.	.	.	.	+	.	.	.	.	++	.	.	.	.	.	.
Sparganium sp.	s	+	.	.	.	.	.	.	.	.	.	.	+	++	+	.	.	.	.	.	.	.	.	.
Stellaria graminea	s	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	+	.	.	.	.	.	.	.
S. neglecta	s	.	.	.	.	.	.	.	.	.	.	.	.	.	.	+	.	.	.	.	.	.	.	.
cf. *Thalictrum flavum*	s	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.
Trifolium scabrum	p	.	.	.	.	.	.	.	.	.	+	.	.	.	.	.	.	.	.	+++	.	.	++	.
Ulex cf. *europaeus*	tw	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	++	.	.	.	++	.	.
Urtica dioica	s	.	.	.	.	.	.	.	.	.	.	+	.	.	.	.	.	.	.	.	.	.	.	.
cf. *Vaccinium* sp.	s+p	.	.	.	+	.	.	.	+++	.	+	.	.	.	.	.	+	.	.	++	.	.	.	.
Valeriana dioica	p	.	.	.	.	.	.	.	++	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.
V. officinalis	p	.	.	.	.	.	.	.	+	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.
cf. *Vicia* sp.	p	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	+	.	.	++	.	.	.	.
L. copodium clavatum	sp	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	+	.	.	.	.	.	.	.
Ly selago	sp	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	+	.	.	.	.	.	.	.
O.smunda regalis	sp	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.
Pilularia globulifera	sp	.	.	.	.	.	.	.	.	.	.	.	.	.	.	+	.	.	.	.	.	+	.	.
Pteridium aquilinum	lvs	.	.	.	.	+	+++	++	++	+	.	.	.	.	.	+++	.	.	.	.	.	.	.	.
Eurhynchium spp.	lvs	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	++
Hypnum cf. *molluscum*	lvs	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	+
Polytrichum commune	lvs	.	.	++	.	.	.	.	.	.	.	.	.	++	.	.	.	+	.	.	.	.	.	.
Sphagnum spp.	lvs	.	.	.	.	.	.	.	.	.	.	+++	++	++	.	.	.	.	.	.	.	++	.	.
Musci	lvs	.	.	++	.	.	.	+++	++	.	.	+++	.	.	+	+	.	+	.	.	.	.	.	.
Chara sp.	oosp	.	.	++	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.
Nitella sp.	oosp	.	.	.	+++	.	.	.	++	.	.	.	.	.	.	.	++	.	.	+	.	+	++	.

Abbreviations: sc = catkin scale; fr. = fruit; f.st = fruit stone; lvs = leaf; n = nut or nutlet; oosp = oospore; p = pollen grain; s = seed; sp. = spore or sporangium; tw = twig. + = rare (usually single finds). ++ = occasional (usually 2–5 finds). +++ = frequent (usually > 5 finds).

Fagus sylvatica

Darbishire (1874) reported finding abundant leaves and 'trees' of the beech in the 'leaf bed' and the overlying 'forest bed' of his excavation (table 6). However, parts of artifacts also identified at that time as made of *Fagus* wood are known to have been misidentified as also was the *Fagus* pollen recorded by Piggott (1954) from a peat sample from Ehenside (Godwin, personal communications). In the current investigations no macroscopic remains of *Fagus* have been found and only eight pollen grains have been recorded, from eight separate samples, from Zone C21 onwards. Notwithstanding the known low pollen representation of *Fagus* it seems *very* unlikely that the tree ever grew in any quantity near Ehenside, and Darbishire's (1874) record will be treated as an unfortunate error in an otherwise admirable report.

TABLE 6

tentative pollen zonation ...		VIIa C14–C16	Post-Atlantic hiatus–C22b
stratigraphic description			
identification	remains*	leaf bed	forest bed
Alnus glutinosa	lvs	++	
Betula sp.	lvs + trees	++	+++
Corylus avellana	n + lvs + trees	++	+++
Fagus sylvatica	lvs + trees	+++	+++
Lonicera periclymenum	lvs + tw	.	+
Quercus sp.	fr + lvs + trees	+++	+++
Osmunda regalis	caudices	.	+++
cf. *Polyporus* sp.	fructifications	.	+
Bos longifrons	horn and bone	.	+

* Abbreviations are the same as those used in table 5.

Gentianella cf. *campestris* agg.

Two seeds, with high probability attributable to this aggregate species although one was but two-thirds the normal mean size, were recovered from between 600 and 650 cm in diagram A (C19, Stage *C*). The only other record from the British Isles is the tentative recognition of 'cf *Gentiana campestris* (L) H. Sm.' pollen from the late-Glacial at Liverpool (Godwin 1959). Both species included in this aggregate by Clapham *et. al.* (1952), viz. *G. campestris* and *G. baltica*, occur today in the Cumberland Lowland, and the seeds do not allow a close identification to be made. The ecological indications of either, however, are grassy, unshaded places on rather base rich soil, possibly coastal dunes.

Juniperus sp.

Pollen grains of *Juniperus* occur at the base of both pollen diagrams where they are thought to derive from late-Glacial or early post-Glacial growths of the shrub. In both diagrams too, the pollen also occurs in Zone C 23 (Stages *E* and *Ee*) indicating the presence of treeless countryside at that time where the juniper grew either naturally, protected for winter feeding of stock, or planted for ornament or wind-break.

Humulus–Cannabis

Pollen of the *Humulus–Cannabis* type is now well known from European post-Glacial deposits (cf. Anderson 1954), but the high values recorded in Zones C22b and C23

(Stages *D*, *Dd*, *E* and *Ee*) are comparable only with those at Skelsmergh Tarn, Westmorland (Walker 1955*a*). At Ehenside the high values of this pollen type occur at levels where there is no evidence of widespread fen woodlands where *Humulus* might naturally have grown. It is therefore tempting to attribute it to human activity; to the culture of either hops or hemp. There is no tradition of hop culture in Cumberland and the plant is not considered a native there or in Westmorland where, however, it does infrequently grow 'in hedges, generally near houses' (Wilson 1938). Hemp, on the other hand, was extensively farmed at least as early as the seventeenth century. In the siege of Dalston Hall in 1645 the defending Royalists were reduced to eating 'hempseed, dogs and rats' (Tullie 1840) and by 1709 T. Lawson, in a list of plants 'not observed by Mr Ray' (Robinson 1709) wrote of it as a wild plant, growing 'plentifully on the skirts of Cross-Fell and other places within both these counties'. It seems very probable, therefore, that the pollen at Ehenside derived from cultivated hemp, *Cannabis sativa*.

Linum catharticum

One seed of *L. catharticum* was recovered from between 52 and 45 cm in diagram B (C23, Stage *Ee*). Although occurring together with many seeds of the next species, it was quite distinct from them and from immature type material of *L. usitatissimum*.

Linum usitatissimum

Seeds of *L. usitatissimum* were frequently and consistently found in material of Zone C22b (Stages *Dd* and *E*) where the pollen is also consistently present. A single pollen grain from Zone C22a (Stage *D*) is also recorded in diagram A. Seven seeds, unsupported by contemporary pollen, were recovered from between 45 and 52 cm in diagram B (C23, Stage *Ee*). Flax has been grown in the British Isles since Neolithic time (Helbaek 1953). Between about 1830 and 1845 Sir Robert Brisco used Ehenside Tarn for the retting of his flax, which he was growing 'experimentally' in the district (Darbishire 1874) where a century earlier it had been a popular crop (Dickinson 1852). It is possible that the *Linum usitatissimum* seeds of Zone C23 had this origin. The earlier material, however, can hardly have been so recent, although a similar manner of introduction of the seeds into the mud at an earlier period seems likely.

Origanum vulgare

The occurrence of this species in Zone C23 is unusual in view of its preference for calcareous soils. Its other ecological requirements, rough dry turf or open scrub woodland, are easily imagined in Stages *E* and *Ee*, or at any time on coastal dunes where an adequate calcium carbonate supply might also have been available. Nevertheless, at the present day it is almost completely restricted to limestone soils in Cumberland (Hodgson 1898).

Pastinaca sativa

Pollen of this species is recorded from Zones C13 to C22b, excluding Zone C16. It has been identified from late-Glacial deposits in the British Isles and, more sporadically, from post-Glacial deposits where it is usually associated with other indicators of unshaded habitats. In the Ehenside diagrams from Zone C17 onwards, the pollen occurs only in forest clearance stages but the records from Zones C13, C14 and C15 (five pollen grains totally) more probably indicate plants growing in coastal treeless habitats. Like *Origanum vulgare*, *P. sativa* has an apparent preference for chalky soils, but it may be that coastal sands offered many sufficient habitats (Salisbury 1952). Hodgson (1898) does not record the plant for Cumberland, the nearest locality, apparently, being railway banks near Barrow-in-Furness (Wilson 1938).

Petroselinum segetum

One fruit of *P. segetum* was obtained from between 200 and 170 cm in diagram A (C22b to C23, Stage *E*). It is now a plant of grassy banks and is not recorded from Cumberland (Hodgson 1898).

Plantago spp.

P. lanceolata, *P. major* and *P. maritima* were all identified by their pollen, which constitutes the main contribution to the shade-intolerant herb group of the forest clearance stages. All three species are represented in all the clearance stages except that *P. maritima* does not appear before Zone C19, i.e. it is absent from Stages *A* and *B*. *P. major* occurs sporadically also in Zones C14 and C15 and two grains of *P. lanceolata* are recorded from Zone C15, i.e. before any recognizable clearance stages. They may, of course, represent clearance of some kind which is otherwise not indicated, but they might equally well derive from open coastal habitats. From Zone C16 (VIIa) onwards, *P. lanceolata* has a continuous record in both diagrams. In diagram A, where the record is most complete, the *P. major* curve is discontinuous. Pollen of *P. maritima* is never abundant and occurs sporadically, except in the early part of clearance Stage *C* (Zone C19).

Polygonum spp.

Of the records under this heading those of *P. convolvulus* (C23) and *P. bistorta*-type (22a) (Hedberg 1946), which almost certainly derive from *P. bistorta* itself, probably indicate plants growing in waste or farmed land. The rest are of plants which might have been growing around the tarn edge.

Potentilla cf. *crantzii*

If the two seeds tentatively attributed to this species on the basis of their surface pattern do in fact indicate the occurrence of this plant near sea level in Zones C19 and C20, its present restriction to upland habitats is all the more remarkable. The species is reported as low as 120 m (400 ft.) O.D. in Scotland but not below 180 m (600 ft.) O.D. in England (Wilson 1956). Hodgson (1898) does not recognize it in the Cumberland flora and in Westmorland it is very rare, growing between 1800 and 2000 ft. (Wilson 1938).

Poterium sanguisorba

An unmistakable pollen grain of this species is recorded from 100 cm in diagram B (Zone C22b, Stage *Dd*). This is yet another record of a plant with a strong preference for calcareous soil which was probably growing on sea shore sand as an alternative (cf. *Pastinaca sativa*, *Origanum vulgare*).

Stellaria spp.

Two seeds, one of *S. graminea* and the other of *S. neglecta*, were recovered from Zone C22b (Stages *Dd* and *E*). Both are predominantly shade plants, although they do also occur in hedgerows, and Godwin (1956) has noted the apparent association of post-Glacial *S. graminea* with cultivation. Pollen of Caryophyllaceae has been included amongst the indicators of forest clearance partly on the grounds that *Stellaria*-type pollen was not present.

Trifolium scabrum

Fourteen pollen grains of this species are recorded from Zone C23 (Stage *Ee*) and one from the hiatus (?Zone C22b) in diagram B. The grains are identifiable from those of *T. striatum*, which they closely resemble, by their larger size, narrower pores and their coarse reticulum which has thick meshes leaving irregularly shaped lumina giving the wall a rugulate appearance in optical section. At present *T. scabrum* is a plant of Mediterranean, S. European and W. Asian distribution (Hegi 1924) which seems to find its northern limit in Great Britain. Its scattered distribution in the north may imply association with humanly maintained habitats for it is a plant of well drained, light soil. It is included here amongst the indicators of forest clearance, but it is evidently not a plant of the clearance expansion period (it occurs in a forest regeneration stage when, however, very many open habitats were still available) and might just as well have been a plant of coastal habitats. The growing plant is not recorded for Cumberland (Hodgson 1898; Druce 1932).

Ulex cf. *europaeus*

Spines of gorse, thought to belong to *U. europaeus*, were recovered from between 170 and 200 cm in diagram A (Zone C22b to 23, Stage *E*) and from between 45 and 52 cm in diagram B (Zone C23, Stage *Ee*), confirming the tentative identification of the pollen of the genus through Zones C22b and C23 (Stages *Dd*, *E* and *Ee*) in both diagrams. The plant is intolerant of shaded habitats and its presence during Stages *Dd* and *Ee* emphasizes the treelessness of the vicinity even during the 'forest regeneration stages'. A favourite habitat in Cumberland today is the broken tops of old field boundary ridges and walls.

Isoëtes spp.

The separate identification of the microspores of *I. echinospora* and *I. lacustris* is confirmed in diagram A by the similar distribution of the more easily separable megaspores of the two species. The absence of *I. echinospora* from the present Cumberland flora gives some local interest to its persistence at Ehenside until very recent times (end of Zone C23).

Pilularia globulifera

Two megaspores of *P. globulifera* were recovered, one from Zone C22b and the other from Zone C23 in diagram B. These appear to be the only records of this plant in the British Isles between the Boreal period and the present day. Hodgson (1898) records its infrequent occurrence in Cumberland ponds and cites one record in a pond at Nethertown, near St Bees.

The ecological development of the tarn

Although the shape of the original hollow at Ehenside and the nature and age of the earliest deposits it contained are unknown, it seems very probable that it originated as a kettle hole in the sandy drift of the retreating ice after the Scottish Readvance Glaciation. The sandy clay-mud with gravel, which marked the depth limit of investigation over most of the tarn, was penetrated near the middle of Transect *A* (figure 20) and a fine detritus mud discovered beneath it. This is undoubted evidence of a period when conditions were relatively favourable for the growth of organisms—at least micro-organisms—in and around the tarn. The sandy clay-mud, however, indicates a fall in organic productivity of the site together with a marked increase in the supply of inorganic material from the shores, perhaps by solifluction. The organic mud immediately above this, from which the first certain indications of age and ecological conditions are available, was deposited during Zone C9 (IV–V). It is reasonable to suppose, therefore, that the sandy clay-mud is of the immediately preceding periods, viz. C7 and C8 (III), the last phase of the late-Glacial.

Throughout Zones C9 to C13 (VI–VIIa) the ecology of the tarn is difficult to reconstruct. The overall accumulation rate was slow, but this might have been due to frequent and large changes in water level exposing the muds to oxidation and erosion. For the most part, however, the pollen diagram suggests continuous but very slow accumulation of mud in a tarn poor in water plants. *Potamogeton* spp., *Nymphaea alba* and *Myriophyllum alterniflorum* are sporadically represented but the general barrenness of the basin at the time is very difficult to account for. It may be that, in the middle of the forest, light was a limiting factor but the evidence of macroscopic tree remains suggests that shading was not so intense during that period as later.

The disturbance of the basal muds at the lake margin exposed in the archaeological excavation is certain evidence of re-working of existing organic material and movement of the surrounding slopes towards the end of Zone C12 (VI). This might well have been the result of a rather sudden change in water level, the evidence for a marked fall being rather stronger than that for a corresponding rise. Whatever the true explanation of the marginal phenomena, it must also explain the almost complete cessation of accumulation at the centre of the tarn during Zones C12 and C13, or the later removal of deposits laid down then.

In Zone C14 a more readily recognizable situation was established. There is still little evidence of water plants but the accumulation of finely detrital organic mud took place in the centre of the lake whilst at the margins the accumulation rate was somewhat increased by the abundant detritus from the fringing woodlands of *Betula pubescens* and *B. verrucosa*, *Quercus petraea* and *Alnus glutinosa*, in which grew *Osmunda regalis* and *Polypodium* sp. These conditions persisted through Zones C14 and C15 and into Zone C16, except that the lack of woody detritus and the abundance of leaves in the marginal muds of Zones C15 and early C16 suggest that the woodlands were not then so close at hand as formerly, possibly the result of a slight rise in water level in the tarn.

At the centre of the tarn conditions remained substantially unchanged until the end of Zone C16, when a layer of sand was incorporated in the mud, so fine as to have been ignored in the majority of the stratigraphic borings. Immediately above this level, *Potamogeton* spp. are consistently represented by pollen until the middle of Zone C19. At the middle of Zone C17, *Nymphaea alba* must have become fairly frequent in the lake, whilst somewhere around the banks *Sphagnum* spp. had become well established. By the end of Zone C19, however, the earlier barrenness of the lake had returned. *Calluna* had now joined *Sphagnum* as an indicator of acid conditions but may have been growing in the opening woodlands on podzolic soils, rather than as part of a marginal hydrosere. From the beginning of Zone C18 to the end of Zone C20 (through forest clearance Stages *B* and *C*) fine charcoal fragments occur with fair regularity in the mud suggesting settlement or forest clearance, in which fire played an important role, close to the shores of the tarn. It may be, too, that Stage *B* involved settlement at the lake edge which temporarily enriched the tarn waters encouraging the growth of *Potamogeton* spp. and *Nymphaea alba*. There is no evidence of a marked change in water level from the beginning of Zone C17 to the end of Zone C20. All that can be deduced is that, at the beginning of Zone C17 the water level cannot have been lower than 8 m below the site datum and at the end of Zone C20 not below 5·5 m below site datum. It is likely that the water stood at least as high as the upper of these two levels throughout this period.

The appearance of *Isoëtes lacustris* during Zone C21 and its frequent occurrence until the middle of Zone C22b must indicate the availability of fairly shallow water over a stony or clayey substratum. It is unlikely that this sort of habitat existed, uncovered by organic mud, in the area covered by water at the end of Zone C20. A small rise in water level early in Zone C21, however, would undoubtedly have flooded many areas of bare boulder clay around the shores, by then substantially cleared of woodland. The appearance of *I. lacustris* might therefore be slight evidence for a rise in water level during the first half of Zone C21. If this were the case, then the abundance of *Nymphaea alba* in Zone C22a might derive from the flooding of shores where organic soils had already developed.

There is no certain evidence of conditions at the lake margin between the early part of Zone C16 and Zone C22b, a period represented by only 5 cm of organic material in the archaeological excavation. This must mean either an almost complete cessation of accumulation or accumulation followed by erosion, the last phase of which took place at the beginning of Zone C22b. There is no positive evidence of erosion such as the disturbance of accumulation elsewhere at the site or the incorporation of older material in the mud accumulating at the middle of the lake. It would also be difficult to explain why the erosion should stop at such a uniform level; why, nowhere in the sections exposed by the archaeological excavations, were deposits younger than this particular early phase of Zone C16 found beneath the deposits of Zone C22b. The alternative hypothesis, however, also presents many difficulties. The preservation of the muds beneath the timbers and the gravel spread which occupy the hiatus, implies that they were continuously waterlogged after their formation. Had the water level lain above the top of the leafy mud, however, it is difficult to understand why a reed swamp, fen or bog did not develop there and leave an appropriate organic deposit. If, by some unknown mechanism, the mud was preserved whilst the surface dried out it is beyond understanding that no evidence of overgrowth by any kind of plant remains. The timbers which occupy the hiatus may have fallen from the higher part of the bank early in Zone C22b, or they might have been cut and placed in position by humans at any time between Zones C16 and C22b. If the former origin were the true one, the paucity of the smaller branches and the abundance of large ones is very strange. Whilst it is also true that undercutting of the bank might have caused the fall of the boulders which also lie in the hiatus, the lack of evidence for such undercutting, as well as the comparative rarity of stones of such size in the local drift, make this explanation unlikely. There seems to be considerable circumstantial evidence, therefore, for supposing the timbers and boulders to have been placed by men for their own purposes around a part of the lake margin at some time between Zones C16 and C22b. If the hiatus is anthropogenic it may have been caused by continuous settlement around the lake of a kind which, whilst leaving earlier deposits waterlogged, prevented the growth of reed-swamp in the shallows. Alternatively men may have removed deposits down to what is now recognized as the top of the leafy mud. There can be no direct evidence for the last process but the pollen diagrams may give some indication of the *possibility* of continuous occupation around the shores. The beginning of the hiatus corresponds with the early part of forest clearance Stage *A*. In pollen diagram A evidence for human settlement close at hand, such as charcoal and abundant sand in the mud, is lacking. There is considerable evidence of this kind, however, through Stages *B* and *C*. It may be that, during these stages, men were living around the tarn margins and inhibiting the development of reed-swamp. At some time during that period (roughly Zones C18, C19 and C20) they may have placed the timbers and boulders in the shallow water and disturbed the underlying mud slightly down to what is now recognized as the top of the leafy mud. A piece of wood penetrating the timbers of the hiatus was radiocarbon dated to 2091 ± 115 B.C. and 2165 ± 115 B.C. (Q303, Godwin & Willis 1960). Comparison with the radiocarbon dated diagram from Scaleby Moss (part II) suggests a position early in Zone C18 for such a date. This is about the level in diagram A from Ehenside at which the evidence for human occupation of the tarn *edge* begins. If the sand layer recorded at 717·5 cm in the boring for pollen diagram A were known to be the equivalent of the sand and gravel spread at the base of the hiatus in the marginal sections, the beginning of Zone C17 (VIIb) would be indicated for the earliest disturbance at the lake margins. This does not conflict with other evidence for the sand layer in diagram A, if it is not the equivalent of the sand and gravel found in the archaeological excavation, can be taken as an indicator of a particular early and less intense phase of disturbance.

The evidence for intense human activity around the lake margins ends at the end of Zone C20. Evidence has already been adduced from pollen diagram A for a rise in water level early in Zone C21. This may not have directly affected the human occupation of the shores but it was sufficient to flood and preserve the material in the hiatus and to allow the accumulation of organic deposits there again, apparently unhindered by human activity. The stratigraphy suggests that the water level stood about 225 cm below site datum by the beginning of natural accumulation in Zone C22b.

In summary, the interruption of normal organic accumulation at the lake margin is thought to have been due to human interference which was at its strongest in the immediate vicinity during Zones C18 to C20. A rise in water table early in Zone C21 was roughly coincident with the end of intense human interference but some inhibition of accumulation continued until Zone C22b. If, as seems reasonable, Darbishire's (1874) 'surface of the leaf bed' and his 'base of the forest bed' are to be equated with the hiatus deposits, they are archaeologically typified by one unpolished axe of Langdale origin, two grinding stones and a wooden, bow-shaped object.

With the rise in water level which seems to have taken place early in Zone C20, larger areas of shallow water were created around the lake edges and reedswamp plants were more abundant in Zones C21 to C23 than formerly (e.g. *Schoenoplectus lacustris*, *Sparganium* spp.) as also were *Potamogeton* spp. The stratigraphy does not indicate the formation of extensive reedswamps, however. At the beginning of Zone C22b, *Sphagnum* seems to have become more abundant and it may have been at this time that the bog became established along the margin of the 'island'. *Isoëtes lacustris* and *Nymphaea alba* became much less frequent during Zone C22b but *Isoëtes echinospora* and *Littorella uniflora* appeared and spread, and were joined, in Zone C23, by an increased abundance of *Potamogeton* spp. (particularly *P. berchtoldii*) and *Myriophyllum alterniflorum*. Most of these changes conform with increasing acidity of the lake water and the accumulation of organic mud in the shallows. The lake was almost certainly at that time surrounded by treeless farm land, however, and even if the management of this were not of such a kind as to provide a supply of bases to the tarn water (e.g. permanent pasture) the trampling of cattle around parts of the beach might still have ensured sufficiently stony habitats for *Littorella uniflora*.

At the end of Zone C23, Ehenside Tarn was still largely open water with intermittent marginal stands of pond weeds, reed swamp and *Sphagnum* bog. It was in this state when it was drained in 1869 and boulder clay spread across the exposed mud surface. During the past ninety years, encouraged by reflooding and the relatively base-rich conditions provided by the redistributed boulder clay, extensive reedswamp has covered almost all of that part of the basin here described.

The excavations at Ehenside Tarn in 1957 were directed by Professor Stuart Piggott and Mr Brian Blake who generously provided facilities for the field work described as well as advice and stimulating discussion. The farmer of Low Ehenside kindly allowed this work to be carried out on his land.

Appendix. Supplementary pollen analytical data

1. Samples of mud associated with probable archaeological objects (p. 91) were analysed and the following results obtained. All frequencies are expressed as percentages of total arboreal pollen.

sample reference ...	EA1	EA2	EA3	EA4	EA5
Betula	50·5	48·6	52·4	54·5	59·2
Pinus	0·8	0·5	1·0	2·0	1·6
Ulmus	1·7	2·2	2·6	1·8	2·3
Quercus	28·3	21·3	26·4	22·2	14·8
Alnus	18·5	27·1	17·6	19·5	22·2
Fraxinus	–	–	+	+	+
Corylus	21·8	30·5	28·0	31·5	49·7
Salix	0·6	+	1·0	+	1·1
Gramineae	12·1	7·8	6·5	8·8	18·0
Cyperaceae	4·7	3·2	4·0	2·4	5·2
Plantago spp.	0·8	0·5	0·2	1·2	2·3
Varia (incl. aquatics)	9·0	9·2	10·2	7·4	30·8

Samples EA1, 2, 3 and 4 all gave very similar results, each directly comparable with those commonly found in the hiatus between 114 and 118 cm in diagram B. Sample EA5 gave results comparable to those between 75 and 50 cm (Zones C22b to C23, Stage *E* to *Ee*) in diagram B.

2. A column of deposit was collected from the south-east face of trench 1, vertically beneath a surface point 22 ft. 6 in. (6·8 m) from the site datum. The column was about 50 cm long × 5 cm wide × 5 cm deep and crossed the sand and gravel associated with the timber layer and there containing a flint flake (p. 92). Sample levels are measured from the top of the column (itself 40 cm below ground level); the mud with sand and gravel extended from 19 to 24 cm and the level of the flint flake was 23 cm on this scale. Samples from the column gave the following results on analysis:

level (cm)	10	15	20	25	28	37	40
Betula	57·2	59·6	56·6	40·0	51·3	38·8	41·5
Pinus	+	1·7	1·3	1·0	–	–	+
Ulmus	1·3	0·7	1·0	2·5	1·3	1·0	1·6
Quercus	14·7	13·8	18·3	35·8	22·2	39·4	37·0
Alnus	26·2	23·9	23·0	20·4	25·0	21·0	19·8
Corylus	33·4	34·4	37·0	23·6	18·0	19·7	19·8
Salix	1·9	3·0	0·7	+	+	+	–
Gramineae	9·9	12·1	11·0	3·5	7·4	2·0	2·6
Cyperaceae	3·2	2·7	3·0	2·9	2·9	1·0	1·0
Plantago spp.	0·6	+	1·0	+	1·6	+	–
Humulus-type	1·6	1·7	3·0	–	–	–	–
Linum usitatissimum	–	–	+	–	–	–	–
Varia (incl. aquatics)	21·7	26·0	23·3	6·9	8·7	2·3	3·5

The sequence of results between 40 and 10 cm is roughly comparable with that between 137 and 65 cm in diagram B (Zones C15 to C22b). Immediately beneath the sand and gravel layer (Sample 25 cm) the analysis is exactly similar to that in the corresponding stratigraphical position in diagram B (119 cm). The analysis of Sample 20 cm, however, suggests that in this more marginal, higher, position, mud did not begin to accumulate in and over the sand and gravel until a time represented by about 105 cm in diagram B. The flint flake is located, pollen analytically, within the hiatus between Zones C16 and C22b.

V. STRATIGRAPHY AND POLLEN ANALYSIS AT BOWNESS COMMON AND POST-GLACIAL CHANGES IN THE RELATIVE LEVELS OF LAND AND SEA

Bowness Common and Glasson Moss consist of peat and mud deposits overlying marine materials on the southern coast of the Solway Firth, Cumberland. Stratigraphic and pollen analytical studies of these and the associated sites at Glasson Shore, Wigton and Wreay, allow the reconstruction of the ecological history of the sites and the general vegetation history of the area during the period since the Boreal–Atlantic Transition. Data for the study of land- and sea-level change since the late-Glacial period are also presented.

Introduction

The southern edge of the Solway Firth between Carlisle and Silloth bears strong evidence of former high sea levels in the form of raised beaches and elevated terraces of marine and estuarine alluvium ('warp': Dixon *et al.* 1926). There is also evidence, in the offshore occurrence of 'submerged forest', of a period or periods when the land stood higher relative to the sea than it does now. Large raised bogs occupy almost half the area of the terraces sometimes, but not always, hemmed in by ridges of boulder clay and the raised beaches between them. Bowness Common is one such bog but Glasson Moss, though lying on the uppermost terrace of warp, seems always to have had free drainage northward to the Solway Firth. Glasson Shore is a nearby site of the 'submerged forest'. Inland, layers of peat or mud are not infrequently recorded (e.g. Wigton and Wreay) which indicate different drainage régimes in the past, probably to be associated with the coastal changes.

BOWNESS COMMON AND GLASSON MOSS

Geography and stratigraphy

A promontory of land projects westward from Drumburgh (Nat. Grid Ref. 266599) and Kirkbride (Nat. Grid Ref. 231569) for about 9 km (5 miles) between the main channel of the River Eden to the north and the estuary of the River Wampool to the south (figure 24). The promontory is roughly lozenge-shaped and owes its form primarily to the position and alinement of large drumlins of the Scottish Readvance Glaciation linked on the north, west, and south coasts by raised beach deposits. The upper of the two terraces of warp, now at about 8 m to 9·5 m (26 to 31 ft.) O.D., lies within the beach or seaward of the drumlins where the raised beach does not occur. The lower terrace of warp, at about 7 m (23 ft.) O.D., occurs rarely and intermittently outside the raised beach. It also forms the base of a shallow trough, about 0·5 km ($\frac{1}{4}$ mile) wide, which runs in a south-west to north-west direction dividing the promontory from the wide area of upper terrace of warp to the east. Repeated examination of the lamination of the warp deposits at the interface between the two terraces strongly suggests that both are aggradational features.

A ridge of boulder clay runs across the promontory from Bowness in the north (Nat. Grid Ref. 223628) to Whitrigg in the south (Nat. Grid Ref. 221579), its highest points rising to between 15 and 23 m (50 and 75 ft.) O.D. West of this ridge the area within the rim formed by the drumlins and the raised beach is almost wholly occupied by a large raised bog, Bowness Common. The bog is now relatively dry over most of its surface and is dominated by tussocky *Calluna vulgaris* with *Eriophorum vaginatum* and *Tricophorum caespitosum*. Locally wetter areas, some rich in Sphagna (e.g. *S. cuspidatum*, *S. megallanicum*, *S. papillosum*) and others bush-grown (*Betula pubescens* and *Salix* sp.), and the record of a lake on the western end of the bog in nineteenth-century maps (e.g. Greenwood & Greenwood 1823) suggest that the mire has grown unevenly upwards creating regions of

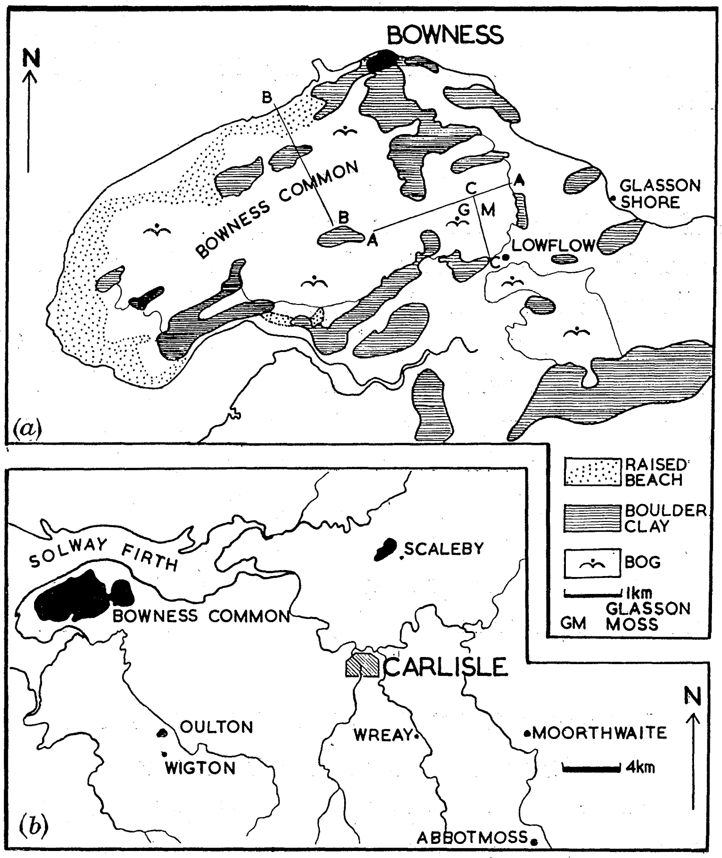


FIGURE 24. Bowness Common, Glasson Moss and associated sites, Cumberland. (*a*) Bowness and Glasson Moss showing their relationships to other superficial deposits and the positions of the transects of borings (AA, BB, CC.). (*b*) The relative positions of other investigated sites in the area.

internal drainage on its surface (cf. Osvald 1923). The bog edge has been extensively cut for fuel and the alluvium exposed around its margins conforms to the level of the upper terrace of warp. It seems very unlikely that Bowness Common has ever drained freely to the sea since the formation of the raised beach.

East of the boulder clay ridge, the much smaller Glasson Moss also lies on the upper terrace of warp. It is partially surrounded by drumlins, but these are not joined by raised beach deposits and it seems likely that free drainage was always possible eastward to the Solway Firth and southward into the trough filled with lower terrace of warp. Glasson Moss is cut and disturbed all round the edge and very extensive drainage operations have affected the southern part which is now almost totally dominated by *Calluna vulgaris*. The middle of the bog, however, seems to be still comparatively unaffected and a complex of shallow hollows and low hummocks is well developed in which active peat accumulation seems to be continuing.

Glasson Moss and Bowness Common were evidently once continuous across the lowest point in the dividing boulder clay ridge (Nat. Grid Ref. 230602). The thickness of peat there can never have been very great and is now reduced to an oxidized surface detritus.

The stratigraphy of Bowness Common and Glasson Moss was investigated by three related transects of borings. Transect *B* began at a point on the north-west coast of the peninsula between North Plain and Bigland House (Nat. Grid Ref. 206619) and ran S 30° E for a little over 2 km (1½ miles) to the northern edge of Rogersceugh Hill (Nat. Grid Ref. 215599), a drumlin rising from beneath the bog. This transect crossed successively the terraces of the modern salt marsh, the lower terrace of warp (largely occupied by a road), the raised beach and the exposed upper terrace of warp behind it, a low ridge of boulder clay, the disturbed bog edge and, finally, the bog surface itself. Transect *A* ran roughly at right angles to Transect *B*, beginning near the eastern edge of Rogersceugh Hill (Nat. Grid Ref. 221599) and running E 20° N across the bog surface, crossing the divide between Bowness Common and Glasson Moss at its lowest point and continuing across the latter to its eastern margin (Nat. Grid Ref. 245606) where the upper terrace of warp beneath the bog was exposed. The third line of borings, Transect *C*, lay almost parallel to the first, originating near the centre of Glasson Moss at Boring 11 on Transect *A* (Nat. Grid Ref. 239604). From there it ran S 10° E for about 1 km (½ mile) to the southern edge of the bog (Nat. Grid Ref. 241596) near Lowflow where the boundary between the upper terrace of warp on which the bog lies, and the lower terrace is marked by a low cliff about 1 m (3 ft.) high. The two bogs are evidently stratigraphically different, particularly in their lower deposits, and will first be separately described.

Bowness Common (figure 25)

Beneath the unconsolidated deposits of Bowness Common lies the boulder clay of the Scottish Readvance Glaciation forming an uneven surface of low ridges with intervening basins, some of which are interconnecting. A ridge of raised beach gravel bounds the seaward edge of the most north-westerly basin and bars any possible connection between the basins and the sea. In the middle of the basins, where the sequence of deposits is most fully represented, the lowest material is a grey, or blue-grey, stiff, silty clay frequently with dark, blue-black, horizontal laminae and devoid of plant remains. This warp interdigitates with part of the raised beach gravel. The upper surface of this stratum varies from 6·4 m (21 ft.) to 7·2 m (24 ft.) O.D. and the contact with the raised beach gravel was observed at 6·8 m (22 ft.) O.D. Above this lower warp there is often a short transition to a layer of dark brown, friable, coarse detritus mud rich in *Carex* and *Phragmites* remains with occasional fruits of *Scheuchzeria palustris*, *Hippuris vulgaris*, *Schoenoplectus lacustris* and *Carex* spp., and entirely devoid of inorganic sediment. This layer varies from 16 to 40 cm in thickness. Above it lies an upper warp: a grey to buff-grey, slightly silty or sandy, clay-mud with frequent fragments of *Phragmites*, *Carex* and *Equisetum* stem and occasional fruits of *Cladium mariscus* and *Hippuris vulgaris*. The thickest occurrence of this material recorded measures 56 cm and the upper surface lies between 7·6 m (25 ft.) and 8·8 m (29 ft.) O.D.

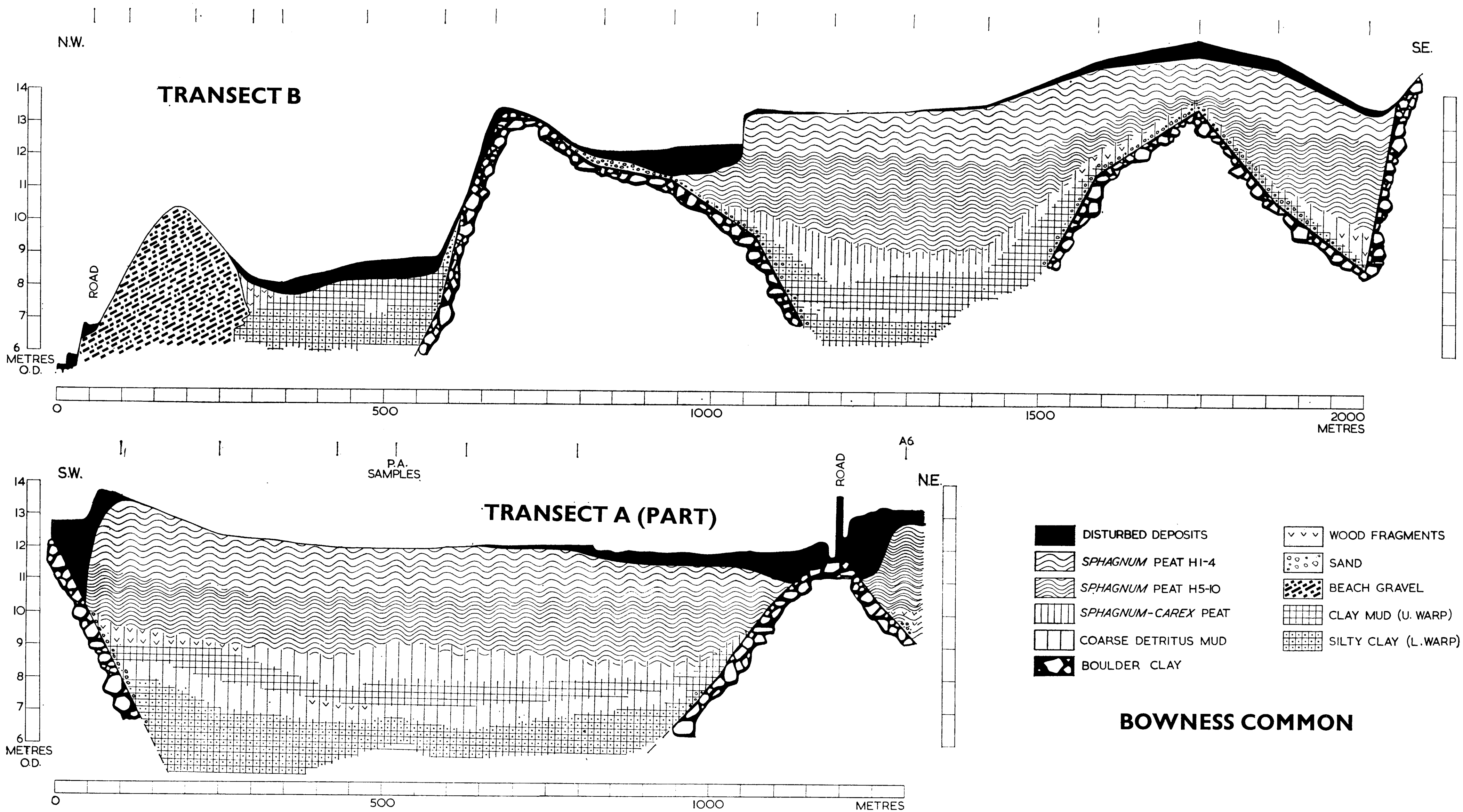


FIGURE 25. Bowness Common. Stratigraphy of deposits along Transect *B* and part of Transect *A*. (cf. figure 24*a*).

No certain evidence of the relationship between this deposit and the raised beach gravel has been obtained. At the edges of the basins these lowermost deposits are not represented or are so mixed with marginal sands and boulder clay as not to be clearly discernible.

Above the upper warp, and not distinguished from it by any sharp boundary, lies a bed of medium- to dark-brown coarse detritus mud with abundant remains of *Phragmites* and some *Carex* spp., seeds of *Scheuchzeria palustris*, *Hippuris vulgaris*, *Cladium mariscus* and one of *Lycopus europaeus* as well as occasional concentrations of wood fragments. This deposit is up to 120 cm thick and is continuous up the sides of the basins crossed by the transects, becoming very woody where it directly overlies the boulder clay. The uppermost 30 cm of this mud often contain traces of *Sphagnum* spp., forming a transition to the next higher deposit. This is a bed of medium-brown *Sphagnum* peat, reaching 300 cm at its thickest point, containing variable admixtures of *Calluna vulgaris* and *Eriophorum vaginatum* remains and varying in humification from H 5 to H 10. Within this peat narrow layers of pool mud were occasionally encountered but it was not possible to relate these from one boring to another. The boundary between this deposit and the overlying, less humified, peat is clear where the deposits overlie a basin but less so where the underlying deposits are shallower. The uppermost peat is probably everywhere disturbed to some extent at the surface but at some points this may affect only the topmost decimetre. It is a medium- to light-brown peat, rich in *Sphagnum* and with rare *Calluna* and *Eriophorum vaginatum* remains, the humification ranging between H 1 and H 4. Pool muds were only rarely encountered in the borings.

The highest point of Bowness Common crossed by the transects was at 15·6 m (51 ft.) O.D. over a boulder-clay hillock. The highest level of the bog surface above deep basin deposits was about 13·6 m (45 ft.) O.D., some 3·2 m (11 ft.) above the crest of the raised beach at 10·4 m (34 ft.) O.D.

Glasson Moss (figure 26)

The lowest material proved beneath Glasson Moss is the boulder clay of the Scottish Readvance Glaciation. Along the two transects bored, however, this was only found at three points, two of them marginal to the main area of the bog. More commonly, the deepest deposit is a brown to grey-brown, usually laminated, clayey sand with occasional pebbles, small woody fragments and rootlets. The upper surface of this deposit is of variable level but never exceeds 9·3 m ($30\frac{1}{2}$ ft.) O.D. and can commonly be observed in borings and ditch sections between this level and 5 m ($16\frac{1}{2}$ ft.) O.D. Around the north-east and south-east edges of the Moss, where the peat has been cut away, this material extends as the upper terrace of warp.

The surface of this deposit is covered by a thin layer of compact, dark-brown, muddy peat, with abundant but decayed fragments of *Phragmites* and *Carex* spp. Except in the deep hollow crossed by Transect *A*, the next superimposed layer is a medium brown, friable peat, rich in wood fragments of cf. *Alnus* and cf. *Corylus*, which may reach 70 cm in thickness. Above this again there is occasionally a layer rich in *Carex* sp. but this is only of local occurrence (boring *A* 12) and contains a fair admixture of *Sphagnum* spp. and seeds of *Menyanthes trifoliata*. Over the greater part of the transects, however, the woody peat is overlaid by a dark-brown, humified (H 6–10), *Sphagnum* peat with occasional fragments

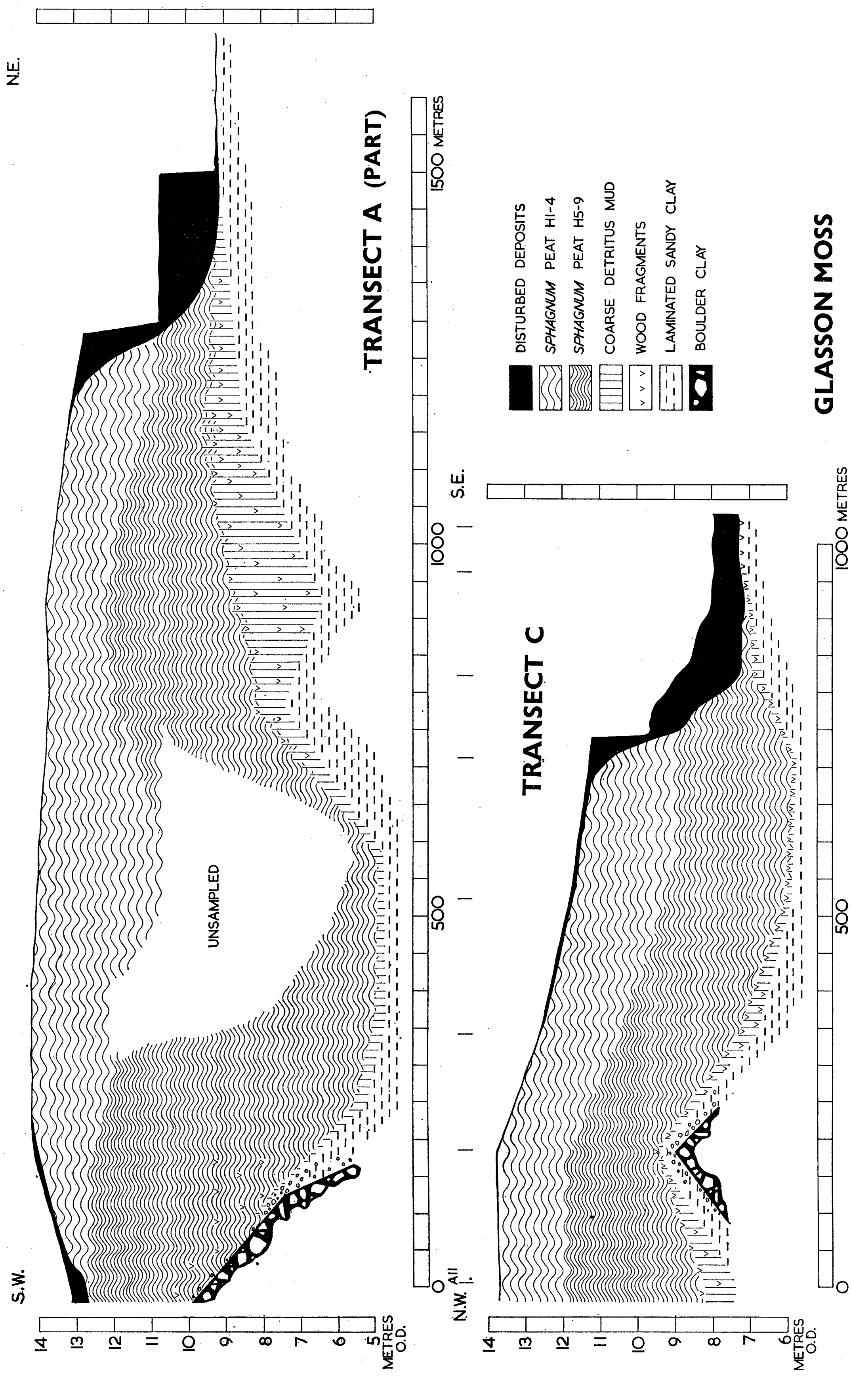


FIGURE 26. Glasson Moss. Stratigraphy of deposits along part of Transect *A* and Transect *C* (cf. figure 24*a*).

of *Calluna vulgaris* and *Eriophorum vaginatum*. The total thickness of this peat may be as much as 660 cm, but 300 to 400 cm is more usual. The interface between this and the uppermost of the undisturbed deposits is fairly clear. The superposed peat is considerably less dense and less humified (usually H2–3), lighter brown in colour, still with occasional *Calluna* fragments but with *E. vaginatum* extremely rare. An average thickness for this layer is about 200 cm.

The highest point of the present surface of Glasson Moss crossed by the boring transects is at 14·2 m (47 ft.) O.D., 5 m (16½ ft.) above the exposed level of the upper warp immediately to the north-east.

A comparison of the general stratigraphy of Bowness Common and Glasson Moss suggests that the two layers of *Sphagnum* peat in each might be roughly contemporary deposits. The underlying muds, clays and sands above the boulder clay, however, are not simply duplicated in the two sequences, nor is there any trace of raised beach materials beneath or around Glasson Moss.

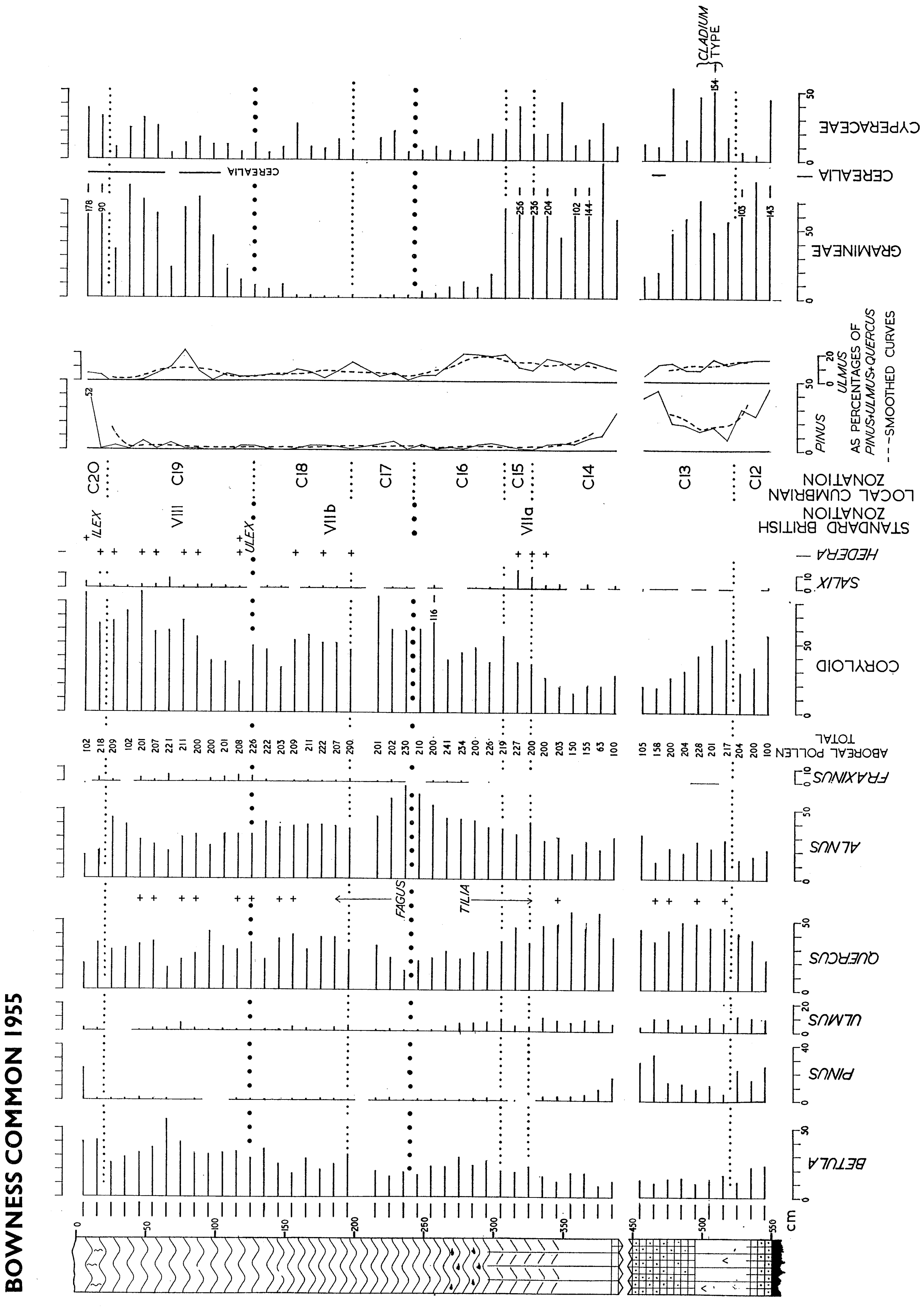
Pollen analytical results and chronology

Bowness Common

The main pollen diagram from this area is constructed from the analysis of samples from Bowness Common where the stratigraphic investigation indicated the most complete sequence of deposits. The samples were collected from boring *A*3a on Transect *A* (figure 25) where the detailed stratigraphy was recorded in the field as follows:

cm	
0–7	oxidized peat
7–21	*Sphagnum* peat with occasional *Eriophorum vaginatum* and possibly *Trichophorum caespitosum*. Medium brown. H3
21–131	light brown *Sphagnum–Eriophorum vaginatum* with rare *Calluna* fragments. H3–4. A very fresh band of *Sphagnum* peat 82–92 cm. H2
131–263	medium brown *Sphagnum* peat with occasional twigs of cf. *Myrica*. H4–5
263–296	dark brown, rather structureless, peat with occasional *Calluna* fragments. H6
296–384	very dark brown monocotyledonous peat with some *Sphagnum* remains, becoming clayey at the base
384–407	buff, clayey, mud with monocotyledonous stems
407–495	blue-grey silty clay with dark blue laminae and occasional sedge remains ('upper warp')
495–525	dark brown monocotyledonous peat, entirely free of clay. Small woody fragments rare
525–538	transitional mud
538–550	grey sandy clay-mud
550–590+	blue-grey, sandy, silty clay ('lower warp')

The samples from the upper part of the upper blue-grey silty clay and the lower part of the overlying buff clayey mud, i.e. the samples between 450 and 390 cm, contained too few pollen grains to enable a valid count to be made. The analyses of some of the adjacent


BOWNESS COMMON 1955
BETULA
PINUS
ULMUS
QUERCUS
FAGUS
TILIA
ALNUS
FRAXINUS
ABOREAL POLLEN TOTAL
CORYLOID
SALIX
HEDERA
ILEX
ULEX
STANDARD BRITISH ZONATION
LOCAL CUMBRIAN ZONATION
PINUS
ULMUS
AS PERCENTAGES OF PINUS+ULMUS+QUERCUS
- - -SMOOTHED CURVES
GRAMINEAE
CEREALIA
CYPERACEAE
CLADIUM TYPE
cm

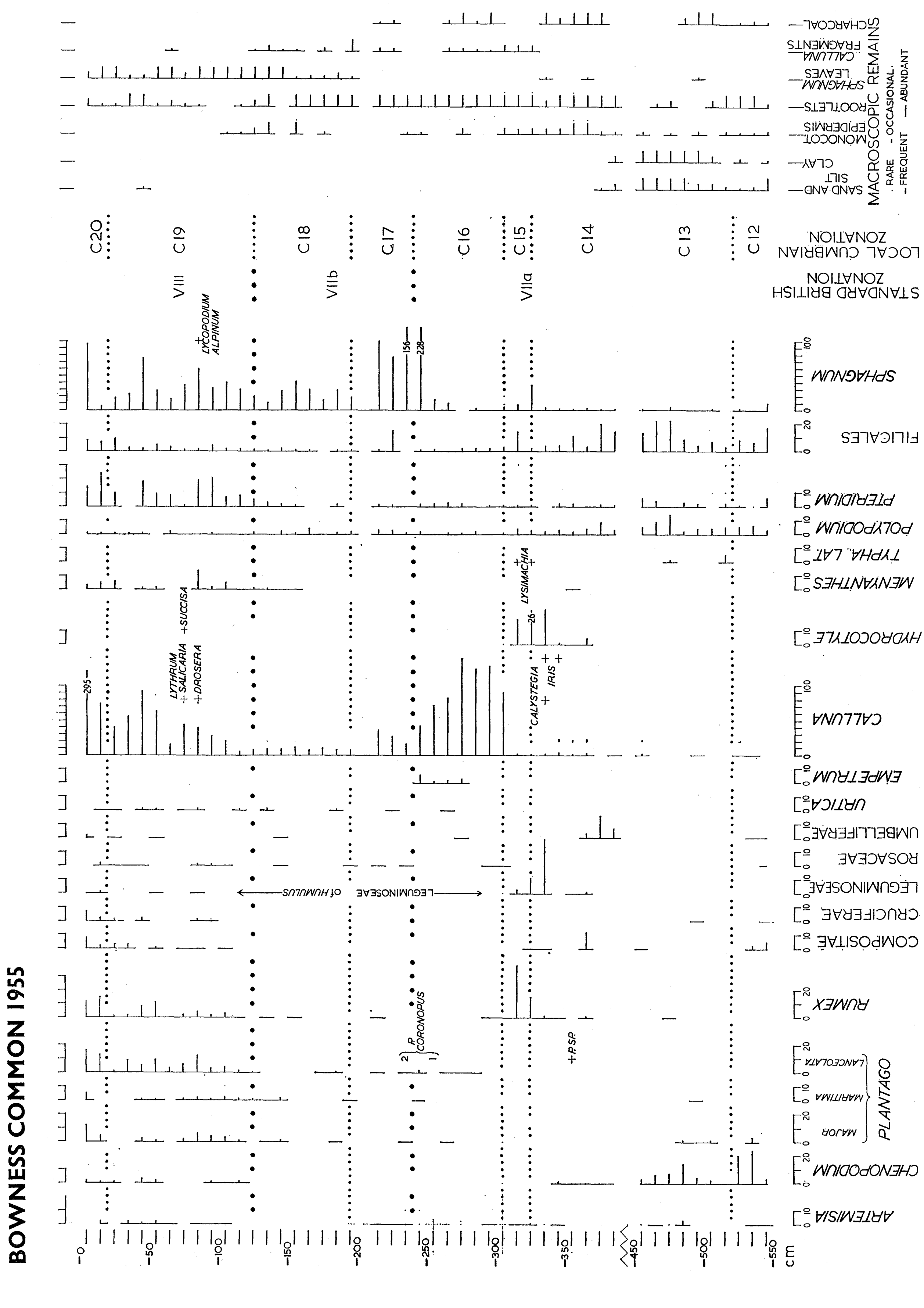


FIGURE 27. Bowness Common. Pollen diagram through the post-Glacial deposits. The frequencies of pollen or spores of all taxa are shown as percentages of the arboreal pollen total of the appropriate sample.

samples are also based on rather small total counts. These deposits, together with the basal clay-mud and clay, were evidently laid down under marine or estuarine conditions about 5 km (2 miles) from a continuous land mass of any size but much closer to a number of small islands (e.g. Rogersceugh Hill). Whilst this distance from a large area of land might be expected to ensure a balanced regional component of the pollen rain, the conditions of sedimentation in saline moving water and the possible admixture of pollen derived from older deposits by erosion might well have led to the selective accumulation of some pollen types in the clays and muds. Thus, whereas *Quercus* and *Alnus* pollen falling on the water surface might be expected to fall to the bottom rather rapidly, the buoyancy of *Pinus* pollen might have resulted in the enrichment of the mud with this type in some places and its depauperation in others. For this reason the analyses from 545, 465, 455 and 385 cm are not considered significant for purposes of zonation. Another source of pollen analytical confusion during the flooded period might have arisen from the number of islands around the site, the litoral flora of which (salt marshes and fringing fen woodlands, etc.) would contribute very considerably to the pollen rain. The resulting over-representation of marginal plants is unlikely to be such a danger to the correct interpretation of a diagram as it would be in the case of a small lake site fringed with relatively wide fens. It might, however, explain why, at some points in the lower part of the diagram, the curves for *Quercus* and *Alnus* seem to react inversely with one another whilst the curve for *Quercus* as a percentage of the total pollen of dry land trees pursues an entirely independent course. The pollen diagram (figure 27) has been zoned with these possible anomalies in mind and the greatest credence given to the interrelations of the dry-land trees and to analyses from entirely autochthonous organic deposits.

The diagram is zoned according to the standard British and the local Cumbrian schemes. No deposits pre-dating the Boreal-Atlantic transition are recorded.

The 'Boreal-Atlantic transition'

Cumbrian Zone C12 Bowness Common, 550–520 cm

Even though the lowest analysis, in clay-mud, is not dependable, the curves show some trends comparable with the transition between the relatively steady states of Zones C11 and C13 recorded elsewhere. *Pinus* values are relatively high but falling. *Alnus* is fairly constant but low in level, whilst *Quercus* values rise to the end of the zone. *Corylus* values are about 30% *A.P.* The upper limit of the zone is drawn where the *Pinus* values (as percentages of *Pinus* + *Ulmus* + *Quercus*) complete their fall, where *Quercus* values cease to rise and where *Alnus* values rise slightly.

British Zone VIIa

Cumbrian Zone C13 Bowness Common, 520–375 cm

Samples 465, 455 and 385 cm are excluded from the interpretation (see above).

Pinus values remain relatively steady at about 10% *A.P.* and *Betula* values are similar. *Quercus* frequencies lie between 45 and 50% *A.P.* As a percentage of *Pinus* + *Ulmus* + *Quercus*, however, *Quercus* values rise slightly and erratically as *Ulmus* values fall. *Corylus* values rise at first then fall to their minimum for the diagram (*ca.* 20% *A.P.*). Three pollen grains of *Fraxinus* and four of *Tilia cordata* are recorded in this zone. The upper limit of the zone is not clearly distinguished but is drawn where *Pinus* values appear to have fallen significantly once again and where the curve for *Ulmus* as a percentage of *Pinus*+ *Ulmus*+ *Quercus* begins to rise again slowly and erratically. At the same level *Betula* values increase slightly, probably as a result of local seral change.

Cumbrian Zone C14 Bowness Common, 375–325 cm

Pinus values fall to zero and *Ulmus* values rise slowly and erratically. *Alnus* and *Betula* curves are fairly steady. *Corylus* frequencies are low at first but rise toward the top of the zone. One grain of *Tilia cordata* and one of *Hedera helix* are recorded from the zone.

Cumbrian Zone C15 Bowness Common, 325–305 cm

The zone begins where the curve for *Ulmus*, as a percentage of *Pinus*+ *Ulmus*+ *Quercus*, begins to climb steeply and ends where the curve achieves its maximum, about twice its former values. *Pinus* pollen is absent from the zone. *Quercus* values fall and *Alnus* values rise equally slightly but *Betula* frequencies are notably higher than before (*ca.* 20% *A.P.*), perhaps as a result of the seral change from fen to bog. *Corylus* values continue to rise to about 40% *A.P.*

Cumbrian Zone C16 Bowness Common, 305–240 cm

The *Ulmus* level declines almost to extinction (though less regularly when expressed as percentages of *Pinus*+ *Ulmus*+ *Quercus*). *Pinus* pollen reappears, but not in significant quantity. *Quercus* values fall (although as percentage of *Pinus*+ *Ulmus*+ *Quercus* they rise considerably) whilst *Alnus* values rise. *Corylus*, steady at first, rises to about 60% *A.P.* at the top of the zone. *Fraxinus* pollen is recorded from three levels in the upper half of the zone. The upper limit of the zone is drawn where *Ulmus* values reach their minimum.

British Zone VIIb

Cumbrian Zone C17 Bowness Common, 240–195 cm

Values for *Ulmus*, as percentage of *Pinus*+ *Ulmus*+ *Quercus*, rise slowly to 13% at the top of the zone. *Pinus* frequencies, though still very low, become significant once again. *Alnus* values, after attaining their post-Glacial maximum of 67% *A.P.* at the base of the zone, fall to about 40%. The counts for *Quercus* rise slowly, contrary to their behaviour when expressed as a percentage of *Pinus*+ *Ulmus*+ *Quercus*. *Betula* values are rather low (*ca.* 20% *A.P.*) and *Corylus* fairly consistently high (*ca.* 60% *A.P.*). *Plantago* spp. are consistently recorded from the base of this zone upwards. The upper limit of this zone is drawn where the curve for *Ulmus*, as a percentage of *Pinus*+ *Ulmus*+ *Quercus*, achieves its new maximum, where *Quercus* and *Alnus* values seem to have reached temporary stability and where *Betula* values rise rather distinctly.

Cumbrian Zone C18 Bowness Common, 195–*ca.* 125 cm

Ulmus values fall to an ill-defined minimum which marks the top of the zone. *Betula* values climb erratically to about 30% *A.P.* *Hedera helix* and *Fagus sylvatica* are recorded.

British Zone VIII

Cumbrian Zone C19 Bowness Common, *ca.* 125–20 cm

Quercus values fall slightly but fairly consistently through the zone. *Ulmus* frequencies, though very low at base and top, show a marked temporary maximum near the middle, above which *Pinus*, though erratic, is on the whole more frequent than since Zone C17. *Alnus* levels vary about 25% *A.P.* and, but for a temporary maximum at 65 cm, *Betula* values are remarkably steady at about 30% *A.P. Fraxinus* pollen, present in significant quantity throughout, is particularly abundant in the lower half of the zone. *Corylus* values rise. *Fagus sylvatica*, *Hedera helix* and *Ulex* sp. are recorded.

Cumbrian Zone C20 Bowness Common, 20–5 cm

The features which are thought to characterize this zone might here be artifacts resulting from the shallow depth of the samples and the resultant differential destruction of pollen grains by oxidation. The rise of *Betula* and *Ulmus* frequencies and the coincident fall of *Alnus* values may, on the other hand, be real indications of the opening of Zone C20.

Glasson Moss

Samples for pollen analysis were collected from the basal deposits in boring 12, Transect *A* (figure 26). The strata from which samples were taken were described as follows in the field.

cm	
0–500	not sampled for pollen analysis
500–672	medium brown peat with frequent *Sphagnum* and abundant *Carex* and cf. *Scheuchzeria* remains
672–724	dark-brown woody (cf. *Alnus*) peat with some monocotyledonous fragments
724–740	transitional mud with *Phragmites* stems
740–750+	dark grey-brown, laminated, sandy clay

Table 7. Pollen analytical results from Glasson Moss

	frequency of pollen types as percentages of total arboreal pollen													
sample level (cm)	*Betula*	*Pinus*	*Ulmus*	*Quercus*	*Tilia*	*Alnus*	*Corylus*	*Salix*	Gramineae	Cyperaceae	Ericaceae	Chenopodiaceae	Umbelliferae	Varia
705	10	1	7	50	.	32	31	3	60	24	2	3	4	12
715	10	3	8	28	+	51	21	2	81	62	1	3	12	17
725	8	3	11	54	.	24	27	3	104	32	1	16	3	26
735	6	5	10	47	.	32	20	1	75	60	3	27	1	31

The results of the analyses of the four samples taken are shown in table 7. It is difficult to avoid comparisons between them and the spectra of Cumbrian Zone C14 (VIIa) of the Bowness Common diagram, particularly when the likelihood of over-representation of local *Alnus* communities, evidenced by the wood in the peat, is taken into account. In particular, the frequencies of *Pinus* and *Ulmus* in relation to total arboreal pollen and to each other can hardly be matched anywhere but in Zone C14. This strongly suggests that organic accumulation at Glasson Moss began shortly after the end of the deposition of the upper clay-mud at Bowness Common.

The plant list

Three large samples of mud from the Bowness Common boring for pollen analysis samples were examined in the laboratory and the contained macroscopic plant remains identified. These records, together with those of a few seeds from the pollen analysis samples themselves, are listed in table 8.

Atriplex hastata

The record of a number of seeds of this plant from Zones C12 and C13 (VIIa) bears out Godwin's (1956) suggestion that this is a species of the full- and late-Glacial periods which has survived the post-Glacial in forest-free areas. These records indicate that this plant probably became restricted to coastal refugia where it is still most common at the present day.

Table 8. Macroscopic plant remains from Bowness Common

	standard British zone . . .	VIIa	VIIa				VIIa	VIIa		VIIa	VIIb	VIII
	local Cumbrian zone . . .	C12 to 13	C13				C13	C14		C13 to 16	C18	C19
species	level in (cm) . . . / remains	538–500	505	495	445	435	495–400	345	335	384–300	165	115
Andromeda polifolia	lvs	.	.	.	.	.	.	.	.	.	.	+
Atriplex hastata	s	+ +	.	.	.	.	+	.	.	.	.	.
Blysmus rufus	s	.	.	.	.	.	+	.	.	.	.	.
Carex laevigata	fr	+ +	.	.	.	.	.	.	.	.	.	.
Carex sp.	n	+	.	.	.	.	.	.	.	+	.	.
Chenopodium rubrum	s	+ + +	.	.	.	.	.	.	.	.	.	.
C. cf. *album*	s	.	.	.	.	.	+ +	.	.	.	.	.
Chenopodium sp.	s	+ +	.	.	.	.	.	.	.	.	.	.
Cladium mariscus	fr	+ + +	+	+ +	.	.	+	.	.	.	.	.
Erica tetralix	s	.	.	.	.	.	.	.	.	.	+ +	.
Hydrocotyle vulgaris	s	.	.	.	.	.	+	.	.	+	.	.
Juncus cf. *gerardii*	s	.	.	.	+ +	+ +	.	.	.	.	.	.
J. cf. *maritimus*	s	.	.	.	+ + +	.	.	.	.	.	.	.
Lychnis flos-cuculi	s	.	.	.	.	.	.	.	+	.	.	.
Menyanthes trifoliata	s	.	.	.	.	.	.	.	.	+	.	.
Origanum vulgare	s	.	.	.	.	.	.	+	+	.	.	.
Rhynchospora alba	s	.	.	.	.	.	.	.	.	.	.	+
Shoenoplectus lacustris	fr	+ +	.	.	.	.	+ + +	.	.	.	.	.
Scirpus sp. (s. lat.)	s	.	.	.	.	.	+ +	.	.	.	.	.
Sium latifolium	s	.	.	.	.	.	.	.	.	+	.	.

fr = fruit; lvs = leaves; n = nutlets; s = seeds. + = rare; + + = occasional; + + + = frequent.

Blysmus rufus

A single, but certainly identified, seed of this plant provides another record of a salt-marsh plant in Zone C13 (VIIa). This species has only previously been reported from the Hoxnian Interglacial (Godwin 1956).

Humulus–Cannabis

Pollen on the *Humulus–Cannabis* type, recorded in Zones C19 and C20 (VIII), occurs in samples of raised bog peat and in rather low frequency. It therefore seems unlikely that these pollen grains derive from wild hop plants, for which no habitat seems to have been available locally at the time, but that they may be from cultivated *Cannabis sativa*.

Origanum vulgare

The two seeds of *O. vulgare* from Zone C14 (VII a), probably indicate the occurrence of this species in coastal habitats where the relatively high base status compensates for the normal calcicole requirements of the plant (Salisbury 1952). Apart from interglacial occurrences (Godwin 1956) the species is only recorded from Zone C23 (VIII) from the coastal site at Ehenside Tarn (part IV).

Plantago spp.

Of the four species of *Plantago* recorded in the pollen counts, *P. coronopus* is least abundant, occurring only sparsely in Zones C16 and C17 (VII a, b). *P. major* has the longest record (Zones C12, 13 and 16 to 20: VII a–VIII) but *P. lanceolata* is more continuously and abundantly present from Zone C16 (VII a) onwards. *P. maritima* is recorded from Zones C16 and 18 to 20 (VII a–VIII) and is most abundant where the two commoner species also show maxima (e.g. 85 cm: C19). The earlier records (Zones C12 to 14: VII a), associated as they are with those of other salt-marsh plants, probably derive from coastal communities. The same may also be true of the later occurrences, but *Plantago* pollen generally is there so abundant and unaccompanied by other salt-marsh indicators and so remote from the salt marshes *of the time*, that the *P. maritima* was probably on land cleared of forests.

Rumex spp.

The greater part of the pollen recorded for this genus in the pollen diagrams is of the *R. acetosella* type, except for that from samples 365 to 305 cm inclusive (C15 to 14: VII a) at Bowness Common. There the pollen is larger (*ca.* 34 μm in diameter) and might easily belong to *R. hydrolapathum* or *R. conglomeratus*. This tentative identification gains some support from the association of this type with the pollen of *Hydrocotyle vulgaris*, *Lysimachia vulgaris* and Leguminosae (*Lotus* type) in a fen mud.

Sium latifolium

A seed of this plant, together with those of its ecological associates *Carex* sp., *Hydrocotyle vulgaris* and *Menyanthes trifoliata*, is recorded from Zones C13 to 16 (VII a) and is the first *certain* subfossil record of the species for the British Isles (Godwin 1956).

THE ECOLOGICAL DEVELOPMENT OF THE SITES

The lower warp of Bowness Common, which interdigitates with the raised beach, is a marine or estuarine deposit which is unlikely to have been laid down in less than 1 m of water at high tide. The same type of material is at present being deposited up to 3 m (10 ft.) O.D. in the Solway Firth. Beneath Bowness Common it is aggraded to a height of 7·2 m (24 ft.) O.D. suggesting a mean sea level about 4 m (13 ft.) higher than the present sea level at the end of its deposition during Zone C12 (Boreal–Atlantic Transition). Before that time the Bowness Common basin complex was probably open to the sea but the transition to a clay-free organic detritus mud during Zone C12 and the early part of

Zone C13 (VIIa) must indicate that the basin then became isolated from the sea. This may have been the result of a fall in relative sea level but, in view of subsequent events, a more economical hypothesis would be that, for a time, the building of the raised beach completed the connexion of the drumlin islands, creating a lagoon in the basin which was only reached by the highest tides. The pollen diagram and the records of macroscopic plant remains do not certainly indicate how complete was the isolation of the lagoon from salt water influence, for *Phragmites communis*, *Cladium mariscus*, *Schoenoplectus lacustris* and *Carex laevigata* are all plants tolerant of brackish conditions. The lithology of the mud, however, is certainly very closely similar to that of fresh water swamp-fen deposits. Parts of the margins of the swamp were evidently forest-free at this time and supported, doubtless amongst a great variety of herbs, *Chenopodium rubrum* and *Atriplex hastata*. It also seems extremely likely that alder swamps fringed the islands here and there whilst oaks occupied the heavy clay soils of the emergent drumlins.

Before long, however, the lagoon must once more have been flooded by the rising sea, presumably the result of some change in channel or tide régimes which restricted the continued upward growth of the raised beach. Unlike the lower warp, the clay deposited during this second inundation is not completely devoid of organic remains and it seems likely that the swamps earlier established persisted around the island edges. There can be little doubt, however, that the greater part of the former swamp became barren mudflat at low tide if it was not, in fact, permanently inundated. This situation persisted into Zone C14 (VIIa) when the transition from clay to peaty mud, rich in the remains of swamp plants, indicates the second emergence of the basin above marine influence. After this stage, which, by analogy with Scaleby Moss (part II), must be dated at about 4100 to 4500 B.C., there is no indication of further marine encroachment and it seems reasonable to suppose that a real fall in the relative level of the sea was involved.

This early period is not represented by any organic deposits beneath Glasson Moss. The organic mud immediately overlying the basal clayey silt or sandy clay dates from Zone C14 (VIIa) which suggests that the latter materials were accumulating for some time before that. That deposit is coarsely laminated, contains rootlet fragments, and is similar in every way to the 'upper terrace of warp' with which it is continuous beyond the margins of Glasson Moss. It seems very likely, therefore, that the region of Glasson Moss was an aggrading salt-marsh whilst that of Bowness Common was a lagoon and, for a short period, a brackish or freshwater swamp. This must have been due to the free seaward drainage of the Glasson Moss region, a condition which was most probably general along the southern Solway coast as judged by the present distributions of terraces and raised beach. At the time of the sealing off of the Bowness Common lagoon it most likely stood at the seaward edge of a wide belt of salt marsh through which islands of boulder clay rose; a salt marsh flooded by practically every high tide.

When the Glasson Moss area rose above the sea the rainfall-drainage balance must still have been such as to maintain more or less permanent pools in the old salt-marsh pans and other hollows. Here small *Phragmites* swamps had their origins and from such sites they spread over the whole area, producing the shallow muddy peat which now overlays the salt-marsh surface. The frequent emergence of boulder-clay islands in the Glasson area must have encouraged this development by impeding the drainage somewhat, for their is certainly no indication that actively aggrading mires covered *all* the salt marsh surface of the Solway coast.

Even after the emergence, Bowness Common swamp would still be an area of inland drainage and it is evident that conditions there were conducive to luxuriant swamp development and the rapid accumulation of mud and peaty mud. In the early stages of this swamp, and near the point from which the pollen analytical samples were taken, *Hydrocotyle vulgaris*, *Iris pseudacorus* and possibly *Lotus* sp. (Leguminosae, *Lotus* type pollen) were quickly followed by *Rumex* sp. (possibly *R. hydrolapathum* or *R. conglomeratus*: p. 132) and *Lysimachia vulgaris*. But the main constituents of the swamp during this period were undoubtedly *Phragmites communis* and species of *Carex* with *Scheuchzeria palustris* and *Cladium mariscus* amongst the common associates. This plant assemblage continued to dominate the site throughout Zones C14 and C15 (VIIa) although detrital *Sphagnum* leaves in the muds from late Zone C14 onwards indicate that, already, acidification of the swamp water had begun at the margins or in small, relatively isolated, pools. This acidification is hardly surprising for masses of waterlogged organic detritus were collecting in the basin, whilst the counteracting effects of drainage water from the small area of beach deposits and forest-grown boulder clay cannot have been very great. Overgrowth by *Sphagnum*-dominated communities was accomplished at the site of the boring for pollen analysis samples at the beginning of Zone C16 (VIIa).

Without complete chronological control of the stratigraphy it is difficult certainly to reconstruct the history of the Glasson Moss area during an equivalent period. Yet it seems fairly certain that the early *Phragmites* swamps were replaced by fen woodlands in which *Alnus glutinosa* played an important role and which were interspersed with relict areas of grass and sedge swamp. For reasons similar to those suggested for Bowness Common, acidification of the surface water took place and *Sphagnum*-dominated communities replaced both fen woodland and swamp. It is no more than a convenient assumption that this took place at about the same time at both Bowness Common and Glasson Moss. The development of a hydrosere, particularly over an old salt-marsh surface, is not entirely accordant with what might be expected in an area the regional water-table of which must have been strongly affected by a falling relative sea level. This is confirmed by the general lack of mire development over the terraces of warp as a whole and local partial impedence of drainage is probably a necessary condition for the genesis of Glasson Moss.

From the end of Zone C15 (VIIa) onwards, Bowness Common, and probably also Glasson Moss, grew upwards as *Sphagnum*-dominated bogs. At Bowness, upward growth was fairly uniform until the latter part of Zone C18 (VIIb) and Sphagna of the section *Acutifolia* seem principally to have been involved, together with *Calluna vulgaris* and *Eriophorum vaginatum*, in frequencies varying greatly from time to time and place to place. During this period, conditions on the bog do not seem to have been substantially affected by any vegetation changes on the nearby dry ground although much of the water received by the bog probably still drained from the surrounding slopes.

From the end of Zone C18 (VIIb) to the end of the period represented at Bowness Common, the generally lower but more varied humification of the peat suggests some change in the ecology of the bog surface. The identification of *Sphagnum* species from leaves in the pollen analytical samples indicates an alternate dominance of *S. cuspidatum* and

S. imbricatum the former usually associated with *Menyanthes trifoliata*. The lateral extent of these alternating layers is unknown; they may indicate some sort of 'regeneration complex' or a series of recurrence surfaces. In either case they suggest a different ecology of the bog surface than formerly, although the reason for this is difficult to determine. It is difficult, too, to be certain that the regions of the bogs crossed by the transects are fully representative of the whole basin complex. Even in historic time the surface of Bowness Common bore a lake at its south-western end (Greenwood & Greenwood 1823) although the site of this is now vegetated peat. Other parts of the bogs—particularly Glasson Moss—are covered by pool-and-hummock complex and are certainly actively accumulating peat. Indeed, it seems very likely that before the marginal encroachment of peat cutting the greater part of the bog surfaces were in this state.

GLASSON SHORE

Geography and stratigraphy

Between the boulder clay hills on which the villages of Glasson and Drumburgh stand, the coast is formed of the lower terrace of warp. This has been eroded into a bay by the channel of the River Eden, the top of the warp cliff standing about 2 m ($6\frac{1}{2}$ ft.) above the level of the foreshore and at 6–7 m (20–23 ft.) O.D. It is, in fact, the north-eastern end of the warp-filled depression in which Lowflow stands. In the most concave part of the bay,

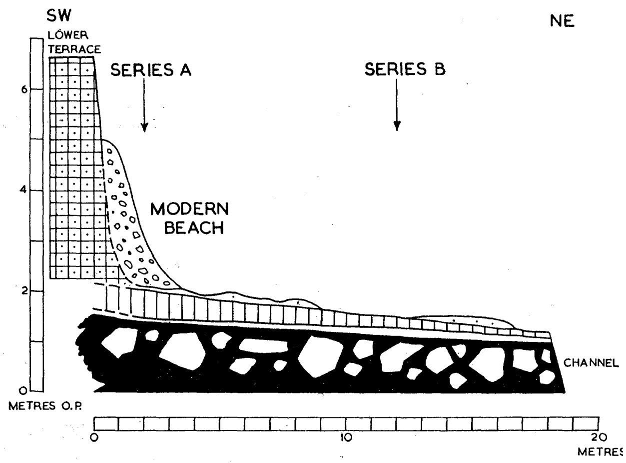


Figure 28. Glasson Shore. Sketch section of the stratigraphy of organic and associated marine deposits. Symbols as in figure 25.

where a small drainage stream joins the sea, the foreshore consists of a variable thickness of sand, gravel and laminated, blue-black, clay overlying a layer of grey, silty, clay containing occasional, rounded, pebbles. The interface between these two deposits is very distinct and whilst the upper is almost certainly a very recent material, the lower appears to be much older. Beneath the grey silty clay lies a layer of dark brown, or black, compact, organic mud. Below this is another light grey clay (the 'seat earth' of the Geological Survey: Dixon *et al.* 1926) overlying the red-brown boulder clay of which it is the leached product. These deposits are now suffering erosion along their seaward edge by a subsidiary channel of the River Eden. Excavation after spring tides showed the organic mud to lie beneath the warp deposits, of which the overlying grey silty clay with pebbles is a basal layer (figure 28).

Pollen analysis and chronology

A single series of samples could not be obtained which certainly covered the greatest possible period represented by the organic muds. Two overlapping series of samples were therefore taken about 10 m apart horizontally (Nat. Grid Ref. 261605). The first series was taken from a shallow pit and boring 2 m ($6\frac{1}{2}$ ft.) seaward from the warp cliff face. The stratigraphy read:

Series A

cm	
0–10	recent blown sand
10–80	laminated, blue-black, silty clay: probably recent
80–87	compact, grey, silty clay with rounded pebbles: terrace deposit
87–100	black, friable, peat with some sand and wood fragments
100–110	black, friable, peat: oxidized and possibly disturbed. No pollen analytical samples taken
110–139	very compressed, medium brown to reddish, moderately coarse detritus mud with sedge fragments and seeds of *Menyanthes trifoliata*
139–144	warm brown fine detritus mud
144–145	transitional mud
145–150	brown silty clay
150–200+	red-brown boulder clay

10 m (33 ft.) seaward from this site a pit disclosed the following stratigraphy:

Series B

0–15	medium brown, coarse detritus mud
15–20	brown, laminated, fine detritus mud with occasional layers of fine sand
20–40	grey clay with sand and occasional rocks
40–65+	red-brown boulder clay

In the field, the level of 145 cm in Series *A* was thought to correspond stratigraphically with the 5 cm level in Series *B*. A comparison of the pollen diagrams from both series of samples (figure 29) suggests that the lowest sample of Series *A* (150 cm) corresponds with that at 10 cm in Series *B*.

The composite pollen diagram shows no similarity with any part of the diagram from Bowness Common nor with the analyses from the base of Glasson Moss. The relatively low values of *Corylus*, together with the total absence of the pollen of any trees other than *Betula* and *Pinus*, indicate that even the uppermost samples must pre-date Zone C10 (VI). The abundance of the pollen of Gramineae and Cyperaceae is probably at least partially due to these groups of plants forming stands in the shallow water beneath which the mud accumulated and cannot therefore be used as zonation criteria. The high values for *Artemisia*, Carophyllaceae, Cruciferae, Compositae and *Empetrum* in the lower part of the composite diagram must indicate some part of the late-Glacial period and, by comparison with the diagrams from Scaleby Moss and Oulton Moss (part II), the upper limit of Zone C8 (III) is best drawn at 135 cm in Series *A*. No further detailed zonation seems justified, but it is evident that the uppermost organic deposit beneath the clay and stones of the warp terrace belongs to the later part of Zone C9 (IV–V).

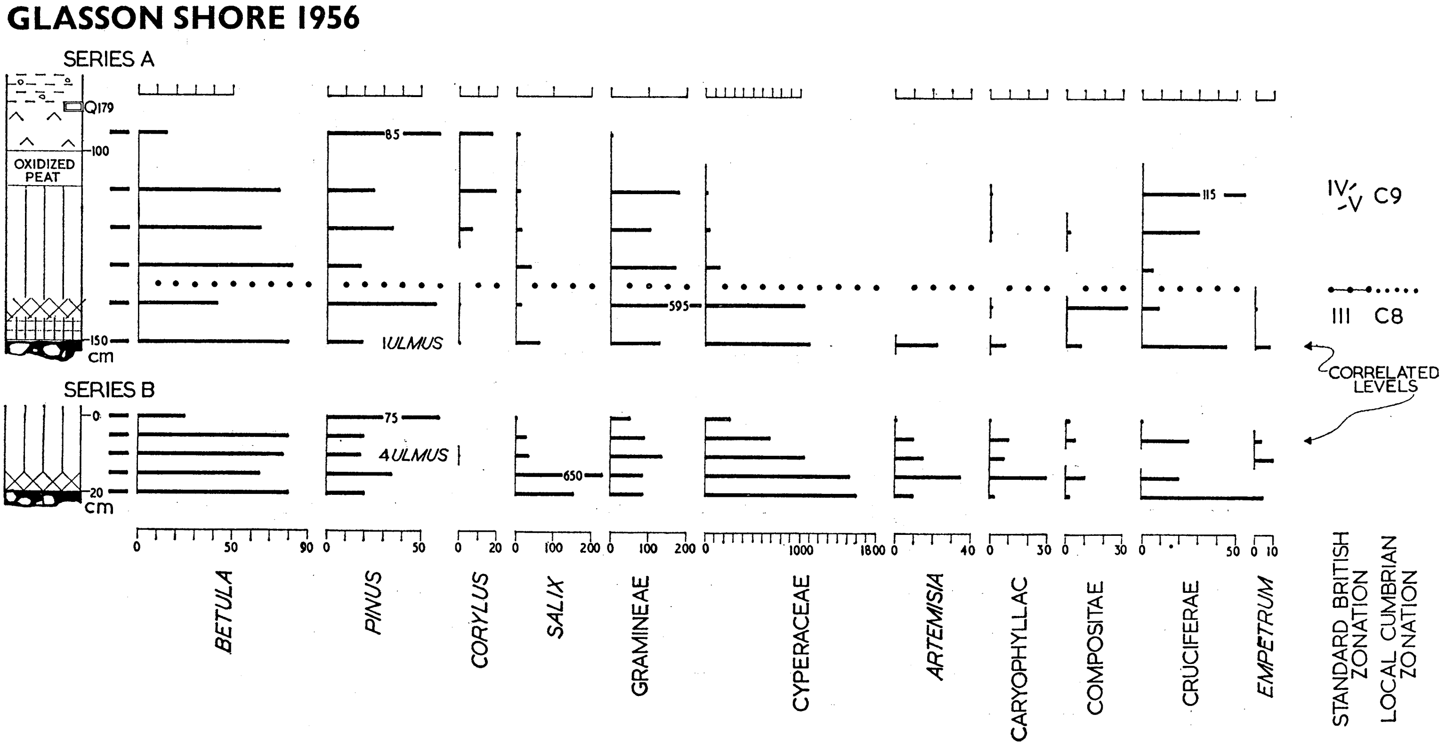


FIGURE 29. Glasson Shore. Pollen diagrams through two sections of the deposits (cf. figure 28).

The ecological development of the site

The organic muds evidently began to accumulate during Zones C7 and C8 (III) in a fairly large, shallow, lake of fresh water in a depression in the boulder clay. The lowest organic mud now lies at 1·3 m (4 ft. 4 in.) O.D. indicating that the mean sea level was at least 4 m (13 ft.) lower toward the end of the late-Glacial period than it is at the present day. The shallow lake was converted into a reed swamp by the overgrowth of sedges and grasses and probably became a damp, shrubby, fen with birch and willow bushes at least over a part of its area. The uppermost muds of the later part of Zone C9 (IV–V) now lie at 2 m ($6\frac{1}{2}$ ft.) O.D. and must imply a mean sea level not higher than -3 m (-10 ft.) O.D. at the time of their formation.

The pebbly clay overlying this mud, the lowest layer of the lower terrace of warp, is a marine deposit. It must date from some time after Zone C9 (IV–V). The sudden stratigraphic change from freshwater fen to marine or estuarine deposits strongly suggests a non-sequence between them. All that can be concluded is that the sea reached a mean level of 5 m ($16\frac{1}{2}$ ft.) O.D. some time after the end of Zone C9 (IV–V). Warp then accumulated to at least 7 m (23 ft.) O.D., the level of the lower terrace, and probably even higher.

Subsequently the level of the sea relative to that of the land must have fallen at least to its present level and possibly lower, a still-stand or a relative rise in the sea accounting for the present erosion of the coastal deposits.

WIGTON

Geography and stratigraphy

Sewerage excavations in 1956 exposed a section of Quaternary deposits at the foot of the north-facing slope of a wide glacial channel between Aikhead and Dockray, about 1 km (½ mile) north of Wigton (Nat. Grid Ref. 256495) at about 21 m (70 ft.) O.D. The precise nature of the deposits varied from point to point in the sections, but the following is a representative description.

Section 2. South-west corner of pit. Zero is ground level.

cm	
0–300	disturbed, false-bedded, sand with gravel at the base
300–305	red silty clay
305–344	grey brown sandy silt with organic fragments and a continuous organic layer at 334–335 cm
344–351	medium brown, laminated, leafy, detritus mud with sand and silt layers and frequent twigs
351–392	intermittent bands of sand, clay and organic fragments
392–395	dark, grey-brown, organic mud with twigs and a *Corylus* nut
395–405	sandy clay with small tree trunk
405+	coarse, sandy, gravel

The basal gravels are rich in erratics and are clearly derived directly or indirectly from the glacial drift. All the deposits above them in this section are undoubtedly fluviatile in origin, the finer grained and organic layers having been laid down in quiet backwaters. Further up the slope of the hillside, these riverine materials are overlaid by almost 2 m (6½ ft.) of red-brown silty clay containing occasional rounded stones and abundant fragments of organic matter. The uppermost 60 cm of this layer is slightly leached and there is some iron oxide accumulation at the base. It is interpreted as a hill-wash from the boulder-clay slopes above, resulting from the undermining of the slope by water or the clearance of woodlands.

Towards the centre of the valley its floor is formed of the uppermost layers of the riverine deposits of the section. The small misfit stream now draining the valley is incised into this material. This strongly suggests that these deposits were laid down during a period of higher base level (probably higher relative sea level) than at present.

Chronology and ecological development of the site

Samples of organic mud from the riverine deposits of Section 2 (above) were examined in the laboratory and the macroscopic plant remains listed in table 9 were recovered. In addition, four vertically superposed samples were submitted to pollen analysis, the results of which are shown in table 10.

The high values for *Alnus* pollen are probably partly the result of local production in strand-line communities but, nevertheless, it seems unlikely that these analyses can date from before Zone C12 (Boreal-Atlantic Transition, VI–VII). The balance of the other arboreal pollen types suggests comparison with Zone C17 (VIIb) at Oulton Moss only 2 km (1 mile) to the north (part II).

TABLE 9. MACROSCOPIC REMAINS FROM WIGTON

species	remains	340–346 cm	389–391 cm
Alnus glutinosa	fr	+	+
A. glutinosa	w	+	+++
Betula pendula or *pubescens*	fr	+	.
Cladium mariscus	fr	+	.
Corylus avellana	n	.	+
Crataegus monogyna	f.st	.	+
Galeopsis tetrahit or *speciosa*	s	+	+
Melandrium rubrum	s	+	.
Ranunculus repens	s	.	+
Urtica dioica	s	.	+

fr = fruit; f.st = fruit stone; n = nut s = seed; w = wood.

TABLE 10. POLLEN ANALYTICAL RESULTS FROM WIGTON

	frequency of pollen types as percentages of total arboreal pollen											
sample level (cm)	*Betula*	*Pinus*	*Ulmus*	*Quercus*	*Alnus*	*Corylus*	*Hedera*	Gramineae	Cyperaceae	*Polypodium*	other Filicales	Varia
330	1	–	–	27	72	31	–	1	1	8	8	1
343	4	1	+	43	52	34	1	2	–	5	9	2
364	5	1	–	15	77	23	3	3	1	8	11	4
392	+	–	+	2	98	5	–	–	–	–	–	–

The Dockray–Aikhead valley is part of a marginal glacial drainage channel now drained westwards by the River Waver and eastwards into the north-west flowing River Wampool. The valley is cut in boulder clay but the gravels exposed at the base of the section may date from late-Glacial times or from a more recent period of redistribution of glacial detritus. Fluviatile aggradation filled the valley to about its present level, probably shortly after the end of Zone C17 (VIIb). Subsequently, boulder clay from the surrounding slopes slumped over the edges of the valley deposits and the modern streams began to cut down into them.

WREAY

GEOGRAPHY AND STRATIGRAPHY

About 3 km (1½ miles) north-north-east of Wreay village, the northward-flowing River Petteril emerges from a gorge cut in Penrith Sandstone into a valley bounded by steep boulder clay slopes. A small tributary valley joins it from the south-west and there a section containing organic deposits is exposed on the west bank of the main river (Nat. Grid Ref. 439509).

Zero is ground level.

cm	
0–20	disturbed upper soil
20–90	grey-brown sandy clay, horizontally bedded, with occasional small pebbles
90–120	dark brown coarse detritus mud with abundant twigs and *Corylus* nuts

Water level at 110 cm

The surface of the sandy clay rises gently up the tributary valley and forms a spread about 0·5 km ($\frac{1}{4}$ mile) wide at about 43 m (130 ft.) O.D. which continues down the main valley and into which the modern river is cutting.

Chronology and ecological development of the site

Samples of mud were collected from levels of 95 and 105 cm below ground surface in the section described above, the analysis of which yielded the results shown in table 11. The high *Alnus* values require these samples to be attributed to some zone younger than C12 (Boreal-Atlantic-Transition, VI–VII). By comparison with diagrams from Scaleby Moss and Oulton Moss (part II) the levels of *Ulmus* and *Quercus* suggest Zone C15 (VIIa) as the nearest equivalent.

Table 11. Pollen analytical results from Wreay

frequency of pollen types as percentages of total arboreal pollen

sample level (cm)	*Betula*	*Pinus*	*Ulmus*	*Quercus*	*Tilia*	*Alnus*	*Corylus*	Gramineae	Cyperaceae	Varia
95	7	1	15	20	2	55	71	6	15	2
105	4	1	12	31	1	51	105	2	63	5

The deposits exposed in the section are all aggradational river deposits. If the pollen analytical correlation is valid it seems that the River Petteril was ponded back sufficiently during the Atlantic period to allow aggradation up to about 39 m (130 ft.) above present sea level. The river is now incising throughout its lower course, and this must imply a fall in base level (probably relative sea level) since the period of aggradation.

THE CHRONOLOGY OF LAND AND SEA LEVEL CHANGE

The stratigraphic and pollen analytical results from Bowness Common, Glasson Moss and Glasson Shore provide some information about changes in relative levels of land and sea in the area.

The indications from Glasson Shore are of a relative sea level rising from below −4 m (−13 ft.) O.D. in Zones C7 and C8 (III), not reaching −3 m (−10 ft.) before the end of Zone C9 (III) but passing +5 m (+16½ ft.) O.D. afterwards. The deposits of Bowness Common and Glasson Moss indicate the achievement of +7·2 m (+24 ft.) O.D. by Zone C13 (early VIIa) and 8·8 m (+28 ft.) O.D. later in the same zone. Thereafter the relative sea level fell to the present situation, evidently punctuated by still-stands or minor rises which cut small terraces in the warps outside the stranded beaches. If the relative fall in sea level from its maximum in Zone C13 to its present position was linear with respect to the radiocarbon time-scale from Scaleby Moss (part II), an assumption of doubtful validity, the still-stand or rise which formed the lower terrace of warp probably dates from about Zone C16 (late VIIa).

The former higher relative level of the sea and its subsequent fall must have had a considerable effect on the drainage régime inland and it is perhaps significant that the fluviatile muds at Wigton, accumulated under conditions of higher water table than at present, do not post-date Zone C17 (early VIIb), whilst the deposits at Wreay indicate a higher water table at least up to Zone C15 (VIIa).

Godwin, Suggate & Willis (1958) have shown that a eustatic rise in sea level, begun by the late-Glacial, was substantially complete by about 3000 B.C. (VIIa–VIIb). This is in harmony with the widely held view that the apparent fall in sea level along north British coasts is the result of isostatic recoil of the land relieved of its load of ice. If, as is usually supposed, the rising level northwards of the raised beach and warp deposits is indicative of increased emergence towards the centre of glaciation, the beginning of the final retreat of the sea might be expected to be registered progressively earlier along the line from the zero isobase of isostatic movement towards the glaciation centre. Radiocarbon dates from peat, and wood enclosed in peat, overlying estuarine deposits around the northern end of Morecambe Bay suggest that the maximum of the marine transgression was probably passed by 4630±144 B.C. (Q260 Godwin & Willis 1961) at Silverdale Moss (Oldfield 1960*a*). However, another determination from the same site indicates a date after 3774±128 B.C. (Q256 Godwin & Willis 1961) and a third a date before 3905±115 B.C. (Q261 Godwin & Willis 1961), whilst from the nearby Helsington Moss (Smith 1959) a date before 3317±120 B.C. (Q85 Godwin & Willis 1961) is suggested. Having regard to the nature of the materials analysed, and to their stratigraphic and geographic positions, it would seem reasonable to conclude that the culmination of the marine transgression at the head of Morecambe Bay probably took place about 4000 B.C., although there is a possibility that it had already happened six or seven hundred years earlier.

The indications of the pollen analytical results are that the marine transgression in the Bowness–Glasson area reached its maximum towards the end of Zone C13 (VIIa) which by comparison with Scaleby Moss (part II) might be expected to have extended from about 5000 B.C. to 4650 B.C. It seems quite likely, therefore, that the greater isostatic recovery in the north did have the effect of accelerating the onset of marine regression by as much as 650 years when compared with the head of Morecambe Bay. Direct comparison of pollen-analytical results from the two areas, however, suggests a more conservative estimate, for overgrowth of the marine clays in Foulshaw Moss and Nichols Moss (Smith 1959) seems to have begun during Zone C14 (VIIa). The modern sea maintains salt marsh in the Solway Firth up to 6 m (20 ft.) O.D., 3·5 m (11 ft.) below the uppermost salt-marsh level beneath Glasson Moss. Silty clay-mud of the kind underlying much of Bowness Common seems not now to accumulate more than about 4·5 m (15 ft.) above mean sea level in the most favoured backwaters, about 4 m (14 ft.) below its uppermost level beneath Bowness Common. These differences in level seem to imply a fall in the relative level of the sea of between 3·5 and 4 m (11 and 14 ft.). This compares moderately well with the vertical difference of 5 m (16 ft.), between the heights of the tops of the raised beach and of the modern storm beach near Bowness. The conclusion seems inescapable that, since Zone C14 time, the mean sea level has fallen at least 3·5 m (11 ft.) and most probably by about 4·5 m (15 ft.). The apparent relative fall in sea level, as judged from the differences between modern storm beach height and the height of the raised beach crest, decreases in a linear manner with distance from Ruthwell, on the north side of the Solway Firth and the most northerly point considered, to Ravenglass, the most southerly point for which observations are available (figure 30). There is therefore no evidence for hinge-line phenomena over this time range, a conclusion broadly in agreement with

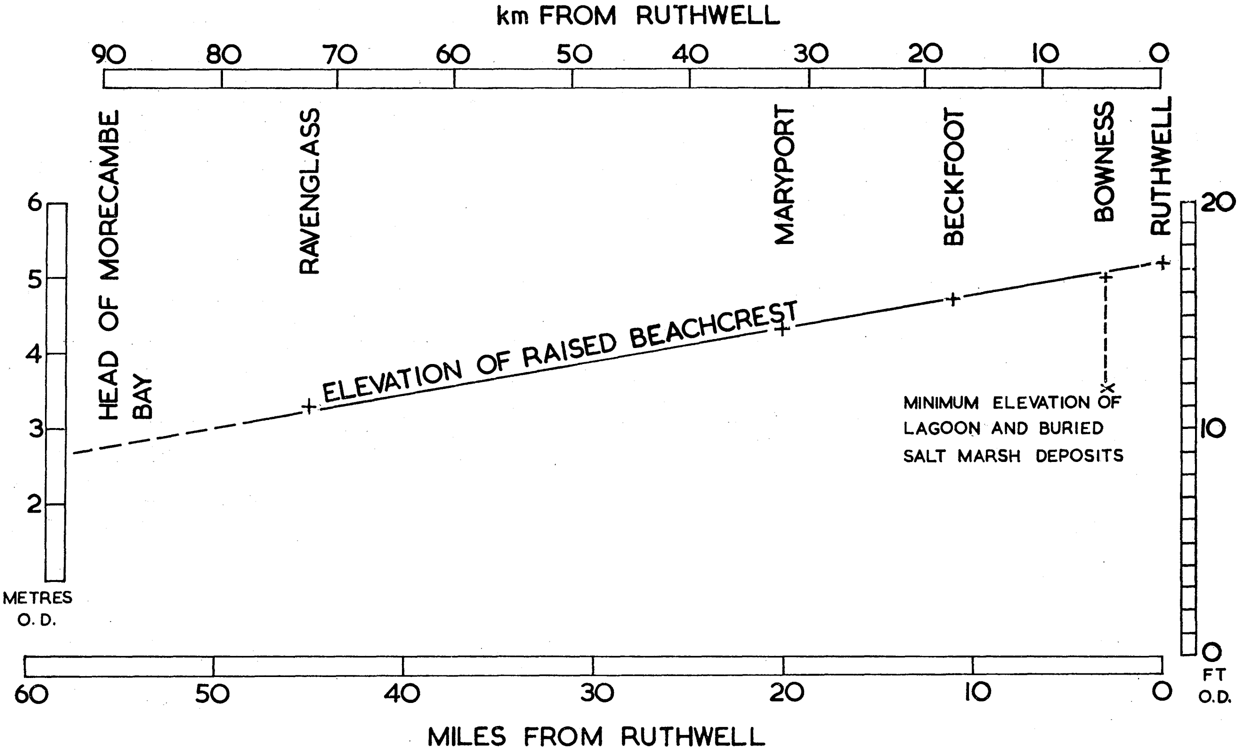


FIGURE 30. Apparent fall in relative sea level since the maximum transgression as documented by apparent elevation of beach and warp deposits southwards from Ruthwell.

Sauramo (1955*a*, *b*) for Scandinavia. The consideration of the vertical distribution of marine and estuarine deposits now protected beneath peat bogs at Bowness Common and Glasson Moss suggests that they may indicate a fall of sea level as much as 1·5 m (5 ft.) less than that indicated by the differences in beach levels. Extrapolation southward of the line for decreasing marine regression suggests a possible fall in relative sea level of 2 to 2·5 m ($6\frac{1}{2}$ to $8\frac{1}{4}$ ft.) since the maximum transgression at the north end of Morecambe Bay. If the same relationship between the levels indicated by beaches and by marine clay deposits can tentatively be assumed, the indications of the marine clays there might be expected to be difficult of interpretation as they might still differ little from mean sea level at the present day (Smith 1959; Oldfield 1960*a*, *b*; Gresswell 1958). The undoubted tilting of the old post-Glacial shore lines along the North Lancashire and Cumberland coasts is in contrast with their horizontality farther north in Scotland (Donner 1959).

Accumulation of consolidated deposits at Oulton Moss (part II) ceased at the beginning of Zone C10 (VI), probably as a result of a rapid rise in regional water table at a time when the sea was still rising over the land. Considerable overgrowth of the lake did not begin again until the end of Zone C12 (VIIa), a time approaching that of the maximum marine transgression when the rate of rise might have slackened. The rate of rise in water level in the Oulton Moss lake increased, however, *after* the time of the maximum marine transgression and, although this might have been due to overgrowth of the outlets once mire vegetation had become established, it nevertheless argues caution in attributing all local changes to one general cause.

Accumulation in Scaleby Moss, the bottom of the basin of which is a little below 33 m (100 ft.) O.D., seems not to have been affected by any changes in ground-water table during the post-Glacial period (part II). It seems likely therefore that the direct effects of the land and sea level changes on the soil conditions of the region were not great outside the area actually flooded and the valleys filled with backed-up water during that period.

At the present day there is little evidence of continuing accumulation along the Solway coast. The weight of evidence from the salt marshes and the lower river valleys is of erosion and incision. This might indicate continued emergence of the land but the nature and amount of this evidence, like that collected by Valentin (1953), are insufficient to transcend the wildly conjectural.

VI. THE PERIOD OF PIONEER VEGETATION

The period of pioneer vegetation in the Cumberland Lowland is defined as that time between the beginnings of deglaciation of the area and the heralding of the establishment of the thermophilous forest trees by the major expansion of *Corylus avellana*. In the early stages of deglaciation the resurgence of ice in the Scottish Readvance corresponded with a period between the Cumbrian Oscillation and the Allerød Oscillation. The correlation of these events with others of a similar nature and chronological position in the British Isles and Western Europe, together with the definition of the boundary between the full- and late-Glacial periods is discussed. The geographical conditions of the period of pioneer vegetation, as well as the constitution and status of the vegetation itself, are inferred from data presented in earlier papers in this series. The variability from place to place induced by local ecological conditions is demonstrated against the background of more general and widespread changes. Finally, an attempt is made to attribute causes to these changes and to estimate the limits of some of the possible climatic determinants from time to time.

Introduction

The purpose of this part is to give an account of the vegetational changes, and of the ecological, climatic and geographical changes with which they were correlated, in the Cumberland Lowland from the time of the earliest plant records (Zone C1, I) to the beginning of the first establishment of closed forest (Zone C10, VI). The data for this synthesis are derived mainly from Scaleby Moss and Oulton Moss, Moorthwaite Moss and Abbot Moss and St Bees (parts II, III and IV).

Chronology

The zonation of the pollen diagrams, according to both local Cumbrian and standard British schemes, depends almost entirely on the relative abundance of tree pollen (particularly *Betula* sp.), of the pollen of particular shrubs (notably *Corylus*) and of the pollen of a number of herbaceous plants which together are thought to indicate open treeless conditions outside the hydroseres of the individual sites investigated. The occurrence of one species or a group of species has not itself been used to characterize a zone, for it is the purpose of the investigation to determine how individual species and recognizable communities contribute to the overall changes referred to above. Within the small region investigated it is likely that this zonation has chronological significance, because it depends very largely on the general regional component of the pollen rain. During this period of pioneer vegetation following the last glaciation, particularly in regions so close to the centres of glaciation that tree-dominated communities were slow to establish, it is hardly to be expected that a fine zonation would prove chronologically valid over a very wide area. Nevertheless, Godwin & Willis (1959*b*) have demonstrated the remarkable synchroneity of the late-Glacial zone boundaries (standard British scheme) in Great Britain and Continental Europe as determined by radiocarbon assay. In the Cumberland Lowland, confidence in the chronological validity of the Cumbrian zonation is gained from the similarity of the radiocarbon datings of Zone C8+upper Zone C7 (Zone γ: upper III) at St Bees, viz. a mean age of 8470 B.C., and the upper part of Zone C8 at Scaleby, viz. 8368 B.C. The correspondence is perhaps even closer than appears, for it is extremely likely, from stratigraphic records, that the wood of the St Bees sample is really specifically from the upper part of Zone C8.

The position of this period of pioneer vegetation in the general deglacial chronology is fixed relatively, by definition, to that time before the establishment of closed forest of thermophilous trees which again seems to have been a roughly synchronous event throughout lowland Western Europe (Kubitzki 1961), i.e. to the late-Glacial, the pre-Boreal and the early part of the Boreal periods. In absolute terms the radiocarbon datings of Zones C5, C7, C8, C8/9, C9 and C10 (Zones II–VI) (Godwin *et al.* 1957; Godwin & Willis 1959*b*)

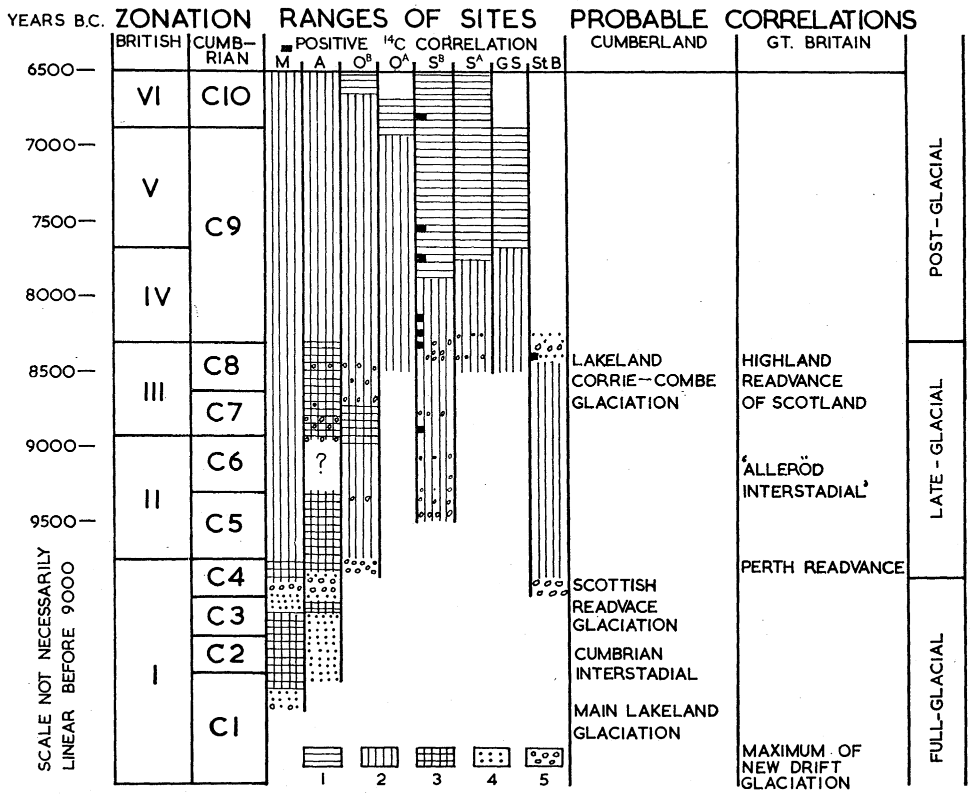


FIGURE 31. The time intervals represented at the sites discussed, with a general indication of the materials accumulated and correlations with pollen-analytical zonations and geological events. Key to symbols: M = Moorthwaite Moss; A = Abbot Moss; O^B = Oulton Moss B; O^A = Oulton Moss A; S^B = Scaleby Moss B; S^A = Scaleby Moss A; G.S. = Glasson Shore; St B. = St Bees; 1 = peat; 2 = organic mud; 3 = clay or clay-mud containing pollen; 4 = clay and silt barren of pollen; 5 = sand and gravel.

confirm this correlation and indicate without any doubt the equivalence of Zones C5 and C6 with the Allerød period and of Zones C7 and C8 with the Younger Dryas Period. The period represented at each of the sites and at Glasson Shore (part V) is shown against the absolute time scale in figure 31. No certain absolute correlation of the earlier zones (C1 to C4) is possible, although it is tempting to find a parallel here with the developments at Star Carr, near Scarborough (Walker & Godwin 1954), Hawes Water, S. Westmorland (Oldfield 1960*b*), Böllingsö, Jutland (Iversen 1942, 1954), Usselo, Holland (van der Hammen 1952*a*) and in Germany (Müller 1953; Firbas, Müller & Münnich 1955; Lang 1952).

The geographical conditions of these early deglacial periods, however, are likely to have been such as to allow the local development of chance-transported plants long before the main climatically determined belts of vegetation had been established over the countryside at large. The presence of these enclaves of vegetation is certain evidence of climatic amelioration since the high glacial and, unless there is positive ecological evidence to the contrary, the end of such a period is most likely to have been caused by local, or general, climatic deterioration resulting in a return to geographic instability. But these phenomena, including the vegetational development, were probably of severely local significance and long-distance chronological correlation of them between sites is inherently unlikely.

Amongst British sites, vegetational fluctuations pre-dating the Allerød period (Zone II, C5 and C6) have only been recorded outside the limit of the Scottish Readvance Glaciation. In the present series of investigations Scaleby and Oulton Mosses were chosen partly in order to determine the dates of first accumulation in the marginal region of Scottish Readvance deposits and these have been shown to be in Zone C5 (II) in both cases. At Whitrig, Berwickshire (Mitchell 1948) and in Scotland (Donner 1957, 1958, 1960; Mitchell 1952) the earliest organic accumulations recorded date from the Allerød period. Geographical considerations make it extremely likely that the hollows of Moorthwaite and Abbot Mosses were available for lacustrine accumulation after the retreat of the Main Glaciation ice. During the maximum of the Scottish Readvance Glaciation, however, the first was completely flooded by a pro-glacial lake whilst the second was probably flooded for part of the time and at other times the recipient of solifluncted materials. Materials attributed to these conditions and to this period overlie pollen-containing lacustrine deposits at both sites and themselves pre-date the beginning of the Allerød period (Zone II, C5). The materials themselves contain pollen, Zone C4 indicating vegetation different from that of preceding (Zones, C2 and C3) and succeeding periods (Zone C5, II). The chronological equation of Zone C4 with the period of maximum effect of the Scottish Readvance around its margins is difficult to avoid. The correlation of the preceding period, best documented at Moorthwaite Moss (Zones C1 to C3), with the Main Glaciation–Scottish Readvance Interstadial follows from this. In order to guard against the use of these data for facile, long-distance, pollen analytic correlation, however, the vegetational changes documented in Zones C1 to C4 will be referred to as the Cumbrian Oscillation, the end of which is equivalent to the beginning of the Allerød Oscillation. The weight of local evidence favours the equation of the Cumbrian Oscillation with the Main Glaciation–Scottish Readvance Interstadial. Local data (Scaleby Moss and Oulton Moss) and evidence from other British sites suggest that the time of the Scottish Readvance marked the end of that part of the deglacial period characterized by geographical instability associated with the local establishment and termination of patches of diverse vegetation and the beginning of the uniformly recognizable and chronologically valid series of late-Glacial and post-Glacial vegetational changes. It is possible that some of these temporary vegetational events might correspond chronologically with positive and relatively large-scale changes in vegetation in continental Europe (e.g. the Bölling Oscillation). But parts of interstadials might so easily be simulated by climatically non-significant vegetational establishment peripheral to the ice front that only independent physical age determinations are likely to provide certain evidence of this.

The end of the 'Hauptwürm-Stadial' in Europe and the beginning of the late-Glacial there is defined by Gross (1957) at the beginning of the ice retreat from the Pomeranian Moraines and the opening of the Oldest Dryas period, pollen analytical Zone Ia (Firbas 1949). On the basis of varve analysis, the Pomeranian glacial stage ended before 14000 B.C. (de Geer 1954); the oldest radiocarbon dates for the Oldest Dryas Period (Ia) do not exceed 13800 ± 800 B.C. (Gross 1957). The beginning of the late-Glacial might therefore be dated at about 14000 B.C. Woldstedt (1956) places the boundary between his 'Mittelwürm' and the late-Glacial toward the end of the first retreat from the Pomeranian Moraine and a chronology similar to the above would also apply. Both these authors include the Bölling as well as the Allerød amongst late-Glacial interstadials.

Van der Hammen (1952*b*, 1957*a*) has defined his 'Pleniglacial'–late-Glacial border by pollen analytical changes occurring at the interface between Older and Younger Coversands in the Netherlands, to which a radiocarbon date of about 11300 B.C. is attributed (van der Hammen 1957*b*). The same geological correlation with the retreat from the Pomeranian Moraine is maintained. Radiocarbon dates of about 10500 B.C. from the 'Oldest-Dryas' (pre-Bölling) material at Usselo (Tauber 1960) are in conformity with this chronology but raise considerable doubt about the chronological equivalence of the 'Oldest-Dryas', 'Bölling', and 'Older Dryas' periods in different parts of continental Europe.

The definition of the full-Glacial–late-Glacial boundary in Great Britain has not been made precisely, other than by location somewhere in pollen analytical Zone I (Godwin 1956). The present data offer two alternatives. If the possibility of the correlation of the Cumbrian Oscillation with the Bölling Interstadial is stressed, the late-Glacial must properly begin in Zone C1 and the Scottish Readvance be relegated to a comparatively insignificant role, correlated with the 'Older Dryas' period and perhaps with van der Hammen's Moraine Line VI (van der Hammen 1957*a*, *b*). On the other hand, if the small pre-Allerød Interstadials are chronologically unreliable it might be more reasonable to define the beginning of the late-Glacial as the beginning of the Allerød interstadial corresponding with the retreat from the Scottish Readvance maximum and the beginning of some regional vegetational stability. This would imply that the Bölling has not yet been recognized separately from the Allerød in Great Britain, in which case the Scottish Readvance would be correlated with the Pomeranian Moraine Stage, or that the Bölling is one of the chronologically unsatisfactory oscillations of the later part of the full-Glacial, in which case the Scottish Readvance would be correlated with the moraine under Bölling. The first alternative would clearly conform to continental European correlation schemes, but the second has the advantage of distinguishing two periods with distinct biogeographic characters. Only further work, and particularly radiocarbon dating, can resolve this problem. In what follows the pollen analytical zones will be used for descriptive purposes and the exact position of the full-Glacial–late-Glacial boundary will not be defined.

Geographical conditions

The 'retreat' of the Main Lakeland Glaciation left sand and gravel spread in Edenside and on the coastal strip south of Egremont. The same may have been true for the rest of the Cumberland Lowland, the present ubiquity of boulder clay at the surface there being the result of the Scottish Readvance Glaciation in one way or another. There is no geological indication of the extent of the retreat of the Main Lakeland Glaciation before the onset of the Scottish Readvance Glaciation (Trotter & Hollingworth 1932*a*). At its maximum, the Scottish Readvance probably contributed further to the outwash gravel and sand around its margins but its retreat is documented by erosional features (overflow channels, etc.) associated with deltaic and similar deposits of very limited extent.

Donner's (1959) data suggest that the isostatic recovery of the land may not have effectively overhauled the eustatic rise of the sea everywhere in Scotland until the time of the Perth Readvance at the end of pollen analytical Zone I (C4). In Cumberland there are no deposits or geographical features attributable to a full-Glacial or late-Glacial transgression so that a marine incursion there exceeding that of the post-Glacial in extent seems unlikely. The bottom of the Oulton Moss basin lies at about modern Ordnance Datum and the lowest point in the boulder clay rim surrounding it can never have been below about 18 m (60 ft.) O.D. The absence of any marine deposit in the late-Glacial sequence there is therefore a fair indication that the sea did not rise so far in comparison with the land after Scottish Readvance time. The data from Glasson Shore do not refer to the earliest periods but from them it is certain that levels within the modern tide range were not affected by marine incursion during the latest part of the late-Glacial and the early post-Glacial (Zones III–V; C8–9). It seems very unlikely, therefore, that the Cumberland Lowland drained to a marine base level relatively higher than that of the present day at any time during the period under discussion. Until the final retreat of the Scottish Readvance ice, however, the region must have had many cold, fresh-water lakes, dammed by glaciers or materials dumped from the ice. This, and the probability of widespread perennially or seasonally frozen ground, must have greatly enhanced the importance of waterlogging of the soil as an inhibitor of plant growth. It is possible that this effect was greatest, on the whole, on the heavy boulder clays of the Carlisle Plain and the coastal strip with their relatively subdued topography, yet the more freely draining sands and gravels of Edenside also had more pronounced topographic variety which led to the impounding of more, if smaller, lakes. It seems important therefore to recognize the probable importance of water logging in the boulder-clay areas but not to underestimate its effects in the sand and gravel regions.

As more of the glacially-determined lakes drained and ground water tables began to fall, the distinction between the boulder clay and sand and gravel areas probably increased. Neither material is likely to have been rich in bases, but it is probable that the boulder clay retained what it had longer than did the sand and gravel in the face of normal leaching processes.

Without much greater knowledge of the distribution of land and sea during the period, it is not very profitable to consider the distribution of vegetation in terms of the geographical contacts of the region. Until after the retreat of the Scottish Readvance Glaciation, the mountains to the north, east and south must have been major barriers to plant movement and a wide lowland corridor between the Lakeland Hills on the east and the rising Irish sea on the west provided the only migration route for vegetation. During the rest of the period it seems very likely that the surrounding mountains were never extensively glaciated although their effectiveness as barriers to tree migration probably persisted through the late-Glacial (Zones II, III, C5 to 8) (Walker 1955*a*, *b*). The lowland corridor would therefore continue to function as the main avenue for encroachment by successive vegetation formations, augmented by broad access from the west which was probably less impeded by sea than at present. In these pioneer phases, therefore, it seems that, apart from the chance dispersal of disseminules over the mountains by high winds or birds, the main sources of vegetation were in the south-west and west and that plants entered Edenside at its northern end.

Between the melting of the last of the Main Glaciation ice at Moorthwaite Moss and Abbot Moss and the onset of the Scottish Readvance, the basins there accumulated silty clay-mud of very low organic content yet containing very little coarse-grain inorganic material. This suggests that, although there was little development of vegetation either in or around the lakes, the surface soil was not sufficiently mobile to move downslope into the lakes. This apparent lack of solifluction may indicate seasonal variations in temperature rarely falling below freezing point, permanently frozen ground, or pronounced continentality of climatic régime. The end of Zone C3 (I) seems to have marked a change in conditions at Moorthwaite Moss and Abbot Moss culminating in the solifluction of coarse sand and gravel from the basin edges into the lakes in Zone C4 (I). These data alone do not allow any closer climatic interpretation than does the silty clay beneath, for a fall in the mean annual temperature, a greater variation about the mean, a periodic rise in the temperature of formerly frozen ground or an increase in the oceanicity of the climate could all result in solifluction. Moreover, only a rise in temperature or a greater oscillation about a consistent mean seem not to be reconcilable with the glacial advance with which the zone seems to have been contemporary.

During Zones C5 and C6 (II) organic muds accumulated at all the sites investigated except Abbot Moss where a clay-mud continued to be laid down, although its organic content was certainly higher than before. At Scaleby Moss and, to a lesser degree, at Oulton Moss occasional bands of coarse sand and even small pebbles in the mud suggest that the banks were not yet free of disturbance. This seems not to have been the experience at Moorthwaite Moss, Abbot Moss and St Bees in spite of the sandier and steeper nature of the surrounding slopes there. It is difficult to avoid the suggestion that this distinction between the boulder-clay sites and the sand and gravel sites is in some way related to differences of soil development and vegetation on the two substrates.

Zones C7 and C8 (III) were associated with solifluction, or at least with increased inwash of coarse sediments, at all sites. At Oulton Moss the organic productivity of the lake evidently fell very considerably during Zone C7, so that the sequence of organic muds was interrupted by the deposition of clay mud. Otherwise there seems to have been little change in the nature of the accumulating materials during these zones and the access of coarse sediments is probably related to changes on the land which did not substantially affect physical conditions in the lakes. This suggests that, although soil temperatures must have fallen below freezing point sufficiently frequently to produce solifluction, the annual period during which the lakes were frozen was not long enough seriously to have inhibited the growth of aquatic plants. Only at Abbot Moss, a site where the lake seems to have been more strongly affected by events on the surrounding slopes throughout its history, is there any good evidence for a depauperation of the aquatic flora during Zone C7 (III). Indeed, at Scaleby Moss, where the aquatic flora had been becoming increasingly poor due to increasing oligotrophy from the beginning of Zone C6 (II), this process was temporarily arrested during Zone C8 (III), presumably as a result of increased base status of the water resulting from the influx of inorganic materials from the banks. The instability of the marginal slopes which resulted in the inwash of inorganic material into the lakes did not reach its greatest development at the same time at all sites considered. At St Bees and Scaleby Moss it was most marked toward the end of Zone C8 (III). At Moorthwaite Moss it extended from the latter part of Zone C7 (III) through Zone C8 (III), but at Abbot Moss it was restricted to Zone C7 (III). At Oulton Moss there seems to have been practically no solifluction, although the change in productivity of the lake itself was restricted to Zone C7. There seems not to have been any direct correlation between topography or soil and the time of greatest instability, and it is possible that the composition of the established vegetation might have been the controlling factor.

The inwash of inorganic materials and accumulation of inorganic sediments, already substantially over at Oulton Moss during Zone C8 (III), ceased at all sites investigated at the beginning of Zone C9 (IV–V). From that time onwards there is no indication in the sediments of the physical conditions of the soils of the surrounding slopes.

Vegetation

Aquatic vegetation

The general development of the hydroseres has been separately described for each site. At Moorthwaite Moss the basin harboured an open pool with varying frequencies of *Myriophyllum alterniflorum* and rare *Nymphaea alba*, *Alisma plantago aquatica* and poor and narrow marginal fens throughout Zones C1 to C8 (I–III). Zone C9 (IV–V) witnessed the beginning of rapid extension of swamp carr and *Sphagnum* rafts into the open water. At Abbot Moss the early history was similar except that the occasional abundance of *Littorella uniflora* suggests longer stretches of gravelly shore and the lesser development of fringing fens. Such fens did develop during Zone C9 (IV–V) but they were unable to extend very fast into the lake, probably because of the very steeply sloping banks. The soil movements of Zones C3 and C4 (I) seem hardly to have affected the aquatic and mire vegetation around these sites. The implication is that the vegetation was already discontinuous and composed of species extremely tolerant of soil movement and, in the case of aquatics, of renewed silting. At Abbot Moss there is a slight suggestion of depauperation during Zone C8 (III), but in general the emergent vegetation seems to have been substantially unaffected.

The hydrosere which began to develop in Zone C5 (II) at Scaleby Moss seems soon to have become sufficiently acid to have reduced the marginal fens to sedge stands by Zone C7, by which time *Sphagnum* had also become well established in the shallow water. This development was not checked until the end of Zone C8 (III), but then the soil movements around the banks, probably associated with freezing for long periods of each year, effectively broke up these mires and reduced them to discontinuous stands of sedges and *Filipendula ulmaria*. These species rapidly took advantage of the changed conditions from the beginning of Zone C9 (IV–V), however, and quickly converted the whole lake to a sedge swamp, the distrophy of which can be gauged by the rapidity with which first *Menthyanthes* and then *Sphagnum* spp. invaded it. A *Sphagnum* bog was established by the latter part of Zone C 9 (IV–V). Although the shallowness of the basin accounts mainly for this early eradication of the lake, the early development of acidity was probably largely the result of conditions on the surrounding land which reduced the base status of the water draining into the hollow.

The shores of Oulton Moss lake seem to have had poorly developed marginal fens during Zone C 5 (II) which began to extend somewhat in Zone C 6 (II). These seem to have disappeared almost entirely during Zone C 7 (III), however, in spite of the apparent lack of solifluction movement, and not to have been re-established until the very end of Zone C 8 (III). In Zone C 9 the tempo of hydrosere development was enormously quickened and poor sedge swamps with *Menyanthes trifoliata* and *Sphagnum* spp. quickly expanded from the edges. In Zone C 10 *Sphagnum–Calluna* bog seems to have replaced the more base-demanding communities almost entirely.

At St Bees open water and fringing swamps predominated during Zone C 4 (I) and were replaced by sedge swamp early during Zone C 5 (II). During Zones C 5, C 6 and early C 7 (II–III) *Salix* bushes were established in the close vicinity of the pool, even though they may not have been directly associated with the hydrosere. Beginning in C 7 and continuing into C 8 (III) the marginal fens seem to have become richer, *Filipendula ulmaria* becoming particularly common until the abrupt deposition of solifluction gravel cut off the record of change. There are strong similarities between events at Scaleby Moss and St Bees, probably due to the shallowness of both basins. The greatest similarity is the way in which the fairly advanced and well established swamp and fen communities at both sites were relatively unresponsive to any environmental changes during Zones C 7 and C 8 (III) until the moderately violent solifluction at the end of the period.

A slightly different approach to the same problem is illustrated in figure 32. The data presented there refer to the actual sites of pollen analytical series and not to the lakes or mires as wholes. These records do not show the greatest advancement of the hydroseres at the sites but only the stages reached at a particular point in each basin, usually a point of deep water in relation to the basin as a whole. The separate sites are not comparable in terms of water depth, distance from a shore, position relative to wind drift and so on, yet their indications of the direction and time of change may have some significance. The characterization of the stages of the hydrosere (0 to 5) has been simplified and some stages have been omitted entirely (e.g. *Ranunculus* sect. *Batrachium* dominance). It is recognized that progress through the stages shown is a reflexion of a complex of variables, notably water depth and base status. The sequence of stages is intended to show only the direction in which hydroseres developed during, and after, the period under discussion. On these criteria it is clear that some deterioration in conditions was being reflected in the increasing barrenness of the lakes at Moorthwaite Moss, Abbot Moss and Oulton Moss from the beginning of Zone C 7 (III), whilst at Scaleby Moss and St Bees the hydrosere continued to progress. Indeed, a recovery was beginning at the former three sites by the time (late C 8) the most serious effects were experienced at the other two. Once the inhibitions of Zones C 7 and C 8 (III) were passed, however, hydrosere development was very quick and nowhere more rapid than at Scaleby Moss.

Land vegetation

Some aspects of the pollen diagrams from the five sites under consideration are summarized in figures, 33 to 37. In these figures a common vertical scale has been adopted, mainly derived from the indications of late-Glacial radiocarbon dates. A purely arbitrary span has been allotted to Zones C1 to C4 inclusive. Finally, sample levels from the separate

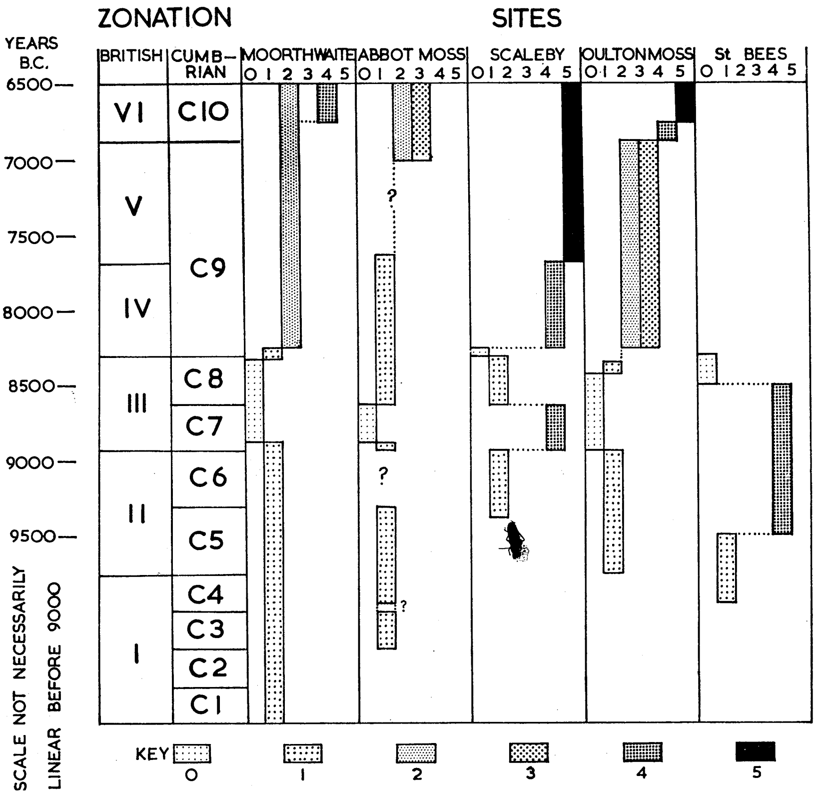


FIGURE 32. The stages of hydrosere development achieved at the points of the main pollen diagrams at the sites discussed correlated with pollen analytical zones. Each stage is represented by a numbered column picked out in specific shading for clarity. Key to columns and symbols: 0 = area apparently barren of phanerogams; 1 = area dominated by *Myriophyllum alterniflorum* sometimes with *Potamogeton praelongus* and *Alisma plantago-aquatica*; 2 = area dominated by *Nymphaea alba*; 3 = area dominated by *Potamogeton natans*; 4 = area dominated by *Phragmites communis* or *Carex* spp; 5 = area dominated by *Sphagnum* spp. The co-dominance of plants of different stages is indicated by the horizontal coincidence of their symbols.

sites have been distributed through each separate zone at distances proportional to their original intervals at the points of sampling. The pollen frequencies shown on these diagrams have been recalculated on a new basis. The new 'pollen sum' comprises all commonly occurring trees and shrubs (*Betula* spp., *Pinus*, *Corylus*, *Salix*, *Juniperus*), and herbs judged to be at least mainly occupying mineral soils at most sites, and the Ericales (*Calluna*, *Empetrum*). The herb section is divided into two components, viz. those types thought to derive from drier soils (Gramineae, *Artemisia*, *Rumex*, *Plantago*, *Helianthemum*, *Armeria*) and the others more likely to represent communities on damper soils (Cyperaceae, Caryophyllaceae (*Stellaria* type), Compositae, Cruciferae, Rubiaceae, Umbelliferae, Chenopodiaceae). In the first section of each diagram the curves for each tree and shrub type are shown, individual frequencies being calculated as percentages of the 'pollen sum', as well as composite curves for each of the four main sections of the pollen rain referred to above calculated on the same basis. The second part of each diagram illustrates frequency variations within the group of herbs characteristic of dry ground, values being percentages

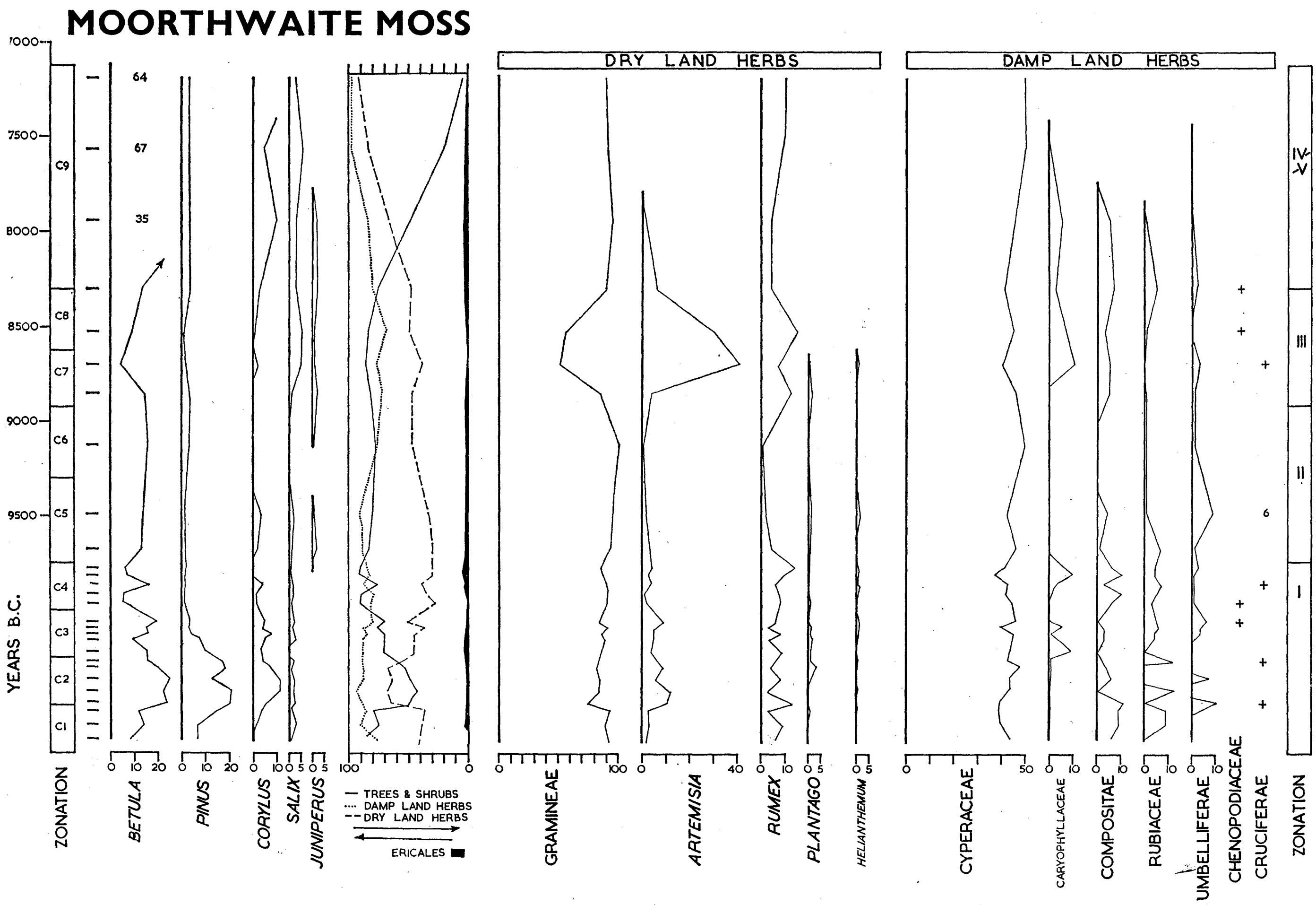


FIGURE 33. Selected pollen curves from the lower deposits at Moorthwaite Moss, recalculated from the data presented in diagram Moorthwaite Moss B. The vertical scale has been adjusted to give an approximately linear timescale above 9000 B.C. as indicated by the radiocarbon dates from Scaleby Moss. Frequencies of trees and shrubs and of the groups trees + shrubs, dry-land herbs, damp-land herbs and Ericales are expressed as percentages of the total of these four groups. Frequencies of individual pollen types within the groups dry-land herbs and damp-land herbs are expressed as percentages of the total for the appropriate group alone. The zonation is derived from the diagram Moorthwaite Moss B.

of the total for this group of pollen types alone. In the third section the herbs of damp ground are similarly treated. The original zonation of this part of each of the original pollen diagrams (parts II to IV) was based on the changing balance between the curves for the pollen of trees and shrubs and that for the sum of herbaceous heliophytes of dry land. Variations of individual curves amongst the herbs did not contribute to that primary zonation so that any correlation now established between such individual curves or between them and the primary chronology is not simply the result of the original zonation technique.

The most striking feature of these diagrams is the dominance of herb pollen over that of trees and shrubs from Zone C4 to Zone C8 inclusive. In view of the criteria on which the herbaceous components have been selected this must imply a predominantly open,

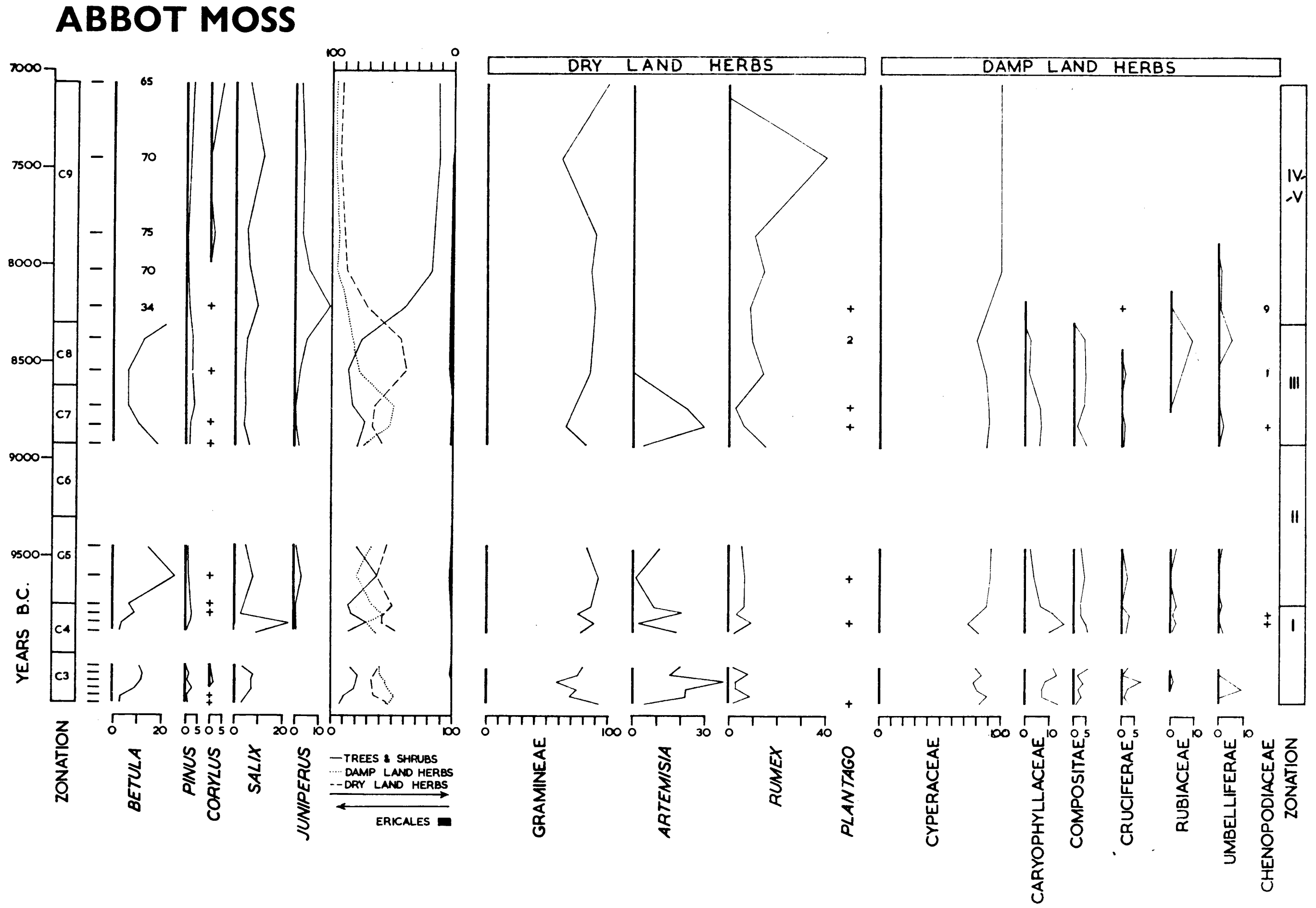


FIGURE 34. Selected pollen curves from the lower deposits at Abbot Moss, recalculated from data presented in diagram Abbot Moss B. For explanation of scales see legend to figure 33.

almost treeless, vegetation throughout the late-Glacial period. During Zone C2 (Moorthwaite), however, there is evidence for more abundant tree growth.

The rate at which the herbaceous communities were replaced by trees and shrubs varied from site to site. At Oulton Moss and Abbot Moss it was rapid, the new balance being established from the old in 100 to 400 years. At Scaleby and Moorthwaite the same change was hardly completely accomplished in 1000 years, particularly at the former site where the development of *Empetrum*-rich vegetation clearly competed with the spread of the birch. These differences may well have been related to the availability of moderately steep and certainly well-drained slopes in the immediate vicinity of the Oulton Moss and Abbot Moss sites which provided better conditions for the rapid extension of woodlands than did the flatter, and presumably more frequently water-logged, lands immediately surrounding Scaleby and Moorthwaite. Whatever the causative factors, this difference emphasizes the frequently exemplified fact of the patchiness of vegetation in this region at any time during this pioneer period.

A further point of similarity between all these diagrams is the way in which all the trees and shrubs which were available at a given site increased their frequencies more or less simultaneously during Zone C5. This must imply a lack of competition between these plants all of which must have been within the limits of their climatic tolerance and readily available from outside the area or from isolated stands within it. Indeed, competition

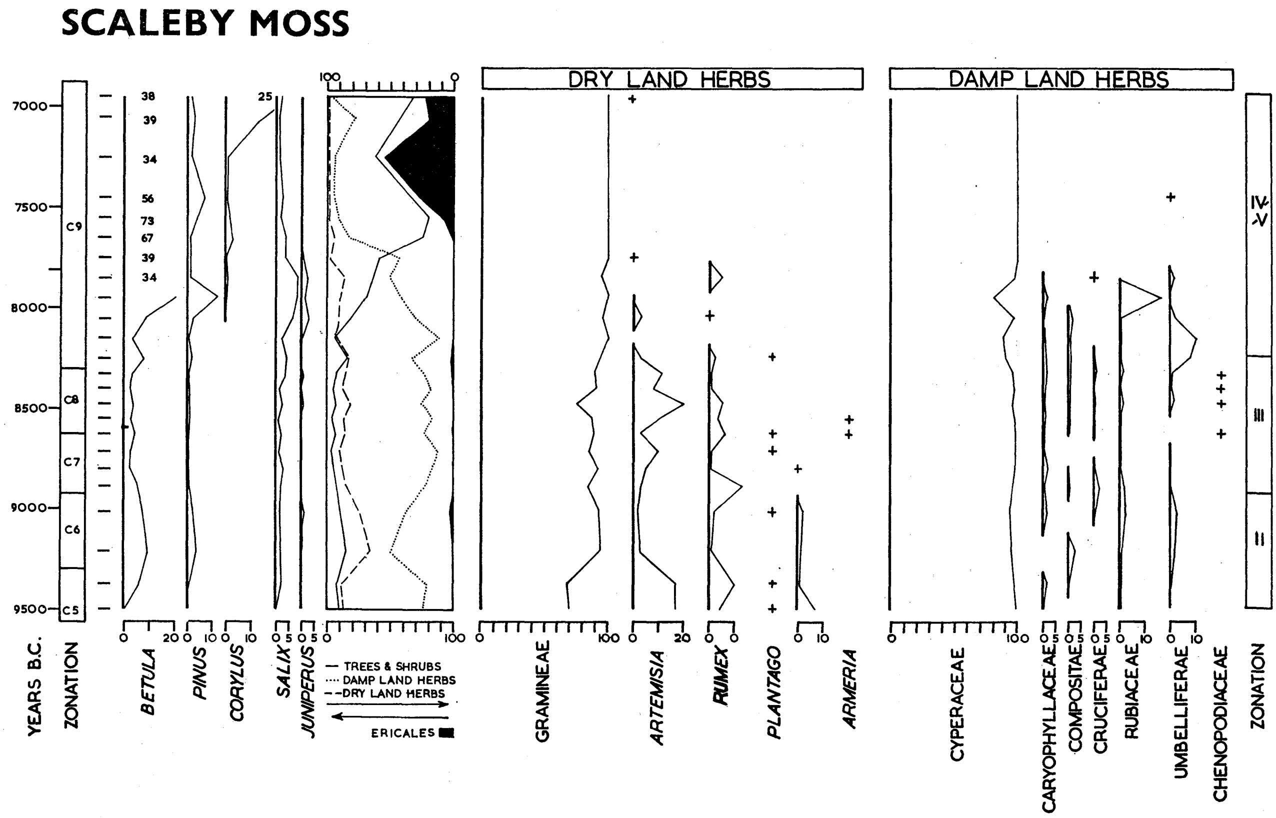


FIGURE 35. Selected pollen curves from the lower deposits at Scaleby Moss, recalculated from data presented in diagram Scaleby Moss B. For explanation of scales see legend to figure 33.

between the woody plants seems not to have been important until the end of Zone C9 when *Corylus* began its great expansion. Except at Scaleby, where the sequence was complicated by the *Empetrum* development, the shade-intolerant *Juniperus* persisted at least from the middle of Zone C8 throughout Zone C9 until the expansion of *Corylus* began. This, as well as the parallel but less continuous occurrence of many herbs (e.g. *Rumex* cf. *acetosella*), must indicate that the high birch frequencies of Zone C9 are not necessarily to be interpreted as the product of closed uniform birch forest but of birch woodland with abundant clearings and open places fringed, or totally occupied, by juniper and willow thickets and into which the hazel could quickly penetrate at the end of Zone C9, or, in the case of Moorthwaite and Oulton Mosses, considerably earlier.

The different rates of change in the pollen diagrams already noted in the rise of the woody plants in Zone C9 is apparently significant and not entirely due to differences in sampling interval. At Oulton and St Bees major changes are usually fairly abrupt, at Abbot Moss they are less so, although still well marked, whilst at Scaleby and Moorthwaite a particular change takes longer to achieve and, as a corollary, is usually less well defined for a number of otherwise separate phenomena necessarily overlap. This difference between sites may simply be a reflexion of the relative contributions of the local and regional components to the pollen rain they received; the more restricted the area from which most of the pollen was derived the more strongly would a vegetation change affecting a particular size of unit be reflected. Sites receiving a larger regional component, on the other

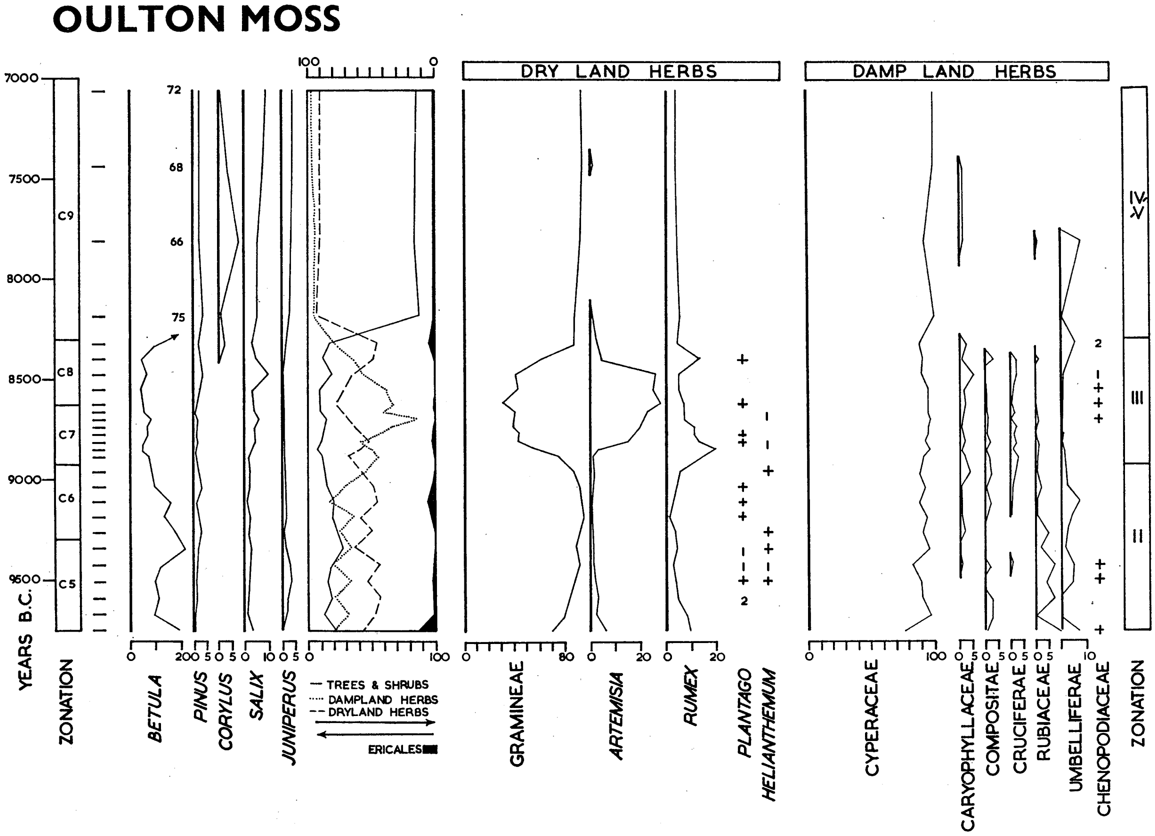


FIGURE 36. Selected pollen curves from the lower deposits at Oulton Moss, recalculated from data presented in diagram Oulton Moss B. For explanation of scales see legend to figure 33.

hand, would always have the effects of local changes 'damped' by this regional stability. St Bees is a site which was strongly affected by extremely local changes, but there seems little reason for supposing that Oulton Moss should have been more influenced in this way than, say, Moorthwaite Moss in spite of the differences in soil, altitude and regional topography which surround the sites. It may well be that it was these very geographical differences which determined the rates of vegetation reaction, the lower, topographically more uniform and more clayey, areas supporting more stable vegetation than the hilly areas with lighter soils.

Another marked distinction between diagrams is in the overall relative importance of dry soil and damp soil herbs. At Moorthwaite herbs of the dry soil group preponderate throughout. At Scaleby the opposite is true whilst at Oulton, Abbot Moss and St Bees there are distinct changes in the relationship from level to level. Nor are these differences solely the result of differences in the proportions of Gramineae and Cyperaceae pollen; for example, when expressed as percentages of total tree pollen, *Artemisia* and *Rumex* are much more abundant at Moorthwaite than at Scaleby. The abundance of flat clay-soil areas around the shallow basin of Scaleby Moss probably explains the importance of the more damp-tolerant herbs there, but it is difficult to attribute the Moorthwaite dominance of dry-demanding herbs to a similar cause. The alternation of dominance between the two groups at the other sites is believed to be related to changes in the physical stability of the soil, an argument which is developed below (p. 159).

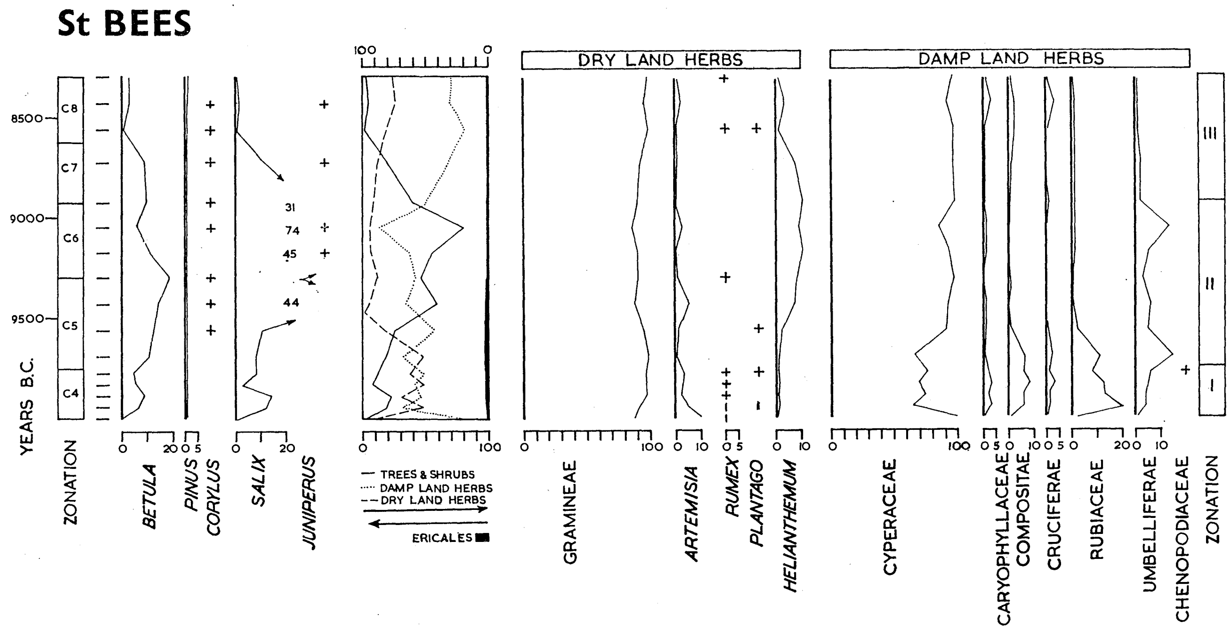


FIGURE 37. Selected pollen curves from the deposits at St Bees, recalculated from data presented in diagram St Bees 1950. For explanation of scales see legend to figure 33.

Throughout the periods represented there (Zones C4 to C8) the pollen diagram from St Bees contrasts markedly with those from the other sites in the relative abundance of *Salix* pollen, the relative scarcity of pollen of *Pinus* and *Juniperus*, and in the composition of the component representing communities of drier soils, in which *Artemisia* and *Rumex* cf. *acetosella* are relatively insignificant whilst *Helianthemum* is very important. The abundance of *Salix* pollen is attributed to the participation of this genus in hydroseral changes at the site whilst the apparent low frequencies of *Pinus* and *Juniperus* may be only the statistical concomitant of this over-representation. The unique balance amongst the herbs, however, is probably to be explained by the greater initial base-status of the drifts in this region, to reach which much of the ice must have passed over a tract of carboniferous limestone or the bed of the former Irish Sea. (Eastwood *et al.* 1931). Those edaphic conditions would certainly have contributed to the success of *Helianthemum* (Proctor 1958) and would also account for the two records of *Poterium sanguisorba*.

Within the framework of these general observations, and using evidence from all the pollen diagrams and from macroscopic identifications from these sites, the sequence and pattern of vegetation development during this pioneer period will be described.

During the Cumbrian Oscillation (Zones C1 to C4 inclusive) the vegetation appears to have been predominantly herbaceous. A wide variety of genera are represented in the pollen diagrams (e.g. *Artemisia, Rumex, Filipendula, Thalictrum, Campanula, Armeria, Koenigia*), but it is difficult to associate these in distinct ecological groups except by picking out those most characteristic of drier soils. This is the group which suffered most at the expansion of *Betula* and *Pinus* which characterizes Zone C2 and which almost certainly represents a greater extension of woodland areas than occurred at any subsequent time during the late-Glacial period. It is notable that *Juniperus* is not recorded before the end of Zone C4. It seems very likely that Zone C1 was a period of more or less complete vegetation cover most of which was herbaceous and susceptible to rapid and ephemeral change induced by physical changes which must have been relatively frequent during the early topographical and soil development following the retreat of the Main Glaciation ice. *Betula* (probably including *B. nana*) and *Pinus* were already present and expanded onto the drier, and probably more stable, soils toward the end of the zone to establish the vegetation pattern diagnostic of Zone C2. In that zone there is little doubt that the vegetation was still predominantly herbaceous but with a liberal scatter of birch and pine, although how far these were of severely local significance is difficult to judge from a single diagram from this period. In Zone C3 these trees, particularly the pine, became less frequent and the vegetation seems virtually to have returned to its Zone C1 condition, although the presence of *B. pubescens* as well as *B. nana* is confirmed by macroscopic records from Abbot Moss. These changes continued into Zone C4 in which the plants of drier soils, notably Gramineae and *Rumex* cf. *acetosella*, seem to have assumed even greater importance amongst the herbaceous flora, at least in the upper part of the zone at Moorthwaite and, to a lesser extent, at Abbot Moss. At St Bees, whilst *Rumex* was certainly more frequent in Zone C4 than subsequently, and *Artemisia* was frequent, the Gramineae were the main contributors to the drier soil herbaceous group. *Betula pubescens* is again recorded from Abbot Moss in this zone certainly indicating that the tree birches did not completely vacate the region, whilst the critical pollen diagram from St Bees illustrates the relative abundance of *B. nana* at the time. It is difficult to avoid interpreting these records as indicative of an open tundra- or steppe-like vegetation with rare tree birches, and possibly pines, in particularly favoured localities (by reason of their aspect or soil) but more extensive shrubberies of dwarf birch and willows. It may well have been a vegetation in which communities were not well differentiated for, as in the earlier zones, there is little of the interplay between the curves for various species which becomes such a characteristic of the following late-Glacial period.

During Zone C5, which is correlated with the beginning of the Allerød period, birches became generally more abundant over the whole region. There is only one positive record of *B. pubescens* (Abbot Moss) but the very low values for *B. nana* pollen at St Bees suggest that the increase of birch pollen in the pollen rain was due largely to the expansion of tree birches. This was maintained during Zone C6 as is confirmed by macroscopic material of *B. pubescens* at Oulton and Scaleby. *B. nana* was still there, however, as records from the same two sites confirm. The pine expanded later (i.e. in Zone C6) and less markedly than the birch and this might indicate only a slight extension of its range beyond its Zone C4 refugia or alternatively a greater vigour within those same areas. Nevertheless, a positive increase in the success of *Pinus* is indicated throughout the region except in the locality of

St Bees and there can be no doubt that the tree was in Cumberland in late-Glacial time, although apparently less abundant then than at the height of the Cumbrian Oscillation. *Juniperus* first assumed importance in Zone C5 and where any significant variations in its pollen curve can be identified (viz. Oulton and Moorthwaite) seems to have been more abundant then than in Zone C6. This might be explained by supposing the shrub to have occupied sites during C5 which were subsequently colonized by birch or pine. But if the relative frequencies of pollen types are any guide, these sites must have been few for herbaceous pollen is still clearly dominant. *Empetrum* must have been an infrequent, but widely distributed, plant during this time.

At Scaleby and St Bees, herbs of damp soil seem to have been a more important component of the vegetation than those of dry habitats, in marked contrast with the localities of Moorthwaite, Oulton and Abbot Mosses. At St Bees this might be the result of local over-representation of Cyperaceae from aquatic sedges in the pollen diagram but the stratigraphy at Scaleby suggests that the sedge pollen there must have been produced by stands of plants on the hard ground beyond the limits of the hydrosere. This would be consistent with the flatter clay-soil areas in the Scaleby locality which have already been contrasted with the well drained, steeper, slopes around Oulton and Abbot Mosses. These, like the gentler hills beyond the immediate margins of Moorthwaite Moss, must have been covered by a predominantly grassy vegetation in which ruderals played a relatively insignificant part.

Zones C5 and C6, therefore, witnessed the extension of wooded areas and the stabilization of the remaining herbaceous swards. It is possible that small patches of more or less closed woodland did develop but the weight of evidence suggests that these were uncommon. Differentiation between the drier slopes with closed grassland and the damp hollows with poor fens became pronounced.

Already towards the end of Zone C6 the frequency of the trees had begun to decrease and the equilibrium which had taken between 300 and 400 years to achieve and had been maintained for a rather shorter period, took only about 150 years to disrupt. At all the sites the transition from Zone C6 to C7 which marks this disruption is characterized by a diminution in importance of the pollen of trees and a disproportionate increase in the importance of pollen of damp soil herbs when compared with that of herbs from drier habitats. This phase of apparent success of damp soil plants was of variable duration: about 250 years at Abbot Moss, 500 years at Oulton, probably about 750 years at Moorthwaite and St Bees and of the order of 1000 years at Scaleby. This is perhaps yet another example of the influence of topography on the rate of vegetational change. The genera contributing to this expansion varied from site to site and from time to time but undoubtedly the Cyperaceae played the major part. At the time of the initiation of these changes at all sites except St Bees, the dry-soil component of the herbaceous vegetation began a sequence of highly characteristic changes. The frequencies of grass pollen in the diagrams from the drier sites fall whilst those of *Rumex* cf. *acetosella* sustain temporary, but well marked maxima. This is followed by a considerable increase in the frequency of *Artemisia* pollen together with a more or less pronounced fall in the relative level of *Rumex*. At Oulton the parallelism between the rising curves of *Rumex* and damp soil herbs is especially pronounced and suggests that both were expanding simultaneously and into areas formerly occupied by closed grassland or open birch woodland. The phase of abundant *Artemisia* lasted at Oulton beyond the maximum of damp-soil herbs into the period in which the overall recovery of the dry-soil herbs took place. At other sites this persistence is less clearly marked but there can be no doubt that this was a period of pronounced vegetational instability in which a reassortment of communities took place. At Oulton, Moorthwaite and Abbot Moss the final diminution of *Artemisia* coincided with a small maximum of *Rumex* cf. *acetosella* which then remained as a fairly small but consistent component of the herbaceous vegetation until the great expansion of the forest trees in Zone C 10. At Scaleby, however, there seems to have been no significant recovery of this species. This sequence of vegetation changes lasted for different periods of time at different sites, from about 600 years at Abbot Moss and Oulton to about 900 years at Scaleby. The points on the pollen diagrams from which these time periods are assessed are, of course, more or less arbitrarily determined because the changes from one phase to another are rarely sharply defined. Nevertheless, they do fairly illustrate the differences in the time taken for a given series of similar changes in different localities. Nor was the new equilibrium *reached* at the same time at all the sites. At Abbot Moss a new, if temporary, equilibrium was established by about 8500 B.C., at Oulton and Moorthwaite by about 8250 B.C. whilst at Scaleby it was delayed until 8000 B.C. if, indeed, it was ever achieved at all.

The period of vegetational instability broadly covers Zones C 7 and C 8 (III) although, as has been seen, at any one time different localities might have reached different stages of change. The instability is further emphasized by the records of *Armeria vulgaris* (Scaleby, Oulton, Abbot Moss, Moorthwaite) *Koenigia islandica* (Oulton) and *Salix herbacea* (Scaleby) from the two zones.

The performance of both pine and birch clearly deteriorated throughout the region at the beginning of Zone C 7 (III) as did that of juniper at sites where it had been of some significance before. Amongst the woody plants, only *Salix* seems to have become more abundant at all sites except Scaleby (from which leaves of *S. herbacea* are recorded!). This might be significant in view of the increased importance of herbs tolerant of damp soil at the same time. But the diminution in the trees was sometimes short-lived (e.g. Abbot Moss), nor was its minimum correlated with any particular stage of the changes within the herbaceous communities (cf. Oulton and Abbot Moss). It seems quite possible, therefore, that the environmental factor depressing the trees was different from that directly affecting the re-assortment of the herbaceous communities.

The recovery of the trees which began during the latter part of this predominantly herbaceous period was restricted almost entirely to *Betula* by the end of Zone C 8, *Pinus* having by then assumed the subordinate role which it was to keep throughout the rest of the pioneer period at all sites except Glasson Shore. Moreover, although *Juniperus* might have begun to increase contemporarily with *Betula* at some sites (Oulton, Abbot Moss) it nowhere reached its highest or most consistent values until the expansion of the birch was well advanced. The different rates at which birch woodland expanded during Zone C 9 have already been noted. The early stages of this expansion were often accompanied by a marked increase in the frequency of *Juniperus* (e.g. Abbot Moss, Scaleby Moss). This was not long maintained, however, suggesting that *Betula* quickly came to occupy sites first colonized by *Juniperus* which was thereby shaded out. However, the continued presence of *Juniperus* in considerable frequency throughout Zone C9 (Abbot Moss, Oulton) or well into the zone (Scaleby, Moorthwaite) strongly suggests that the birch cover was never complete, that continuous tree birch forests were not established. Further indications of the same fact lie in the low but consistently maintained pollen frequencies of Gramineae and *Rumex acetosella* throughout the zone and the occasional records of *Campanula*, *Polemonium*, *Artemisia*, *Plantago maritima* and *Ophioglossum*. In addition *Corylus avellana*, which can hardly have been fertile under a closed birch canopy, attained considerable importance at Oulton and Moorthwaite. At Oulton Moss a new equilibrium was clearly established by about 8100 B.C. and at Abbot Moss by 8000 B.C. At Moorthwaite the trees gained supremacy considerably more slowly, whilst at Scaleby they came into competition for available ground with *Empetrum* cf. *nigrum* by about 7600 B.C. Indeed a steady state was not achieved at these last two sites until after the expansion of *Corylus* and the establishment of more thermophilous trees at about 6900 B.C.

Empetrum had clearly been present throughout the late-Glacial period in the region as a whole, although usually rare and probably restricted to small areas of base-poor sand or rocky outcrops. Its great importance in the pollen diagram from Scaleby between 7500 and 7000 B.C. must indicate the presence of extensive *Empetrum*-heaths in the immediate locality, however, and of ecological conditions which allowed it successfully to compete with birch woodlands. It is difficult to imagine what these conditions might have been but the apparent acidification of the Scaleby lake waters at about 7500 B.C. might indicate that the surrounding soil was by this time already accumulating organic material in the A horizon due to waterlogging of the extensive clayey flats.

During Zone C9, therefore, the vegetation of the region remained patchy. The mosaic was composed of open-canopy birch woodlands with *Juniperus*, *Corylus* or *Salix* along the margins and in the clearings, together with grasslands and with herb-rich communities on the less stable soils and *Empetrum* in places where soil acidity had quickly developed. These treeless patches were encroached upon by woodlands within which, however, *Corylus* continued to play an ever more important role largely at the expense of herbs and *Salix* and, in some cases, of *Juniperus*. It was *Corylus*, too, which was able quickly to take advantage of the reduction in success of the birches in some localities, which coincided with the first establishment of *Ulmus* and *Quercus* and which brought to an end this period of pioneer vegetation at about 6800 B.C.

The emphasis has been on differences of detail between localities, usually on differences in rate of change and of duration of a particular equilibrium state once established. The sequences of changes appear to have been roughly parallel if not strictly coincident from site to site. Because of local ecological conditions a general change may not have affected a particular locality until a further development had taken place elsewhere. The greater impact of the latter on the slowly changing vegetation of the locality in question might have foreshortened the intermediate stage there in comparison with other localities. From time to time, however, the following major tendencies were exhibited by the vegetation as a whole and demand general explanation:

(*a*) During Zone C2 of the Cumbrian Oscillation *Betula* and *Pinus* trees became an important component of the vegetation, only to lose this importance in the subsequent Zones C3 and C4.

(*b*) On the whole, the relatively undifferentiated or widely diverse herbaceous communities of the later part of the Cumbrian Oscillation and the beginning of the Allerød Oscillation (Zones C3 and C4) were replaced by more stable communities in Zones C5 and C6 in which trees were of moderate importance.

(*c*) This stability was broken down in a particularly characteristic way during the latter part of Zone C6 and Zone C7.

(*d*) With the opening of Zone C9, trees began to play a more important part in the vegetation cover than ever before, in spite of their incomplete cover and differences in the degrees of their importance from site to site.

The causes of vegetational change

None of the plants recorded from the full- and late-Glacial periods demand high arctic or alpine conditions in their modern habitats although some, e.g. *Betula nana*, *Salix herbacea*, *Montia fontana*, *Koenigia islandica*, are certainly tolerant of such conditions. Only two species of this group seem likely to be limited in their southerly extension by high maximum summer temperatures, viz. *Koenigia islandica* (24 °C) and *Salix herbacea* (26 °C) (Dahl 1951), the limits for which are modified to 21 to 22 °C and 23 to 25 °C respectively for the British Isles (Conolly 1961). Many more seem to be intolerant of extreme cold at the present day, e.g. *Armeria maritima*, *Helianthemum chamaecistus*, *Hippophae rhamnoides*, *Schoenoplectus lacustris*, *Potamogeton trichoides*. The time available from the first certain macroscopic record of *Betula pubescens* in Zone C3 at Abbot Moss until the end of the late-Glacial period was certainly adequate for a much greater development of birch woodlands than the pollen diagrams indicate. A major ecological factor must have inhibited them. In view of the suitability of all other ecological conditions for their spread it is difficult to avoid ascribing their failure to a climatic check. At the present day *B. pubescens* seems to be tolerant of both oceanic and continental climates but reaches its northern limit at the 10 °C July isotherm. It therefore seems necessary to assume low summer temperatures during some parts of the full- and late-Glacial periods.

In Zone C1 at Moorthwaite Moss there are no records other than those of *Helianthemum* and *Empetrum*, *Betula* and *Pinus* which impose restrictions on a climatic interpretation. In the general vegetational and sedimentary context the *Pinus* frequencies are difficult of interpretation but neither these nor the tree birch pollen records are sufficiently substantial to indicate summer temperatures often exceeding 10 °C. The *Helianthemum* record, however, though represented by only a few pollen grains, suggests that winter temperatures were not extreme, i.e. consistently below −2 °C (Proctor 1956). Such conditions would not prevent the local growth of the oceanic *Empetrum nigrum*. Moreover, they do not necessarily imply serious physical disturbance of the soil as a result of freeze-thaw action, a fact which corresponds well with the apparent continuity of the herbaceous vegetation cover and the lack of accumulation of solifluctED material into the basin. The plants of Zone C2 are neither more nor less restrictive on climatic interpretation except that the increase in real abundance of *Betula* and *Pinus* pollen must indicate a climatic amelioration, probably a small rise in the maximum summer temperature, whilst the relative abundance of the latter might suggest less oceanic conditions than applied at other times.

The records from Zone C3 are hardly more diagnostic. Although the falls in *Betula* and *Pinus* pollen curves at Moorthwaite Moss imply a return to more exacting temperature conditions, the records of *Koenigia islandica* and *Armeria maritima* at Abbot Moss only impose a maximum possible summer temperature of 24 °C (Dahl 1951) and a minimum winter temperature of −8 °C (Iversen 1940) respectively. The continued presence of *Helianthemum* indicates the infrequency of extreme winter temperatures. This zone has been correlated with the Scottish Readvance glaciation and culminated in severe solifluction movements at both Moorthwaite Moss and Abbot Moss. The vegetation data, whilst allowing a cooling of the climate during this period and possibly a slight decrease in continentality, do not require high arctic conditions to have pertained around the edge of the Scottish Readvance ice. The vegetation seems to indicate a mean January minimum somewhat above Manley's estimate of 16 °F (−9 °C) for inland Lake District at this stage (Manley 1951, 1953).

Similar conditions seem to have continued into Zone C4. In the latter part of this zone, which is thought to have been contemporary with the final melting of the Scottish Readvance ice, changes began which continued through Zone C5 and culminated in Zone C6. The pollen analytical evidence strongly favours a climatic amelioration during this period which allowed first the tree birch (*B. pubescens* at St Bees, Oulton, Scaleby and Abbot Moss) and then the pine to become more frequent. During the first half of Zone C6, summer temperatures must commonly have exceeded 12 °C (cf. Iversen 1954). *Juniperus*, first recorded in Zone C4, became generally significant in Zone C5 but at some sites (e.g. Oulton) it suffered a setback in Zone C6. The absolute frequencies of this pollen type are never high however, and if the diminutions in Zone C6 are correctly interpreted as the result of competition with trees for favourable sites, *Juniperus* cannot have formed very extensive thickets of tall bushes except in particularly favoured spots. According to Iversen's (1954) interpretation of juniper ecology this might imply that many otherwise suitable habitats were still snow-covered in winter. *Hippophaë rhamnoides* is recorded from Zones C5 and C6 at Oulton and the actual growth of this plant in the north-west of England at this time is confirmed from other sites (Walker 1955*a*; Smith 1958; Oldfield 1960*b*). This plant's intolerance of snow cover (Iversen 1954) might seem to contradict the tentative conclusions derived from the relatively low absolute frequencies of *Juniperus* pollen, but the steep, well-drained, south-facing slope bordering parts of Oulton Moss might well have provided a habitat suitable for *Hippophaë* whilst the less favoured areas were subject to long snow lie. It is also significant in this respect that *Hippophaë* is frost-resistant (Pearson & Rogers 1962). At the other extreme, *Polemonium coeruleum* at the same site need not indicate intense cold; Pigott (1958) has shown that north-east aspect and damp soil are sufficient for the success of this species in the uplands of the Midlands and the north of England at the present day. Moreover, *Helianthemum* cf. *chamaecistus* was present at all sites except Abbot Moss indicating the general infrequency of very cold winters. The occurrence of *Poterium sanguisorba* at St Bees is doubtless a reflexion of the base status of the local soils but it must also imply summer temperatures above those of the sub-Arctic (cf. Averdieck & Döbling 1959; Firbas 1954), for it hardly extends beyond 60 °N in Scandinavia now (Meusel 1943; Hulten 1950). Amongst the water- and mire-plants *Littorella uniflora* indicates temperatures at least as high as in the sub-arctic (Samuelsson

1934) whilst *Typha latifolia* is said to require summer temperatures of 14 °C (Iversen 1954, cf. Casparie & van Zeist 1960) and *Potamogeton trichoides* today only just reaches Southern Sweden (Samuelsson 1934; Hulten 1950) and Scotland (Clapham *et al.* 1952). It is possible that summer temperatures were only a little lower than at present in the Cumberland Lowland. The general climatic indications for this period, therefore, are of an amelioration in which the summer temperatures increased markedly whilst the winters remained cold enough for much of the considerable precipitation to fall as snow. Such a régime, which need have involved little regular freezing of the ground, would accord well with the absence of solifluction material in the basins and the beginnings of organic accumulation there. The expansion of the trees, however, was clearly inhibited more than the supposed summer temperature levels demand, and this might have been the effect of long, if comparatively warm, winters. It might also have been an effect of severe wind blast which would be likely to have modified the success of trees and shrubs more than that of herbaceous plants. The overall implication that summer temperatures improved more than did winter temperatures is in agreement with Manley's (1951, 1953) estimates of a rise of 7 °F (4 °C) in July mean but of only 1 °F (0·5 °C) in January mean. Frost-thaw movement of the ground and the establishment of permafrost are inimical to the development of a continuous and stable vegetation (Benninghoff 1952). The conditions suggested for the Allerød period in this region, on the contrary, seem likely to have been conducive to the formation of a more or less complete herbaceous cover, with the consequent stabilization of the ground surface.

A new vegetational instability had already begun during the latter part of Zone C6 and continued through Zone C7 into Zone C8. There was a small but regional diminution in the success of trees, suggestive of a slight climatic deterioration of some kind. *Juniperus* was also less frequent than before, indicating that areas newly vacated by trees were not reoccupied by *Juniperus* presumably, although not necessarily, because of some climatic limitation such as low temperature or exposure to cold winds. The herbaceous plants do not indicate any marked *temperature* changes from the immediately preceding period. *Helianthemum* cf. *chamaecistus* was much diminished, however, even at St Bees, suggesting the possibility of a decrease in mean maximum winter temperature below −2 °C. *Armeria maritima*, which is recorded from all sites except St Bees, remains witness to the oceanicity of the climate, as does *Littorella uniflora*. *Typha latifolia* is recorded from Scaleby Moss and Abbot Moss and, although *Potamogeton trichoides* is not recorded, *Schoenoplectus lacustris* and *Ranunculus flammula* (not ssp. *reptans* (L.) Syme) at Scaleby and *Sagittaria sagittifolia* at Oulton hardly allow arctic conditions in the region at that time (Hulten 1950; Iversen 1954). On the other hand, *Koenigia islandica* (Oulton) and *Salix herbacea* (Scaleby) are both arctic plants but their known temperature requirements only indicate summer maxima below about 22 °C in Britain (Conolly 1961). The minimal temperature changes required between the height of the Allerød period and the most rigorous conditions of Zones C7 and C8 (III) seem to be a lowering of the maximum summer and minimum winter temperatures by a very small amount. Yet pronounced changes in the pattern of herbaceous vegetation took place which suggest (*a*) an increased area of effectively wet soil, and (*b*) a complete disruption of the dry-soil communities which remained leading to the unprecedented abundance of the ruderal *Artemisia* there. An associated indication of soil conditions at the time is the accumulation of limited solifluction materials in all the basins investigated. If winter temperatures fell sufficiently to induce moderately frequent winter freezing of the ground water and the formation of patterned ground, this would almost certainly inhibit the free drainage of soil water during the summer thaws, even in areas formerly well drained. The areas most favoured for drainage would still be disturbed and the growth of ruderals would be encouraged there at the expense of continuous turf. It is significant that the period of greatest accumulation of solifluction material in the basins, although different at each site, is contemporaneous at all except Scaleby with the greatest abundance of *Artemisia* on dry land. In the lakes themselves, only Oulton seems to have become generally productive at this time whilst at Scaleby the access of solifluction material seems temporarily to have arrested the development of oligotrophy. Nevertheless, at all the points from which the pollen diagrams are drawn there is positive evidence of the depauperation of the phanerogamic flora at some time during Zones C 7 and C 8 perhaps implying a small temperature change which was insufficient to affect the rest of the aquatic fauna and flora. It seems that all the recorded vegetational and stratigraphic changes during Zones C 7 and C 8 (III) can be accounted for by a small fall in winter temperatures enough to produce periodic freeze and thaw of the ground and resultant solifluction movements. The climatic indications of individual species, such as they are, suggest winter temperatures commonly falling below −2 °C but rarely exceeding −8 °C and summer temperatures regularly falling below 10 °C, perhaps for only a relatively short period, and frequently rising to about 14 °C in favoured localities. Manley (1951, 1953) does not require such a fall in winter temperatures but reaches a somewhat similar conclusion about the fall in mean maximum summer temperatures between the Allerød and the post-Allerød climatic deterioration. His modification of these conclusions for the north-west of England particularly (Manley 1959), seems to be in much closer agreement with the present vegetational interpretation.

In Zone C 9 richly organic mud accumulated at all the sites and the hydroseres at the points of pollen analysis progressed without any apparent environmental check.

Except at Scaleby, where the events of the early post-Glacial were more complex, the herbaceous vegetation had hardly gained stability before it was substantially replaced by trees and shrubs. Apart from the record of *Betula nana* pollen at Scaleby, none of the plants recorded from the zone require climatic conditions more rigorous than those found in the Cumberland Lowland today. It is only necessary, therefore, to try to assess the degree and rate of the climatic amelioration implied. Continuous forests were not immediately established although the components were available in profusion. The temporary abundance of *Juniperus*, as well as its continued frequency later, must imply the growth of juniper thickets independent of snow cover. The expansion of *Betula pubescens* indicates the early achievement of mean summer maxima considerably above 10 °C.

During Zone C 9, *Corylus avellana* certainly became established early in some localities but not until the end of the zone did it expand very markedly. Tree cover was not complete so that competition for sites is unlikely to have inhibited its spread: it seems likely that temperature conditions restricted it to more favoured localities. This would imply that mean July temperatures did not generally exceed about 15 °C over the region as a whole. This condition does not conflict with the known tolerance of any of the other plants recorded from the zone, although possibly somewhat marginal for *Pilularia globulifera*. Winter temperatures are difficult to assess, even approximately, during this period. It is clear from the behaviour of *Juniperus*, as well as from that of *Corylus*, that snow did not lie long in winter. This may have been a result of pronounced oceanicity of the climate with relatively mild winters. As *Corylus* was established during this period, if only in favoured localities, it is difficult to imagine that the development of closed *Betula pubescens* forest was inhibited by a climatic factor alone. The climate cannot have been sufficiently favourable for tree growth for its effects to overcome the selective effects of local edaphic conditions, particularly where communities were already established which were particularly well adapted to both climatic and edaphic conditions. The differences in rate of expansion of the birch woodlands at the different sites, and particularly the success of *Empetrum* cf. *nigrum* at Scaleby, might be attributable to this edaphic differentiation. *Empetrum* cf. *nigrum* is also an indicator of the pronounced oceanicity of the climate at the time (Jessen 1949; Smith 1961).

The opening of Zone C10 (VI) at about 7000 B.C. was marked by a great expansion in the abundance of *Corylus avellana* which must indicate a complete lack of climatic inhibition and mean maximum summer temperatures of at least 15 °C and an absence of late spring frosts. The climatic amelioration from the middle of Zone C8 until the end of Zone C9, a period of about 1500 years, need not have been great in order to account for the vegetation changes and, if it was not great, it evidently progressed slowly. The rapid and marked change took place at about 7000 B.C., a change of which those trees and shrubs already established within the region in a pioneer role were able most quickly to take advantage.

The determinants of vegetation change during the full- and late-Glacial and early post-Glacial periods were primarily climatic changes of small magnitude which nevertheless crossed and recrossed the tolerance thresholds of communities and individual species, causing an almost continuous reassortment of these communities both directly and by affecting soil conditions. At different localities aspect, soil conditions and the nature of the established vegetation modified the effects of the overall climatic trends.

The general vegetation pattern of the British Isles

The place of the Cumberland Lowland in the developing vegetation pattern of the British Isles is best appreciated by comparing the record there with those from critically zoned sites elsewhere omitting those within the larger upland masses. The sites considered are Drymen (Donner 1957), Garscadden Mains (Mitchell 1952; Donner 1957), Cannons Lough (Smith 1961 *b*), Neasham (Blackburn 1952), Witherslack Hall and Helton Tarn (Smith 1958), Skelsmergh Tarn (Walker 1955 *a*), Hawes Water (Oldfield 1960 *b*), Star Carr (Walker & Godwin 1954), Moss Lake (Godwin 1959), Aby (Suggate & West 1959) and Hockham Mere (Godwin & Tallentire 1951). These authors' own interpretations of their diagrams have been accepted and comparisons attempted using the general British zonation scheme without subdivision.

Even the latter part of Zone I has not been widely documented in the British Isles. Nowhere, however, was closed woodland established then and the vegetation was at the best dominated by herbs with occasional shrubberies and rare pioneer trees. At this stage the vegetation of the Cumberland Lowland seems to have been quite undifferentiated from that of the rest of Lowland Britain.

In Zone II, however, some regional differentiation of vegetation can be discerned. From East Anglia to Cumberland birch woodlands were established, their continuity roughly decreasing from East Anglia and Lincolnshire, where pine was also undoubtedly established, towards the north-west where, in all but the most favoured niches, herbaceous and shrub-dominated communities still remained of paramount importance. Beyond, in Northern Ireland and Southern Scotland, treeless communities still predominated. At this time, therefore, the Cumberland Lowland was in the van of tree migration.

During Zone III, whilst trees seem to have been less successful than before all over the region considered with the exception of the Hawes Water basin, extension of herbaceous communities seems to have been most marked in the north of England. At most sites all elements of the Zone II vegetation seem to have persisted, many in a drastically reduced condition. At Cannons Lough in Northern Ireland shrubs and possibly rare birch trees became established, suggesting that their former absence might have been due solely to lack of time for migration from farther south and east.

At Hockham Mere it is evident that the expansion of the birch to form closed forests was rapidly accomplished at the beginning of the post-Glacial period, and the same is true of the Star Carr region. Farther west there seems to have been considerable variation from site to site. At Moss Lake, Witherslack Hall and Helton Tarn the rate of closure of the forest seems to have been intermediate between that already referred to and the fairly slow spread documented in the Cumberland Lowland and at Cannons Lough. At Hawes Water, Skelsmergh Tarn and Drymen forests seem to have been quickly established. It may be conjectured that climatic conditions on the whole were less conducive to forest development in the north-west but that their effects were offset to some extent by other peculiarly favourable ecological conditions (e.g. soil, aspect) in many localities. The generally greater abundance of the hazel in early post-Glacial time in the north and west might well have been a direct reflexion of a climatic gradient but it might also have been due to the more open nature of the vegetation already established there which allowed the hazel ample opportunity to establish and flower profusely before the arrival of the true forest trees.

VII. THE POST-GLACIAL FOREST PERIOD

The post-Glacial forest period in the Cumberland Lowland opened with the rapid expansion of *Corylus* into the former *Betula* woodlands at about 7000 B.C. quickly followed by *Ulmus* and *Quercus*. It came to an end shortly after 4000 B.C. when the forests became less continuous as a result of a number of factors. During the intervening period of 3000 years the most remarkable event was the expansion of *Alnus glutinosa*, which is attributed to a climatic cause. The slower changes in the balance between the other forest components are attributed to normal ecological processes under oceanic conditions.

Introduction

The purpose of this part is to give an account of the vegetational changes, and of the ecological, climatic and geographical changes with which they were correlated, in the Cumberland Lowland from the beginning of the establishment of closed forest (Zone C10, VI) until the beginnings of its disruption (Zone C15, VIIa). The data for this synthesis are derived mainly from Scaleby Moss and Oulton Moss, Moorthwaite Moss and Abbot Moss, Ehenside Tarn and Bowness Common (parts II, to V).

Chronology

The zonation of the pollen diagrams, according to both local Cumbrian and standard British schemes, depends on the relative abundance of the pollen of the different trees and shrubs, although the beginning and end of the period are also marked by the virtual anihilation and subsequent reappearance in the diagrams of the pollen of shade-intolerant, dry-land herbs. Amongst the tree pollen curves, particular value has been attached to the behaviour of those representing trees least likely to have contributed to hydroseres, viz. *Pinus*, *Ulmus* and *Quercus*. *Tilia cordata* and *Fagus sylvatica* are represented by only a few pollen grains, the occurrence of which has not been used for zonation purposes.

A tentative absolute chronology for this period is provided by the radiocarbon dates from Scaleby Moss. The beginning of Zone C20 (VI) is dated at about 7000 B.C. and the end of Zone C15 (VIIa) at about 4000 B.C. The period corresponds with the greater part of the 'Boreal' and 'Atlantic' periods of the commonly used terminology.

Geographical conditions

The forest cover over most of the Cumberland Lowland can be assumed to have reduced to a minimum the systematic disturbance of the surface soil. Processes of soil development and accumulation almost certainly predominated. The upper courses of many rivers and streams, however, probably changed continuously, if moderately slowly, as the glacial drifts which contained them were eroded. In the lower reaches, whilst the same process undoubtedly occurred, the dominant factor in determining stream activity was the changing relationship of land and sea levels. It has been shown (part V) that before the end of Zone C9 (V) the sea level stood more than 3 m (10 ft.) below its present level but that by the end of Zone C13 (VIIa) it was 8·8 m (28 ft.) above its present level. Thereafter, the relative sea level fell to its present position punctuated by still-stands and possibly by slight resurgences, one of which possibly dates from about Zone C16 (VIIa). The evidence shows that the direct effects of this marine transgression did not extend far beyond the raised terraces of 'warp' now left in the lower river valleys and the fairly broad coastal strip of estuarine or marine clay and silt now partially overgrown by raised bogs. Accumulation at Oulton Moss seems to have been directly affected as it certainly was in the Bowness Common area. Scaleby Moss basin, however, seems to have been sufficiently high to avoid these effects. Nevertheless, the water table in the coastal region must have risen steadily until the end of Zone C13 and thereafter have fallen slightly to the end of the period under consideration. This might well have induced changes in the vegetation of the coastal region which did not occur further inland beyond the vertical range of these effects. Moreover, it seems likely that from about 5500 B.C., when the coast line probably stood at about its present position, the shore line communities themselves might have contributed to the pollen rain at Oulton Moss, Scaleby Moss and Bowness Common and, in smaller degree, Ehenside Tarn. Until after the maximum of the marine transgression the coastline was presumably eroding and the special habitats created (e.g. mudflats, sandbanks, beaches) would be less important then than during the stages of regression. During the transgression, however, the widening sea would present an increasingly effective barrier to plant migration from the south-west, although the lowland strip around the western edge of the Lakeland hills would never be completely cut.

During Zones C9 and C10 (IV–V–VI) the mountain ranges to the north, east and south of the Cumberland Lowland were undoubtedly covered by forest or woodland over their greater part (Godwin & Clapham 1951; Pearson 1960; Walker 1955*b*; Walker 1965*b*). Blanket bog development probably began there in Zone C12 and continued with increasing momentum throughout the rest of the period under consideration. There is no reason to suppose that these ranges offered any serious obstacle to the migration of trees into the Cumberland Lowland.

Hydrosere development

There is little regional parallelism in the development of hydroseres during this period, each site being affected most strongly by strictly local conditions. Although *Sphagnum*-dominated bogs grew at Scaleby, Oulton and Moorthwaite by Zone C12 and at Bowness and Glasson by Zone C15, their surfaces were still below the water-table of the surrounding land and therefore not readily susceptible to any small changes in precipitation. Only Ehenside Tarn lacks evidence of acidification during the period although at Abbot Moss this is not very positive until Zone C16. At Bowness and Glasson, and to a much lesser extent at Scaleby, this tendency was probably partly the result of rather small catchments on mineral soil draining into relatively large areas of swamp, the base content of the richest drainage water being insufficient to offset the acid products of the breakdown of dead vegetation under waterlogged conditions. At Oulton, Moorthwaite and, later, at Abbot Moss, however, the change took place in a large reservoir of open water surrounded by fringing vegetation into which a considerable volume of drainage water must regularly have discharged. The development of oligotrophy under these circumstances argues base-poor drainage water which in turn suggests the development of leached and acid soils on the surrounding slopes.

At Oulton Moss, Bowness Common and Glasson Moss the details of hydrosere development are most readily explicable as the local results of the marine incursion and its subsequent regression, followed by the overgrowth of outlets and the general impedence of free drainage by vegetation. At Moorthwaite Moss and Ehenside Tarn, sites unaffected by these changes during this period, there is some slight evidence for lower water levels in Zones C12 and C13 than at earlier times. Abbot Moss, a much deeper basin, and Scaleby Moss, by then an established bog, show no indication of such a change which was therefore without any regional climatic significance.

The contribution of trees and shrubs to the hydroseres varied greatly from site to site. At Scaleby they were of no significance. At Oulton Moss and Ehenside Tarn they never extended beyond the margins. At Bowness Common fen woodlands were only locally established but at Glasson Moss, where drainage conditions were probably better, an incomplete cover of *Alnus glutinosa* woodland formed a distinct stage in the mire development, probably during Zone C15 (VIIa). At Moorthwaite Moss and in the shallower parts of Abbot Moss woodlands of the swamp carr type were important, at least during Zones C10 to C12 (VI) and from C14 (VIIa) onwards respectively. It may have been the establishment of a drier type of fen woodland in Zone C12 which reduced accumulation at Moorthwaite Moss until true bog conditions developed in Zone C19 (VIIb).

The one similarity between all the sites, other than Ehenside Tarn, during this period was the tendency for open water, eutrophic, lakes to progress towards oligotrophy and the final establishment of *Sphagnum*-dominated bogs, with or without an intercalated fen woodland stage. There is no indication of any development from fen woodlands towards the vegetation of the dry land of the time.

The flora

Some aspects of the ecology of the principal trees and shrubs of the period must be considered before the pollen diagrams can be interpreted in terms of a vegetation pattern.

Betula pubescens

Although *B. verrucosa* was recorded from Zones C13 to C15 at Ehenside Tarn, Zone C10 at Moorthwaite Moss and Zone C14 at Abbot Moss, macroscopic remains of *B. pubescens* were far more abundant and widespread, so that there can be little doubt that the latter was the important birch of the post-Glacial forest period. *B. pubescens* grows northward to regions within the 10 °C July isotherm and within its range behaves as a dominant of stable communities as well as a plant of transitional conditions in both hydroseres and xeroseres. Birch fruits are primarily wind dispersed, those of *B. alba* having been recorded 9 m (30 yd) from a parent tree whilst seedlings have been found as far as 148 m (489 yd) from their reputed parents (Ridley 1930). Having fallen, the fruits are undoubtedly transported further by ground winds and rainwash and, more particularly, by flotation. Their resistance to waterlogging is uncertain but is not so great as that of *Alnus* fruits. Firbas (1949) supposes a migration rate of about 1 km/year to be possible in birch. Seedlings and young trees, whilst intensely light-demanding, are well able to survive on all but the most waterlogged soils and these characteristics, together with its short generation time and light seeds, account for the species' success as a pioneer plant. Even mature trees are intolerant of shade and rapidly succumb in competition with high forest trees. In fens, although it may not tolerate the most persistently inundated parts, it may often grow and reproduce on sedge or grass tussocks rising above a more regularly flooded area. On bogs it will establish on drier tussock tops and will commonly form continuous woodlands on peat only the upper layers of which are frequently not waterlogged. The birch is tolerant of highly acid soil but is not so successful on very basic soil.

Ulmus glabra

Although the taxonomy, geography, and ecology of *Ulmus* species in Britain is not clear, there seems little doubt that *Ulmus glabra* Huds., and possibly particularly *U. glabra* spp. *montana* (Stokes) Lindquist, was the main contributor to the post-Glacial forests of the north of England (Firbas 1949; Godwin 1956). It does not now form woodlands there. The subspecies is spontaneous just north of the arctic circle (Lindquist 1932) in Western Norway and the species limit declines latitudinally across Scandinavia to 62° N in Finland (Firbas 1949). The elm grows best on rich deep loams and clays under which conditions it is more shade-tolerant than the oaks. Competition between oaks and elm within their climatic limits, if it favours the former, is therefore likely to be the result of soil changes. Firbas (1949) suggests a generation time of 30 to 40 years but positive data on migration rates seem to be lacking.

Quercus spp.

Although *Quercus petraea* is today the commoner oak in the Cumberland Lowland *Q. robur* is widely distributed there and an assessment of the status of oak woodlands in the past must therefore take into account the probable presence of both species. According to Jones (1959), *Q. petraea* is the principle oak of the west of Great Britain and the one most frequently growing as a forest tree. In Europe, *Q. petraea* tends to grow on upper slopes and hilltops whilst *Q. robur* is at its best on lower slopes and in valleys. The latter also prefers moister, heavier, more basic, soils and is more tolerant of waterlogging than the former. (Rubner 1953). Consequently, *Q. robur* is more likely to grow with *Ulmus* spp. than is *Q. petraea*. *Q. petraea* is more shade-tolerant than *Q. robur*, the former regenerating best in woodlands, the latter in open places. There is no substantial difference in the northern limit of the two species in Great Britain, although in Norway *Q. petraea* is more strictly coastal and extends only to about 61° N in contrast to the second species which reaches 63° N. Both species are tolerant of greater winter cold than normally occurs in Great Britain and their northern limit appears to be more closely associated with low summer temperatures, July means below about 13 °C being limiting. Oak trees growing in open situations may produce fruit at an average age of about 25 years. In forest-growing trees a comparable figure would be about 40 years. A long, warm, growing season is necessary to ensure a good seed crop. Acorns are susceptible to frost and their intentional burial by the animals which disperse them, or their accidental covering with litter, is of great importance in their winter protection. Seedlings are frequently found about 250 m from the parent tree, so that a migration rate of oaks into fairly open pioneer woodlands of 1 km in 100 years is easily possible. Firbas (1949) indicates much greater possible migration rates and under very favourable conditions advances of as much as 1 km/year do not seem totally impossible. Seedlings of either species will not continue to grow well in very dense shade beyond their first season and in this are superior to *Betula* and *Fraxinus* but inferior to *Ulmus*. The physical conditions of the Cumberland Lowland during the post-Glacial period would therefore have been adequate for the growth of either or both oak species. It is evident that forests were established and it may be, therefore, that, particularly away from the valley floors, *Quercus petraea* was the commoner species. Nevertheless, *Q. robur* probably grew in the valleys on the heavier soil.

Alnus glutinosa

McVean (1953) has pointed out that although the southern and eastern limits of this species may be controlled by insufficient rainfall there is no evident correlation with either temperature or seasonality of rainfall in the north and west of its range. It is less intolerant of cold climates than any tree under consideration other than *Betula pubescens*. Soil moisture is more directly important to the success of *Alnus glutinosa* than is atmospheric humidity and high rainfall is effective in extending the potential range of the tree through this medium only. The mature tree is frost-hardy and flowering catkins are resistant to at least −6 °C (McVean 1953). Wind, principally through its desiccating effect, is an important factor in the reduction of fruit formation (McVean 1955). Running water and wind drift over still water are the principal dispersing agents leading to even-aged seedling stands along strand lines and on periodically flooded areas, particularly where vegetation cover is incomplete and the young seedlings unshaded. Young seedlings are susceptible to late frosts and also suffer, when compared with those of *Betula pubescens*, when lower temperatures follow a relatively mild germination period (McVean 1956*a*).

Corylus avellana

This shrub extends to 68° N in Norway but only to 63° N in eastern Sweden. Along the northern part of its Scandinavian range it flowers progressively later in the higher latitudes, a strong indication of a real temperature control (Hulten 1950). It seems likely that spring temperatures of about 2 °C must consistently be reached and surpassed to enable the successful flowering of the hazel, conditions which, in the present climatic régime, seem to lie broadly within the 15 °C mean July maximum isotherm in north-west Europe. Hafsten (1956) suggests that a June–September mean of 10·5 °C may be a significant climatic limit for *Corylus*. The very infrequent late spring frosts of extremely oceanic climates may well have allowed the greater success of *Corylus* in the past beyond the corresponding summer mean. Within its range, *C. avellana* grows on a wide variety of soils, favouring those which are basic and dry to damp rather than perennially waterlogged. The hazel is intolerant of shade, although less so than the birch, but flowers and fruits profusely under more open conditions. The fruits are distributed mainly by animals (Hagerup 1942), but after an initial period of drying out they will float in water for some time and subsequently germinate (Ridley 1930). The rate of *Corylus* migration across Europe in the early post-Glacial period seems incomprehensible unless water transport is invoked (Godwin 1956), and Firbas (1949) supposes a rate of 5 to 7 km/year to have been necessary at that time.

Hedera helix

This woody climber is common throughout the British Isles and flowers freely when not shaded. It is substantially coastal in Norway extending northward only slightly beyond 60° N (Hulten 1950). Iversen (1944, 1960) and Troels-Smith (1960) have thoroughly reviewed the effects of temperature, light and human exploitation in its ecology. It seems unable to flower at places where the mean temperature for the coldest month is below about 1·5 °C but at sites where this degree of cold is not reached the tolerance of winter cold increases as the mean temperature of the warmest month increases, at least up to values of 12 °C for the latter. It is a truly oceanic species. *H. helix* grows in dense mats on the ground and ascends trees. It is an evergreen. Pollination is by insects and the fruits ripen in the spring of the following year. These fruits are eaten and dispersed by birds, more particularly by woodland birds, so that the rate of migration of ivy within its climatic range depends principally on the prior or contemporaneous establishment of at least some woodlands or thickets to provide an environment suitable for these birds. Given these conditions, its first appearance in an area must almost certainly be climatically determined.

The vegetation

In figures 38 to 43 parts of the main pollen diagrams from the six sites have been redrawn to illustrate the march of the different tree pollen curves and that for *Corylus* against a common vertical scale. This scale is constructed mainly from radiocarbon-dated diagrams from Scaleby Moss and at least some of the apparent similarities between diagrams derive in some degree from the equation of particular events at the different sites with the Scaleby time scale. Thus, although the rise in the *Alnus* curve during Zones C12 and C13 (VI, VIIa) is gradual in most of the original diagrams in which it occurs, this feature is imposed on the data from Abbot Moss by the correlation of the zones of the original diagram from there with the time scale from Scaleby. The justification for this lies in the correlated parallelism of other events about that time throughout all the diagrams, including that from Abbot Moss, together with the fact that, of all the sites considered, Abbot Moss was probably accumulating deposits most slowly at this time.

With each diagram are presented smoothed curves showing the interrelationships between the commoner dry land trees, viz. *Pinus*, *Quercus* and *Ulmus* (see parts II to V for their construction). The courses of these curves in the lower part of Zone C10 (VI) are entirely artificial because *Ulmus* and *Quercus* were hardly yet established whilst the indications of the main diagrams are that *Pinus* was also infrequent and that the greater part of the dry ground was occupied by *Betula* and *Corylus* woodland.

The first *Ulmus* and *Quercus* seem to have arrived in the Cumberland Lowland at about the same time but the former was evidently able to establish more rapidly than the latter, a feature particularly evident at Scaleby Moss. This early expansion of the elm in Zone C10 (VI) was contemporary with the first dimunition in the hazel and the beginnings of the much steadier reduction in birch. It is tempting to think that elm forest replaced birch and, more particularly, hazel woodlands on the richer soils of the region. At this time also all traces of the former open vegetation of the region disappeared. The period during which *Quercus* first extended very considerably seems to have been correlated with a further marked diminution in *Corylus* as well as with the continued reduction of *Betula*, after which the latter particularly seems to have remained in a steady state for some time. The time at which this relative balance was achieved differed from early in Zone C11 (about 6200 B.C.) at Moorthwaite Moss and Abbot Moss to late in the same zone (about 5800 B.C.) at Scaleby Moss and possibly somewhat later at Ehenside Tarn. These changes might well have been due to the replacement of the birch and hazel woods of the poorer and sandier soils by oak (*Q. petreae*) forests and the entry of *Q. robur* into at least some of the elm woodland. This would have established a mosaic of elm and oak forests on the drier land, with

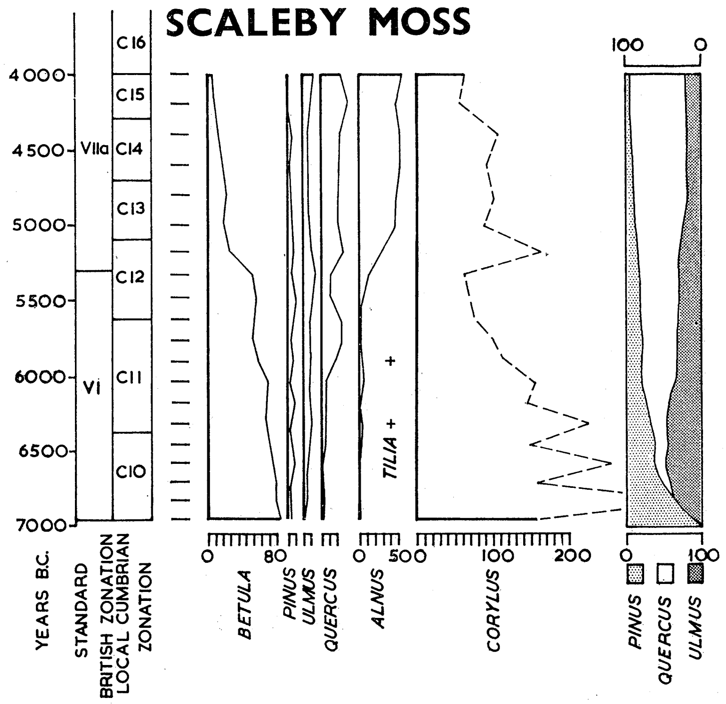


FIGURE 38

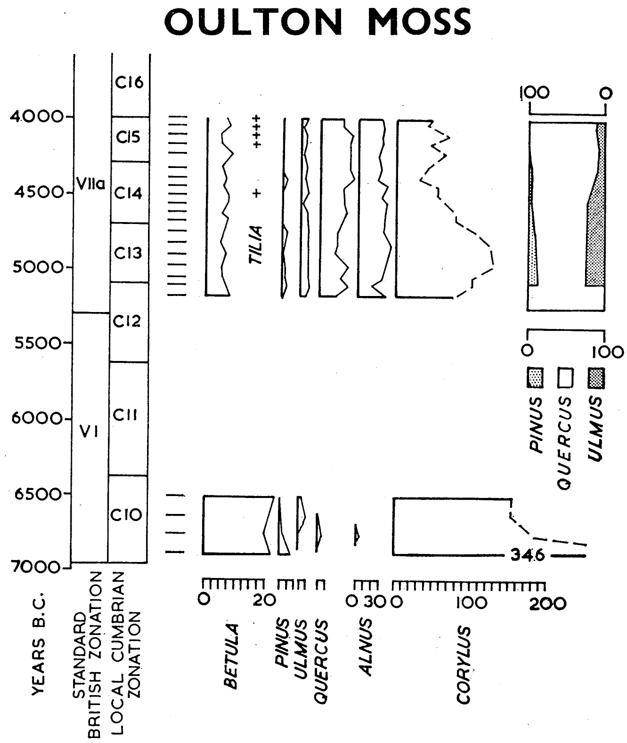


FIGURE 39

FIGURES 38 to 43. Pollen diagrams covering the post-Glacial forest period from six sites in the Cumberland Lowland. A common vertical scale is used throughout all the diagrams and sample positions have been distributed as indicated by the zonation of the original diagrams. Each diagram shows frequencies of trees and *Corylus* as percentages of the arboreal pollen sum (excluding *Corylus*). On the right of each figure, smoothed curves for the frequencies of *Pinus*, *Quercus* and *Ulmus* pollen as percentages of their combined sum are shown.

hazel and birch contributing to their regeneration cycles, but with almost pure, mature, birch woodland in the badly drained hollows and on many of the peaty swamps marginal to the shallower lakes. The pine probably extended its area only a little beyond that of its late-Glacial occurrence; from being limited in its spread by climatic conditions it quickly passed to limitation by competition from species better adapted to the new conditions prevailing during the early post-Glacial.

The balance between the components of the elm–oak–pine forest mosaic was not stable. The smoothed curves for the relative frequencies of the pollen of these trees show a steady increase of *Quercus* at the expense of the other two, punctuated by a number of more

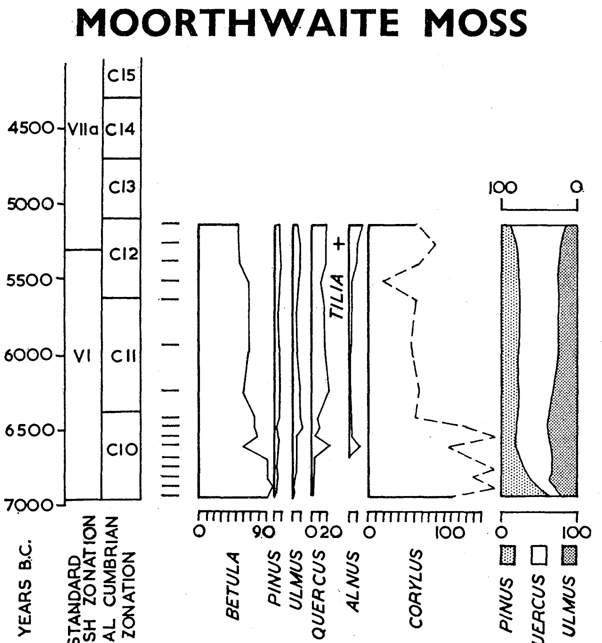


Figure 40

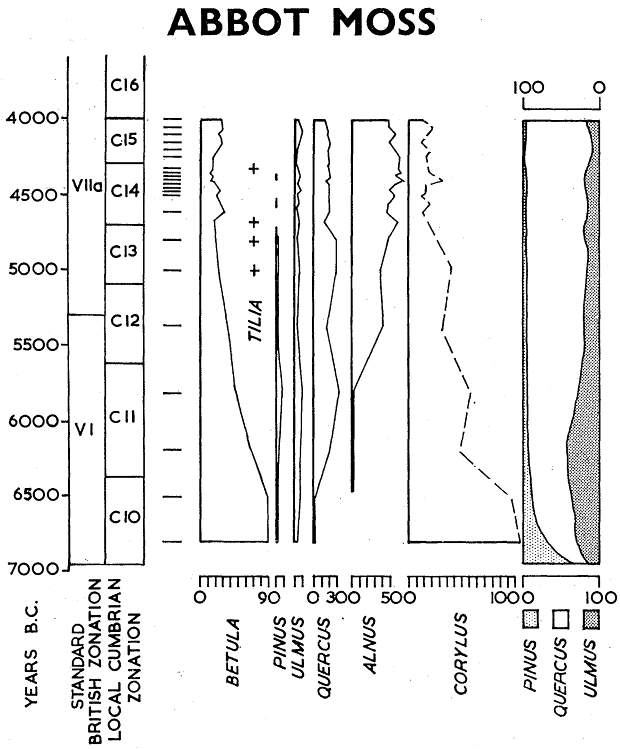


Figure 41

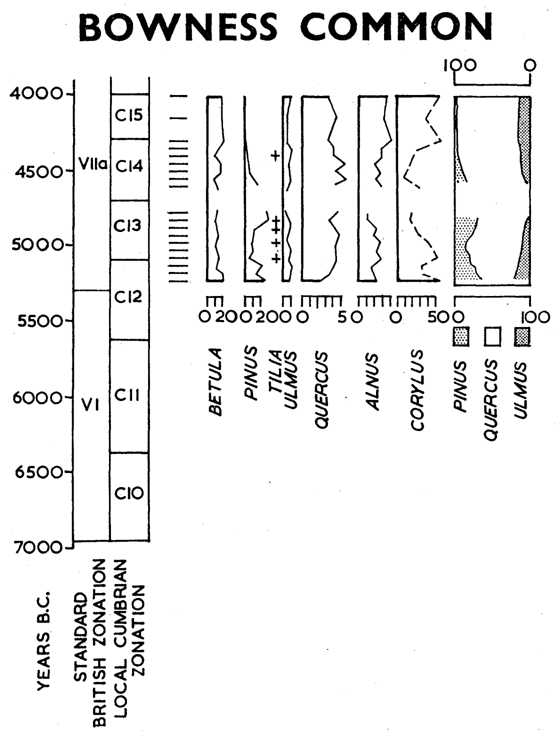


Figure 42

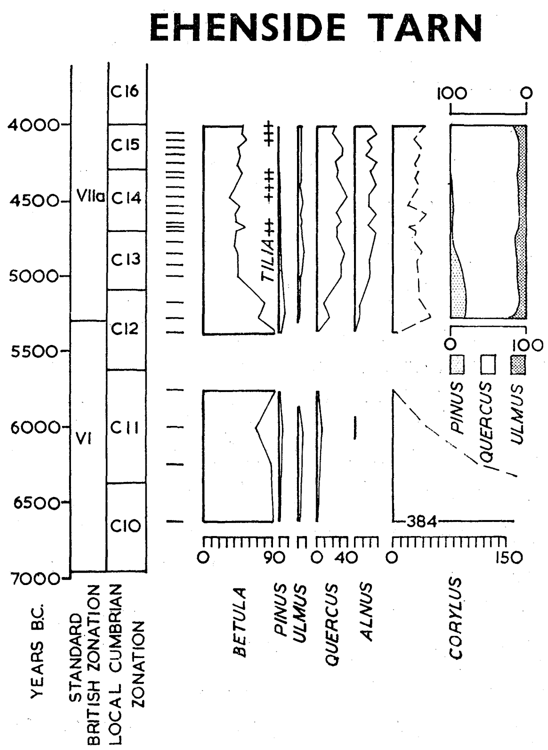


Figure 43

spectacular gains, notably at Scaleby Moss, Moorthwaite and Ehenside Tarn at the beginning of Zone C13 or the end of Zone C12 and at Oulton Moss somewhat later. By the beginning of Zone C14 (VIIa) *Pinus* was clearly no longer a tree of any importance in the lowland vegetation except perhaps near Bowness Common where sand and gravel beaches and spits associated with a constantly changing coastline probably provided a habitat in which *Pinus* had competitive advantage during the latter part of the marine transgression and the earlier part of its retreat. Even so, by the end of Zone C14 (VIIa), *Pinus* was insignificant around Bowness Common. From about the beginning of Zone C14 (*ca.* 4700 B.C.) at all sites except, perhaps, Scaleby Moss, the area or vigour of *Ulmus* was reduced to a critical level and became very susceptible to unusual attack of any kind. Scaleby Moss almost certainly received a considerable component of its pollen rain from the low boulder clay hills between wide lowland valleys, on which *Ulmus* was evidently able to persist longest on the most suitable soils available to it in the region. The more or less steady increase of *Quercus* pollen with respect to the levels of that of *Pinus* and *Ulmus* must imply a physical encroachment of the former into areas occupied by the latter until, as pointed out above, *Pinus* was virtually ousted and *Ulmus* reduced to the occupation of only the most suitable ground in relatively small areas.

This interpretation does not utilize the concept of the 'Eichenmischwald'. The pollen analytical data themselves can hardly be interpreted in terms of a forest with a physiognomy uniform over the whole region at any one time and in which the dominance was shared in a constant manner over the whole region by oak and elm at least, and possibly also by alder, because at any given time the relative frequencies of these components of the pollen rain were not the same at different sites. Moreover, the continuous changes in the vegetation which are generally indicated by all the diagrams together, and particularly illustrated in the diagram from each site, suggest that a truly stable climatic climax was never established during this period. If the variation between sites is due to small edaphically or biologically determined differences within a materially uniform mixed oak forest, some of the components of the mixture were evidently replacing others, although at different rates in different places. The hypothesis of a vegetation *differentiated ecologically from the beginning* but also with labile ecotones presents a simpler model, in terms of which not only the variations between sites but the accommodation of the immigrant alder can be more easily resolved.

The application of Morrison's (1959) test is only possible with any profit to the data from Ehenside Tarn where there is strong indication of local forest clearance during Zone C16 (see part VIII). There is but a trifling fall of *Quercus* values coincident with the onset of the pronounced fall in *Ulmus* values but for the greater part of the latter the level of the *Quercus* curve is virtually unchanged. At Scaleby Moss and Abbot Moss there is a slight tendency for *Quercus* to fall in parallel with *Ulmus*, at least at first, but a similar reaction at Bowness Common was clearly occasioned by the continued rise of the *Alnus* curve. At Oulton Moss, the *Ulmus* and *Quercus* curves behave strongly antagonistically at the appropriate time. At the one site where it can confidently be applied, therefore, the test indicates segregation of forest communities whilst elsewhere the indications are obscure.

Alnus glutinosa was already established in the region during Zone C11 (VI) and might have grown at Moorthwaite Moss in Zone C10. Its extension to assume an important role in the vegetation took place during Zone C12. *Betula pubescens* was evidently further reduced at that time. It therefore seems very likely that birch woodlands were largely replaced by alder woodlands on waterlogged soils. It is also possible that some of the wetter elm and oak woodlands were, at least temporarily, affected by competition from alder around their edges and possibly by the intrusion of alder into their regeneration cycles. The success of the alder over the birch seems to have been less marked at Moorthwaite Moss and at Ehenside Tarn than elsewhere although the diagram from the first is incomplete for the period and that from the second is strongly influenced by the individual trees actually growing near the site of sampling. None the less, places evidently existed where birch remained an important dominant throughout the forest period.

Pollen of *Tilia cordata* is recorded most commonly from different zones at different sites but the record extends totally from Zone C11 (Scaleby Moss) to Zone C15 (Ehenside Tarn). The number of grains recorded is so small, however, as to make it virtually certain that this species was not a part of the vegetation of the Cumberland Lowland. A single grain of *Fagus sylvatica* from Zone C14 (Oulton Moss) and another from Zone C15 (Abbot Moss) and the rare occurrences of *Fraxinus* pollen are similarly insufficient to establish these trees as members of the flora. *Hedera helix* was clearly a frequent and flowering plant from Zone C11 onwards. Only one pollen grain of *Hedera* is recorded from Zone C10 at Moorthwaite but subsequently there is no significant difference in the distribution of this pollen type from zone to zone or site to site, if its occurrences are assessed against the number of samples examined.

The causes of vegetational change

Three processes, active during this period, must be explained, viz. (*a*) the great expansion of *Corylus* followed by the arrival of *Ulmus* and *Quercus* and their establishment as the most significant dominants in the vegetation; (*b*) the encroachment of *Quercus* throughout the period on areas occupied by *Pinus* and *Ulmus*; and (*c*) the establishment and expansion of *Alnus* in competition with *Betula*.

Corylus was already a constituent of the vegetation in Zone C9 (IV–V), although probably restricted to the most favourable, frost-free, localities. Its failure to extend substantially outside these for over a thousand years seems to imply a climatic limitation which was evidently overcome at the beginning of Zone C10 (VI); i.e. at about 7000 B.C. Followed, as it was, by the immigration of *Ulmus* and *Quercus* from great distances away, the most likely cause of the *Corylus* expansion into the *Betula* woodlands seems to have been a rise in summer temperatures together with an almost total eradication of spring frosts. Mean maximum summer temperatures above 15 °C seem probable. *Corylus* expanded before *Ulmus* and *Quercus* because its slightly greater tolerance of cold, together with its short generation time and its aggressive invasion of light habitats, allowed it to cross Europe ahead of the others. The first arrivals in the British Isles may, indeed, have followed a western route, with its more oceanic climate, in order to spread rapidly northward. *Ulmus* and *Quercus* arrived in the area at about the same time. It may be that the oceanicity of the west favoured the germination of the frost-susceptible acorns and so, at least in part, offset the superficially more efficient dispersal mechanism of the elm. The arrival and first establishment of these trees does not indicate any substantial amelioration in climate beyond that already required by the behaviour of *Corylus*. The apparent failure of the oaks to spread so quickly as the elm once both had arrived may well have been the result of the oaks' need for long warm summer periods for repeated production of heavy crops of fruit. Judging from the records of *Hedera helix* such conditions had developed by Zone C11 (about 6300 B.C.) when also the mean temperatures for the coldest winter month must have exceeded about 1·5 °C.

The forests which were so established were not stable, although the explanation of their establishment implies that they were in balance at least with the temperature conditions of the prevailing climate. The progressive modification of the forest composition, resulting from the success of *Quercus* at the expense of *Pinus* and more particularly *Ulmus*, could have been due to the depauperation of the soil and the formation of mor by leaching under the oceanic conditions which prevailed. That the success of the oak should be rather more pronounced near Abbot Moss than near Scaleby Moss is to be expected from this hypothesis because of the ubiquity of sandy soils on good slopes in the former locality. Neither the stratigraphic information from the various sites nor the behaviour of the pollen curves themselves allow that the increase in oak be attributed more than slightly to hydrosere development (Iversen 1960).

The immigration behaviour of *Alnus glutinosa* has been interpreted principally as its replacement of *Betula pubescens* on poor, waterlogged soil and its slight intrusion into the forest of dryer and better soils. It has frequently been observed that the temperature requirements of *A. glutinosa* are no less great than those of the forest trees which were growing in western Europe long before its arrival there. The relative delay in its establishment is variously attributed to insufficiently damp conditions along its migration route (Godwin 1956) or to a want of adequate summer warmth in the west (Firbas 1949; Kubitzki 1961) or to inefficient seed dispersal without the aid of suitable running water (McVean 1956*b*). There can be no doubt that a few alder trees grew in the Cumberland Lowland during Zone C11 and that these were in inland, as well as coastal, sites. The expansion during Zone C12 (Boreal–Atlantic Transition) occurred both within and beyond the tract immediately affected by the rising sea of the time, so this factor alone cannot have been directly and totally responsible for the change in the vegetation. In competition with *B. pubescens*, stable spring weather (i.e. the absence of late cold spells and strong winds) and more consistently high ground water tables with but rare periods of drought for the seedlings seem likely to have been the factors most conducive to the spread of *A. glutinosa*. Although not all aspects of an extremely oceanic climate are favourable to the alder (McVean 1956*b*), it is difficult to see how the changes documented above could have been attained other than by an increase in the precipitation:evaporation ratio through a critical range during Zone C12. It does not seem necessary, however, to suppose this to have been sudden. On the contrary, the evidence suggests that in this region it was the culmination of climatic tendencies which had been reducing the competitive power of the birch for some time.

The major vegetational changes during this period seem to be accountable by assuming a substantial rise in summer temperature maxima and winter temperature minima at about 7000 B.C. and a subsequent increase in precipitation:evaporation ratio. These are two components of a markedly oceanic climate but they did not apparently progress at directly related rates. Thus the temperature change is best envisaged as the culmination of the rather slower amelioration which had been in progress since about 8500 B.C., under humidity conditions which had already long before become distinctly oceanic. The rainfall was clearly adequate then to allow the development of 'mor' soils but it was not until about 5500 B.C. that a further rise in the precipitation:evaporation ratio first began to affect the vegetation of the partially waterlogged soils. It is conceivable, that even though precipitation might have increased regularly from the earliest post-Glacial (C 9, IV) onwards, the establishment of forests itself temporarily retarded the overall effects of this increase, by raising the rate and amount of water loss by transpiration. There is no positive evidence for a 'Boreal' period of pronounced dryness in this region. It seems likely that the temperature changes were part of a general amelioration accompanying deglaciation while the humidity change was the result of the eustatic extension of the oceans exacerbated in this region by the extensive flooding of the shallower areas of the Irish Sea to which it gave rise.

Relations with surrounding areas

The most striking differences between the vegetational development in the Cumberland Lowland and sites to the west, south and east, beyond the mountain barriers are the sporadic success of *Pinus* and the virtual absence of *Tilia* in the former. From Northern Ireland (Smith 1961 *b*; Morrison & Stephens 1960) and the northern fringe of Morecambe Bay (Smith 1959; Oldfield 1960 *b*) the data are clearly indicative of the local growth of considerable stands of *Pinus sylvestris* during Zones V and VI. The suggestion that a real climatic barrier to the extension of pine lay south of the Lake District Hills (Walker 1955 *a*) is now untenable, as is also shown by the present data from Bowness Common and Oulton Moss. Nevertheless, the tree may have been restricted to ecologically special localities and the data could be explained by the fact that all the sites mentioned lie within easy reach of steep, rocky, limestone, slopes, or spreads of loose sand and gravel. *Tilia cordata*, on the other hand, seems to have reached its north-western limit south of the Lakeland hills. There, Smith (1958, 1959), and Oldfield (1960 *b*) and Walker (1955 *a*) have shown that it did establish successfully, although late in comparison with areas further south and east (i.e. in Zone VII a). Soils and other site conditions appear to have exercised a strong selective influence and only where these were at their most favourable did the three flourish, probably an indication of the decreased competitive power of the species under oceanic conditions (cf. Iversen 1960). A comparison between its present-day distribution and those of other trees common during the post-Glacial forest period suggests that summer temperature alone was not limiting its spread.

During the greater part of Zone VI (C 10 and C 11) the vegetation of the Cumberland Lowland was not utterly distinct from that of the rest of lowland England. It was an attenuation of that vegetation: a culmination of tendencies, such as the decreasing success of *Pinus* and of *Tilia*, due partly to distance from the per-Glacial refuges of these plants and partly to the oceanicity of the north-west (cf. Godwin 1956; Kubitzki 1961). It had much in common with the vegetation of the north of Ireland. The oceanicity and the poverty of the tree flora, providing as it did fewer indicators of environmental change, rendered the vegetation of the Cumberland Lowland less susceptible to some of the climatic changes registered farther south. There is no certain indication there of a Boreal dry period (Godwin 1956, 1960). The indications are that the climate was damp from the late-Glacial onward but became even damper at about 5300 B.C. Changes in forest composition did take place but, apart from the expansion of the alder, all that happened between about 6000 B.C. and 4000 B.C. can best be attributed to autogenic developments under oceanic conditions. This is not to deny that climatic changes took place during this period but merely to maintain that recourse to them is unnecessary in order to explain events in the Cumberland Lowland.

VIII. THE PERIOD OF FOREST REDUCTION

The period of forest reduction in the Cumberland Lowland was initiated by changes beginning at about 4000 B.C. on the better soils of the coastal strip and about a thousand years later in the lower Eden Valley. These changes are attributed to the activities of prehistoric husbandmen who were broadly 'nomadic' but who might have stayed in one area for several generations. These early clearances resulted in regional changes in the vegetation, accentuating the natural diminution of the elm, increasing the abundance of birch and hazel, and allowing ash and weeds to become established.

In some places the farming economy changed slowly, the introduction of cereals playing a considerable part and allowing some of the region to be permanently occupied. The effects of these developments were not felt over the greater part of the Cumberland Lowland until about 1750 B.C. when the new economy spread, even reaching the heaviest soils and least attractive environments by about 1400 B.C. This revolution is thought to correspond with the earliest widespread use of the polished stone axes of Lake District manufacture (Secondary Neolithic). The forests over large areas seem to have been irreversibly decimated by this activity.

The evidence for subsequent changes is restricted but indicates renewed agricultural activity immediately after the Roman withdrawal culminating in the improved organization and new crops of the Monastic period.

Positive evidence of climatic change during this period is exceedingly small, but this may partly be due to the obscuring effect of the dominant anthropogenic changes.

Introduction

From shortly after 4000 B.C. (i.e. C16, VIIa–b, onwards) the forests of the Cumberland Lowland were progressively reduced, their place being taken by herbaceous communities, secondary woodland and the remnants of the former forests. The present condition of the countryside is evidence of the continuation of this process to the present day, although woodland of a kind was clearly far more common only 400 years ago (part I). All the sites investigated had been disturbed in the comparatively recent past. The uppermost deposits, therefore, do not contain a record of the more recent events except at Ehenside Tarn where the disturbance was not only short-lived but served to protect the underlying deposits (part IV). So far as can be judged by analogy with the dated horizons at Scaleby Moss, the records from the main sites used extend to about the following dates: Ehenside Tarn, A.D. 1500 (C22); Bowness Common, 500 B.C. (C20); Oulton Moss, 750 B.C. (C20); Scaleby Moss, 1000 B.C. (C19–20); Abbot Moss, 1300 B.C. (C19).

Geographical changes

The marine transgression on the Solway coast reached its maximum toward the end of Zone C13 (about 4650 B.C.) since when the land has emerged at a mean rate of about 1 m in 1500 years (part V). The emergence has not been at a steady rate, however, and there is some slight evidence that the longest pause, or renewed transgression, occurred during Zone C16. The mean annual increment of land during the first thousand years of the emergence was about 0·13 km^2 (0·05 sq.miles). Although small in area, this land provided a continuously renewed habitat for pioneer communities. Much of the new land initially became salt marsh, but large areas, where the drainage was impeded, were quickly covered with bog vegetation. A factor of local ecological importance was that the archipelagos of boulder-clay islands linked by shingle spits in some districts at the maximum transgression (e.g. Bowness–Glasson), became progressively united by more or less dry land.

The effects of the emergence away from the coast were probably very small. There is positive evidence (part V) that at least some of the terraces in the lower reaches of the main river valleys were abandoned during the regression and a fall in ground water table during the period in the low and coastal areas must be supposed. This may have influenced the vegetation in the vicinity of Scaleby Moss and Oulton Moss but is unlikely to have had much effect near other sites. At Ehenside Tarn, however, where the basin itself is well above such possible effects, the narrow emerging coastal strip was only 1 km away and the pollen of plants actually growing there might be expected to be recorded in the pollen diagrams.

The period includes the settlement of the area by human agriculturalists whose activities must not only have influenced the forests directly but must also have modified the equilibrium with the soil. Soil stability was replaced by soil movement much of which may have been temporary. Finally, concentrations of population began to build up in Roman times and, though suffering many vicisitudes, have continued to do so until the present day.

Hydrosere development

The tendency for bog to replace more eutrophic formations, which was already apparent at Scaleby Moss, Bowness Common and Moorthwaite Moss and to a lesser extent at Oulton Moss, developed at Abbot Moss in Zone C16 (VIIa). Thereafter, probably into the Christian era, all these mires grew upwards as *Sphagnum*-dominated units. So far as can be ascertained, the greater part of the central area of each of these bogs rose above the main effects of ground water during the following zones: Scaleby Moss, C16; Abbot Moss, C18; Bowness Common, C18; Oulton Moss, C19.

Ehenside Tarn, although harbouring *Sphagnum* in its catchment as early as Zone C19 and suffering its spread around parts of the lake margins from Zone C22b, never became a bog. Nevertheless, whenever disturbance associated with human occupation slackened, the lake waters tended towards oligotrophy.

The time of achievement of independence of ground water was a function of factors local to each site. The general tendency was marked at all of them and the necessary plants were readily available. But the rate of change was independent of altitude or of the *general* topographic setting of the sites and closely related with the history of the individual mire and the slopes immediately surrounding it. It is clear, however, that the precipitation: evaporation ratio was great enough already during Zone C16 (VIIa) to maintain a growing bog surface independent of drainage water, a fact in accord with the known history of 'blanket' bog on the surrounding uplands (Godwin & Clapham 1951; Precht 1953).

Recurrence surfaces in the upper peat at Scaleby Moss indicate changes in the rate of accumulation which are probably attributable to changes in precipitation (Godwin 1954), possibly to a sequence of increases in rainfall (Walker 1961). Two of these are dated to about 3500 B.C. (C16) and 1900 B.C. (C18). The water level in the Oulton Moss basin rose to about 13 m (42 ft.) O.D. by the end of Zone C18 (VIIb) but this was probably partially related to local conditions there. At Ehenside Tarn a water level rise of about 50 cm occurred during Zones C21 and C22a (about year 0 to A.D. 1000) but no ombrogenous deposits of equivalent youth are available certainly to attribute this to a regional cause.

It is certain that very many of the peat deposits of the Cumberland Lowland were cut for fuel from the Medieval period onward (part I) and probably from some time before. This cutting reduced the bogs to patchworks of ponds and intervening, well drained, ridges and tables. The former are now occupied by wet *Sphagnum* whilst on the latter *Betula pubescens* and *Pinus sylvestris* are common. The larger coastal bogs proved more formidable than the smaller inland mires and, for the most part, only the edges were cut. Bowness Common still retains a surface vegetation of *Calluna vulgaris* with abundant *Sphagnum* from which trees are virtually excluded by periodic fires. Glasson Moss has been even less affected and an actively accumulating, *Sphagnum*-dominated, surface still remains.

General changes in land vegetation

The most significant changes in the composition of the vegetation of the land (figures 44 to 48) were in the relative frequencies of woody and herbaceous plants. Occasional pollen grains of land herbs are encountered throughout the post-Glacial period in all the diagrams, including a few of shade-intolerant plants, particularly during Zone C16 (VIIa). The first marked general increase in herbs at the expense of the forest trees is first recorded between 3000 B.C. and 2750 B.C. (C17, VIIb) at all the sites except Bowness Common, which was at that time peculiarly remote and isolated and the record from which is confused by contributions from hydrosere components (e.g. Gramineae). In a broad sense this change was permanent, for although the forest did recolonize the open areas from place to place and time to time its overall regeneration was short-lived. A second major change during which herbaceous communities became much more widely and substantially established occurred throughout the region between 2000 B.C. and 1500 B.C. (C18–C19). In the neighbourhood of each site a new balance was established at about this time and at Ehenside this was maintained, although modified, at least until about A.D. 1500.

Whilst the physiognomic pattern of the vegetation was changing the relative importance of the contributing trees and shrubs also altered. Some changes which had started much earlier continued. Thus, *Pinus*, never important in this region, only remained a scarcely significant tree after about 3750 B.C. near Ehenside (to 3250 B.C.) and Scaleby (to 2500 B.C.). The general diminution in *Ulmus* which had begun about 6000 B.C. and was intensified from about 5000 B.C. continued at an increased rate, punctuated by a number of distinct and sudden falls and successively weaker recoveries. At Bowness Common, *Ulmus* continued to be represented as a minor, but consistently present, forest tree until about 1200 B.C., at Abbot Moss until about 1700 B.C. and at Scaleby and Oulton Moss only until about 1900 B.C. It may be that the Bowness Common record is more representative of the region as a whole, the other diagrams being more subject to local conditions. If so, it is odd that the diagram from Scaleby should not have shown at least as long a persistence of the elm, in view of the size of the site and the suitability of nearby habitats for the growth of the tree. Near Ehenside Tarn, *Ulmus* was never very abundant but the trees which were there suffered very positively from the reducing factors and by about 1900 B.C. the genus was almost extinct there. A slight recrudescence seems to have started

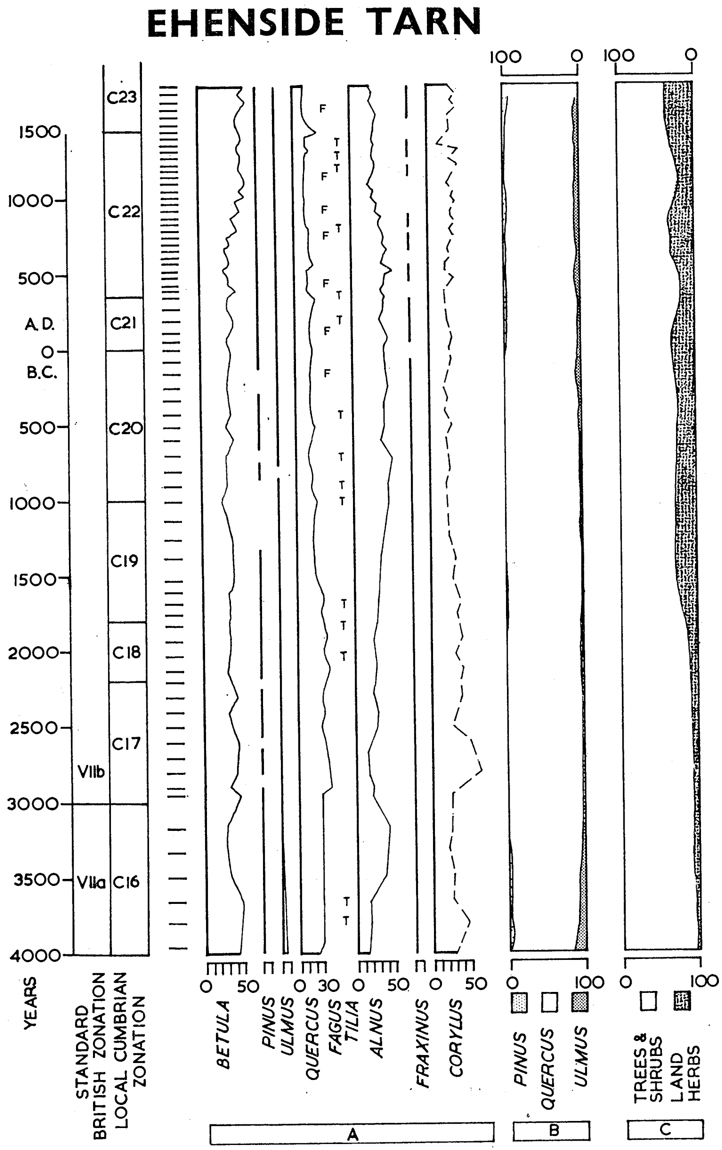


FIGURE 44. Ehenside Tarn. Summary pollen diagram derived from Ehenside Tarn A. The time-scale is derived from radiocarbon dates from Scaleby Moss together with considerations of relative accumulation rates from time to time. Sample positions are spread through each zone as indicated by original diagram zonation. In section A, frequencies of all pollen types are shown as percentages of total arboreal pollen, omitting *Corylus*. In Section B, frequencies of *Pinus*, *Quercus* and *Ulmus* are shown as percentages of their combined totals. In Section C the frequencies of tree and shrub pollen are contrasted with those of dry-land herb pollen as percentages of their combined totals.

at about 1500 B.C., however, and by about 750 B.C. a new and more or less persistent balance had been achieved in the forest to which *Pinus* later contributed. The actual abundance of *Quercus* in the vegetation was, of course, decreasing throughout this period so that apparent increases of *Ulmus* and *Pinus* in the pollen diagrams might only indicate a relative increase in the rate of disappearance of *Quercus*. The reduction of forest trees was probably greater than is indicated in the summary diagrams (figures 44 to 48) where shrubs and trees of the hydrosere contribute to the relevant curve. In the diagram from Ehenside Tarn, for instance, the contribution of certainly dry-land trees to the certainly dry-land vegetation fell from about 50% to about 25% between about 3000 B.C. and A.D. 1500. This diminution would be partially offset, of course, by *Betula*, *Alnus* and

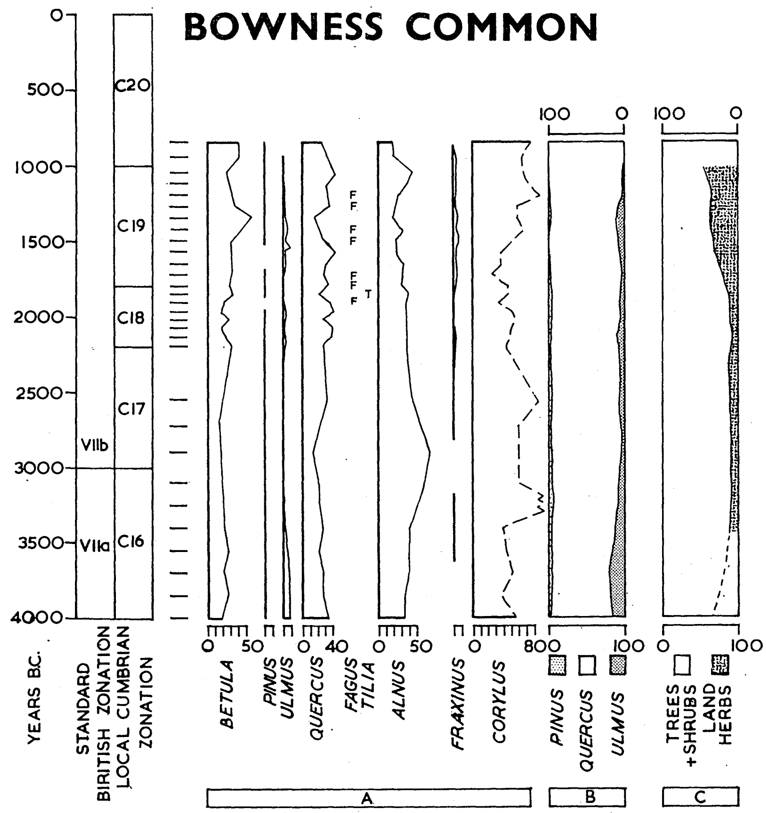


FIGURE 45. Bowness Common. Summary pollen diagram derived from original counts. For further explanation see figure 44.

Fraxinus, which are not included in the sum, growing outside hydroseres in the opened woodlands but, none the less, decimation of the former forests and the increase of open scrub lands as well as purely herbaceous communities was very marked.

The view that *Alnus* and *Betula* were growing in wetter places, if not in hydroseres in the strict sense, is confirmed by the detailed complementary changes in their pollen frequencies throughout the period. Nevertheless, there are also changes with regional significance. *Alnus* seems to have attained its maximum extent or vigour between 3000 B.C. and 2500 B.C. and thereafter to have declined generally, if but slightly and erratically, at least until about 1000 B.C. Near Bowness Common, Scaleby Moss, Oulton Moss and Abbot Moss a positive overall increase of *Betula* began at about 2500 B.C. Although this was due in some degree to *Betula* growing on drier land it seems very likely that from that time onwards *Betula* was proving slightly more successful than *Alnus* in the wetter places and particularly in the maturing hydroseres and on the deeply leached, lighter soils.

The most notable new species in the woodlands of the period was *Fraxinus excelsior.* Rare pollen grains of this species reached all the sites, except Scaleby Moss, from Zone C16 onwards but it became a significant plant late in Zone C18 or early in Zone C19 (about 1750 B.C.). Even then, it was evidently best established in the Oulton–Bowness–Scaleby area, i.e. on boulder clay rather than sand. There is no clear correlation between the trend of the curve for *Fraxinus* pollen and that of any other tree in the pollen diagrams. The association between the time of its significant rise and the second and major increase

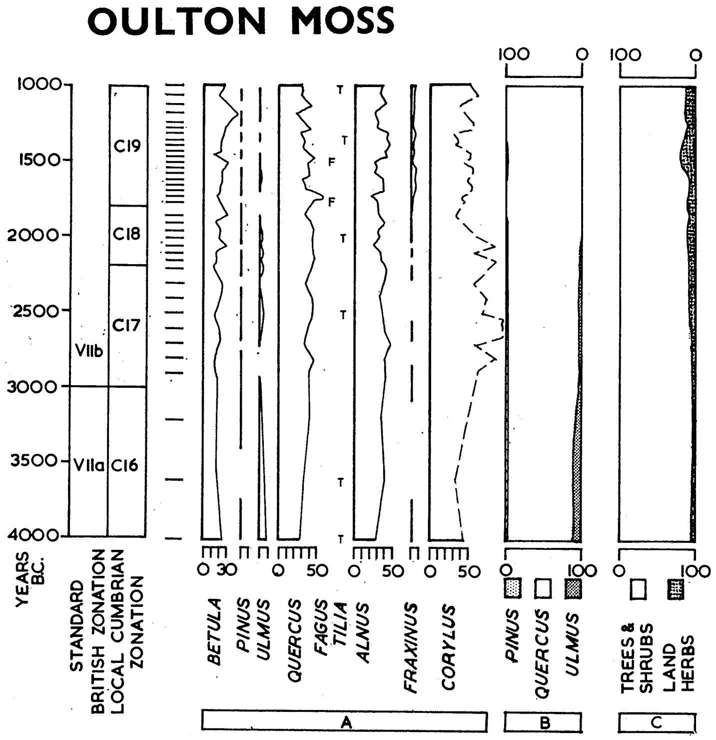


FIGURE 46. Oulton Moss. Summary pollen diagram derived from Oulton Moss A. For further explanation see figure 44.

in the relative abundance of herbs in the vegetation is very marked, however. Wardle (1961) has stressed the role of *Fraxinus* as a pioneer tree, particularly successful on disturbed soil, moist and with pH exceeding 4·2. It is less light-demanding than *Betula* but not so shade-tolerant as *Alnus* (Iversen 1960). *Fraxinus* would therefore have some difficulty in establishing itself in a vegetation where soils sufficiently damp were too acid in reaction if they supported birch whilst those not so acid were supporting alder. Only the destruction of this balance, or of the more shady oak or elm forest, would be likely to allow the expansion of the ash from a few naturally unstable habitats where it had gained a hold as a pioneer plant.

The part played by *Corylus* in the vegetation does not seem to have changed very greatly during the whole period. There is a tendency for higher pollen frequencies to be recorded during Zones C17 and C18 (*ca.* 3000 B.C. to 1800 B.C.) than before and for values approaching these to be maintained, somewhat erratically, afterwards. Computed in comparison only with the certainly dry-land trees, however, *Corylus* values show an increase from about Zone C17 (*ca.* 3000 B.C.) onwards which might be interpreted as an indication of the increasing abundance of the shrub in the recolonization of opened areas.

Tilia cordata, although represented by isolated pollen grains in all the diagrams, clearly was not growing in the region during this period. The same is true for *Fagus sylvatica*, although the occurrence of its pollen as early as the end of Zone C18 (about 1800 B.C.) is of some interest in comparison with neighbouring regions.

The vegetation changes of the period were mainly progressive drifts, but two periods of particular significance can be recognized. The first of these lies in Zone C17 (VIIb)

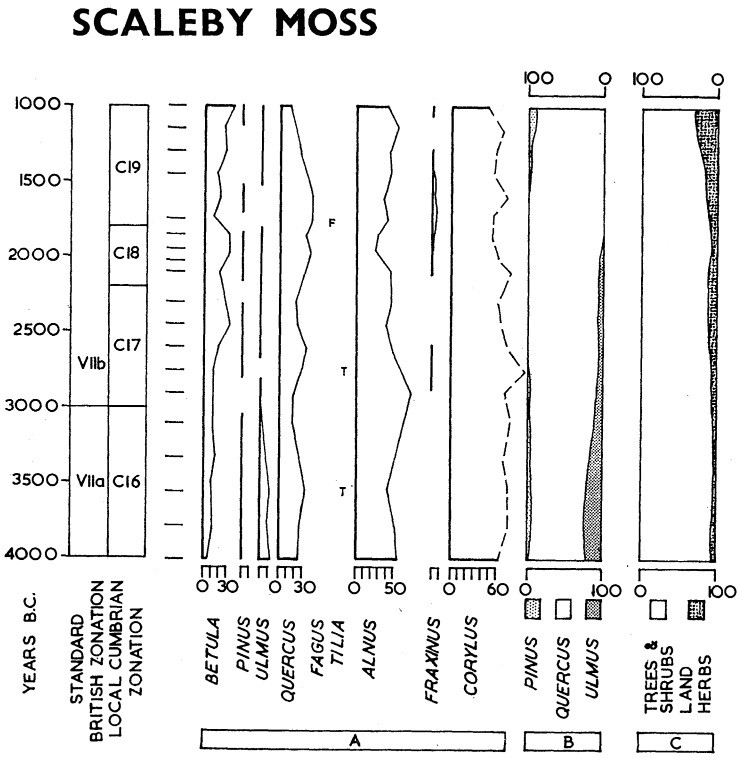


FIGURE 47. Scaleby Moss. Summary pollen diagram derived from Scaleby Moss A. For further explanation see figure 44.

between about 3000 B.C. and 2750 B.C. Then was the first marked increase in herbaceous vegetation, the reduction of *Ulmus* was virtually complete, *Alnus* was at the end of its most successful period and *Betula* was to become progressively more common soon afterwards. *Corylus* was more abundant than before, whilst in the dry-land vegetation *Quercus* was at its most frequent. The second significant time was the end of Zone C18 and the beginning of Zone C19 (about 2000 B.C. to 1500 B.C.) Again herbaceous communities increased considerably, this time largely at the expense of *Quercus*, *Fraxinus* became an important tree in the boulder clay regions and *Betula* increased its rate of expansion slightly.

The general history of *Ulmus* during this period is probably best interpreted as the culmination of the process of replacement of elm forest by oak forest as a result of soil depauperation under increasingly oceanic conditions. This had been accelerated by the increase in precipitation:evaporation ratio to which the expansion of *Alnus* in Zone C12 is also attributed (part VII). All other changes in the woody vegetation can be associated with the changing balance between woody and herbaceous communities and the continuation of podsolization of all but the most fertile soils. The behaviour of the trees does not require any hypothesis of climatic change during the period itself; all the plants represented are well within their climatic limits in Lowland Cumberland at the present day. The understanding of these vegetation changes as a whole, therefore, depends primarily on attributing a cause to the extension of herbaceous communities. There is no *a priori* reason for supposing this to have been climatically induced. The herbs recorded do not include any of great climatic exigency nor any which will not grow well within the ranges of the trees they replaced. By this time podsolization had led to shallow bog and

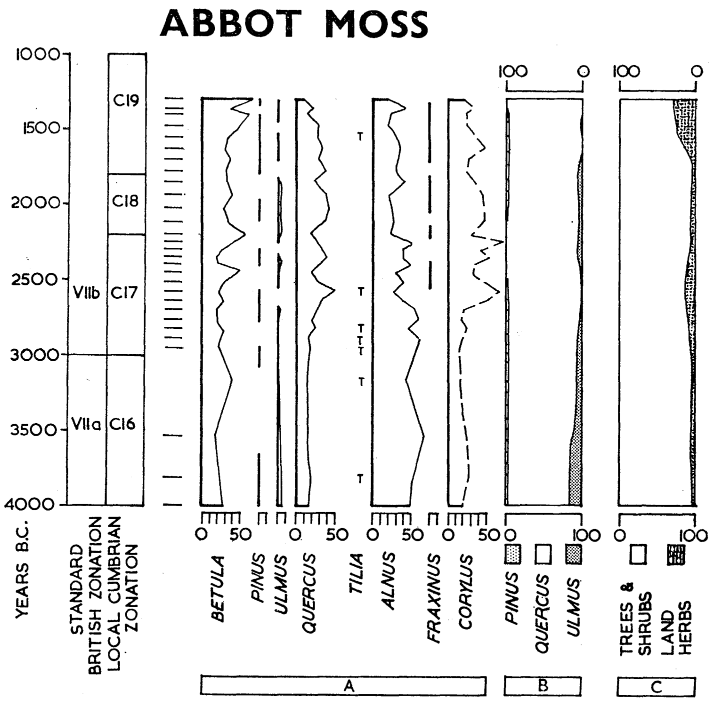


FIGURE 48. Abbot Moss. Summary pollen diagram derived from Abbot Moss A. For further explanation see figure 44.

heath formation on the poorer soils and particularly on the high ground. Some of the wetter parts of these areas are unlikely to have been tree-grown and their herbaceous cover doubtless contributed something to the herbaceous pollen rain. But many of the herbs involved (e.g. *Artemisia*, *Plantago lanceolata*) are not heath plants, and cannot have been growing only in such places. An alternative hypothesis is to suppose that these changes were the result of human interference with the vegetation. Such a possibility gains support from the widespread occurrence of prehistoric artifacts of the Neolithic and later periods in the region (part I) and the general acceptance of the idea that human activity was of prime importance in determining the direction of vegetation change during and since the Neolithic period in Europe as a whole (Iversen 1949, 1960; Troels-Smith 1960; Godwin 1956; Mitchell 1956; Morrison 1959; Watts 1961; Smith 1961 *a*; Hafsten 1956; Fries 1958; Florin 1957; Heybroek 1963). Nevertheless, if this hypothesis is to be upheld, it is necessary to show in detail that each phase in disforestation can be best explained by it and that other explanations are less adequate, and also that correlation with recognized periods of prehistoric human activity is reasonable. This is more particularly important when the stratigraphic record indicates changes in the mechanism of bog regeneration which are probably to be explained at least partly in climatic terms (p. 182 above) and when some of these changes date from times which were amongst the most significant in the history of the dry-land vegetation.

The pattern of forest clearance

The primary hypothesis on which the following arguments rest is that at the beginning of the period the land was largely covered by forests dominated by *Quercus* spp. on the drier, poorer, soil and *Ulmus* sp. on the deeper, richer, soil. *Corylus avellana* grew as an undershrub and clearing plant in both groups of forests. In investigating the breakdown of this arrangement it is therefore reasonable to study the interrelationships of these units and others contributing to the certainly dry-land component of the pollen rain. In figures 49 to 53, the following pollen types are graphed as percentages of their combined sum (cf. part IV):

Pinus	*Plantago coronopus*
Ulmus	*P. lanceolata*
Quercus	*P. major*
Corylus	*P. maritima*
Fraxinus	*P. media*
Hedera	*Plantago* spp.
Ilex	*Artemisia*
	Rumex acetosella
	Chenopodium
	Pastinaca

The sum of the types in the second column is shown as 'Total heliophilous herbs'. Separately from these graphs, frequencies of *Betula*, *Alnus*, Gramineae, and Cyperaceae pollen are shown as percentages of *total arboreal pollen*. Between the two groups of graphs is a column indicating the processes which the pollen curves are thought to represent at different levels. The detailed interpretation of these diagrams is made from the following considerations:

(1) In order certainly to be recognized as a clearance phase a series of changes must culminate in the appearance of heliophilous herbs in unambiguous frequencies (a total of 2% is the usually accepted lower limit).

(2) Clearance phases so marked are likely to have been fairly close to the site of the pollen diagram. Similar clearances at greater distance may be represented by changes in frequencies of trees and shrubs whilst the low-growing heliophilous herbs are only sporadically represented or even totally absent. The difficulty of distinguishing such pollen analytical changes from those representing normal forest regeneration processes makes it impossible to use them as direct evidence for forest clearance.

(3) A fall in the values of *Ulmus* and *Quercus*, without the appearance or expansion of the heliophilous herbs, necessarily results in an increase of *Corylus*. It is unlikely that a real

increase of *Corylus* could occur under a forest canopy and so cause the apparent reduction of the forest trees in the pollen diagram. The usual interpretation of such pollen analytical changes is that the canopy had been reduced and the flowering of *Corylus* thereby encouraged.

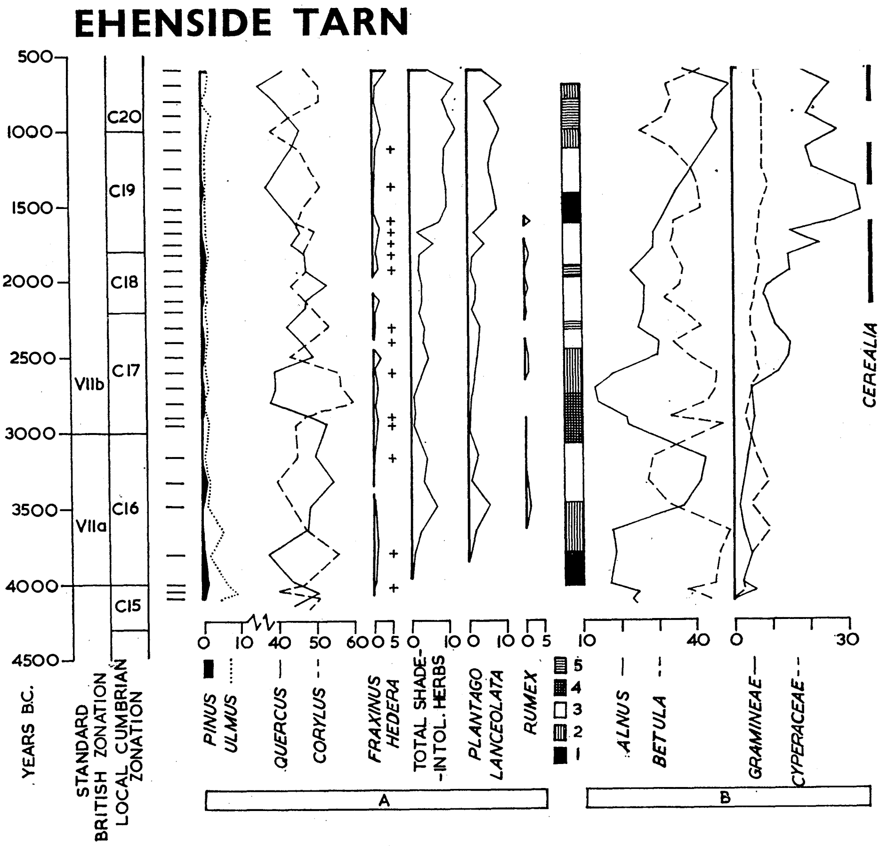


FIGURE 49. Ehenside Tarn. Summary pollen diagram derived from Ehenside Tarn A. The time scale and zonation are constructed as in figures 44 to 48. In Section A, pollen frequencies of *Pinus*, *Ulmus*, *Quercus*, *Corylus*, *Hedera*, *Fraxinus* and the total of shade-intolerant dry-land herbs are shown as percentages of their combined totals. The individual contributions of some of the more important of these herbs to these totals follow. In Section B pollen frequencies of *Betula*, *Alnus*, Gramineae and Cyperaceae are shown as percentages of total arboreal pollen and the range of occurrence of cereal pollen is indicated. Between the two Sections, a column indicates the main stages in clearance and regeneration: 1, reduction in forest canopy; 2, reduction of shrub growth; 3, maintenance of clearing; 4, shrub regeneration; 5, forest tree regeneration.

(4) Where such a development is followed by an increase of *Quercus* or *Ulmus* pollen or both, with a resultant fall in *Corylus* frequencies but still without the intervention of heliophilous herbs, real regeneration of the appropriate forest tree is assumed. If heliophilous herbs do appear or expand at this point, however, they provide the strongest evidence for *increased* opening of the vegetation. The fall in *Corylus* is then interpreted as the clearance of the shrub itself from areas formerly cleared only, or mainly, of high forest trees. Because of the relatively small contribution of low-growing herbs to the pollen rain a diminution in *Corylus* frequency would, notwithstanding the realities of the vegetational situation, lead to an increased representation of the forest trees.

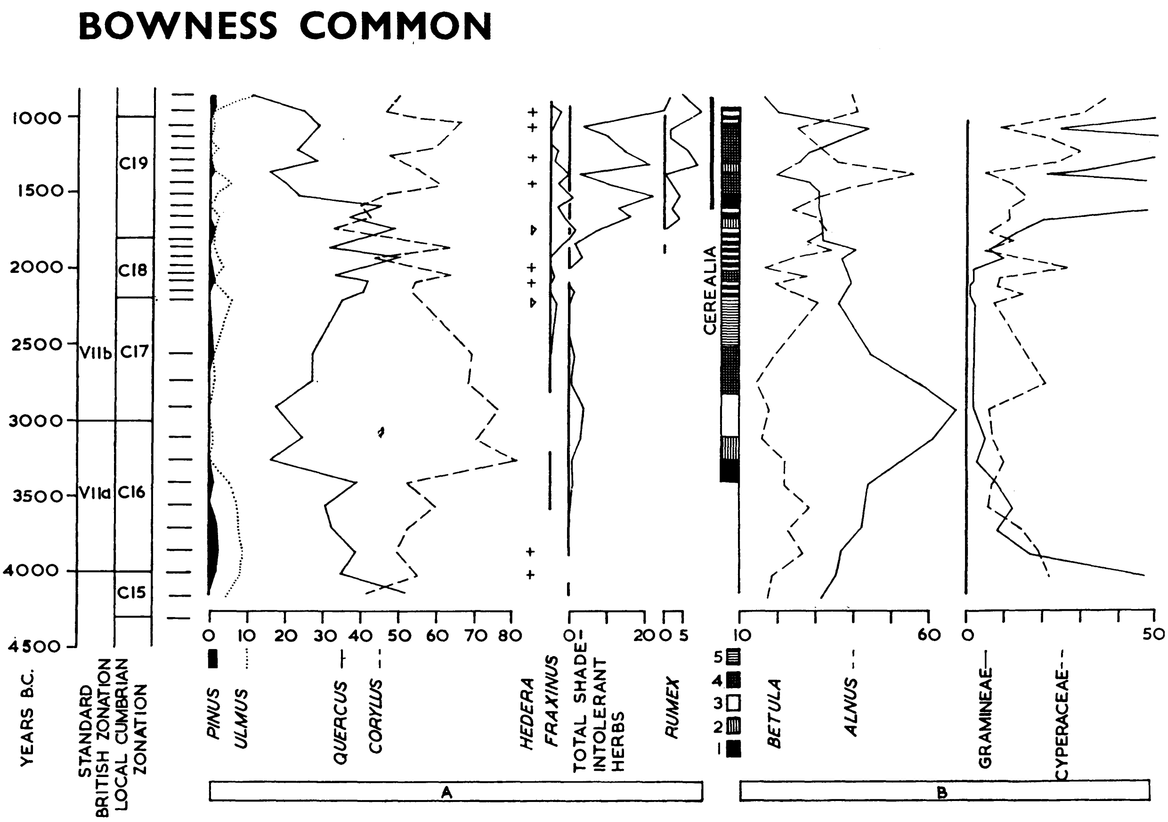


FIGURE 50. Bowness Common. Summary pollen diagram derived from original counts. For further explanation see figure 49.

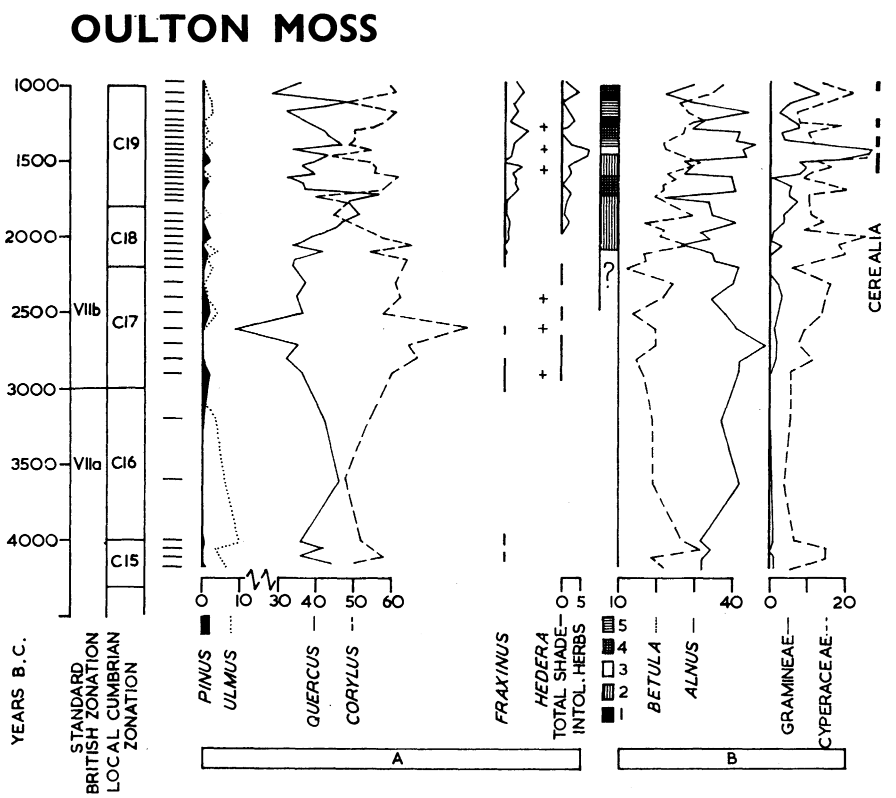


FIGURE 51. Oulton Moss. Summary pollen diagram derived from Oulton Moss A. For further explanation see figure 49.

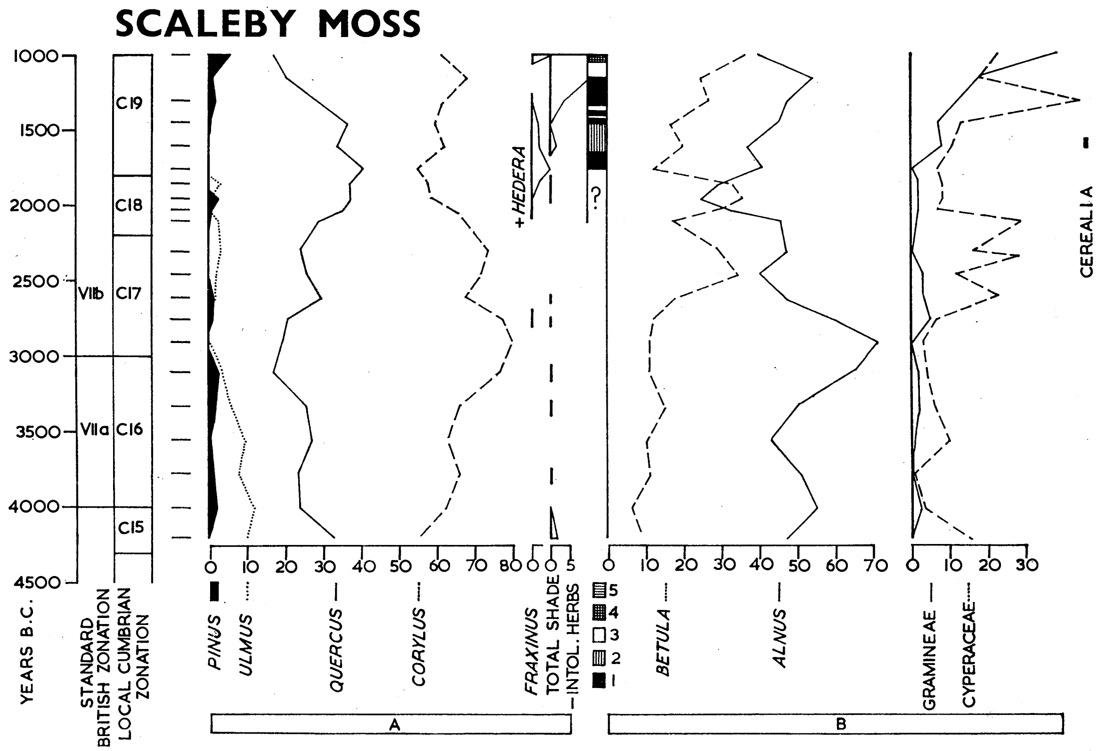


FIGURE 52. Scaleby Moss. Summary pollen diagram derived from Scaleby Moss A. For further explanation see figure 49.

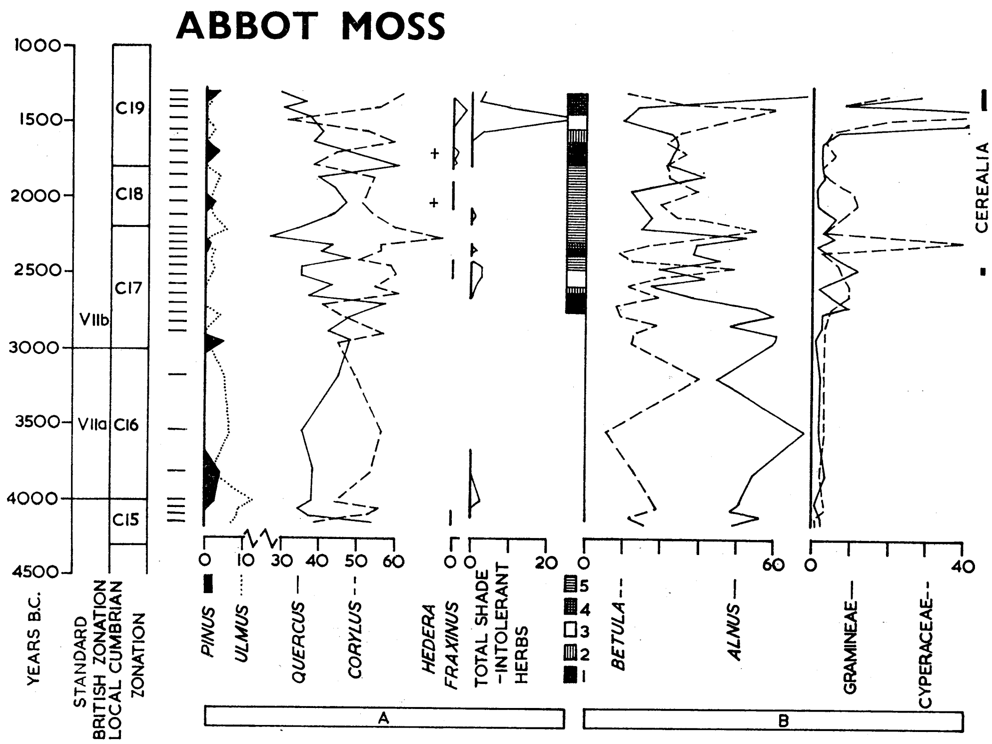


FIGURE 53. Abbot Moss. Summary pollen diagram derived from Abbot Moss A. For further explanation see figure 49.

(5) Where frequencies of heliophilous herb pollen fall, a rise in the frequency of any of the forest trees or shrubs must indicate recolonization by them of the formerly cleared area. Where the rise in any one of these, e.g. *Corylus*, is very great, the frequencies of the other components will be depressed and this does not necessarily exclude the possibility that the actual plants themselves were actively regenerating at the time.

(6) The behaviour of the curve for *Fraxinus* pollen, where it occurs, is interpreted in much the same manner as that for *Corylus* pollen. The curves for *Betula* and Gramineae, neither of which is included in the main calculation, are used only as sources of secondary value, as are the curves for other herbaceous plants (e.g. Compositae, Rosaceae, *Pteridium*, etc.), and for the *qualitative* differentiation of the vegetation.

Using these criteria, vegetational changes in the immediate vicinity of a site which involve the appearance and possibly the disappearance of heliophilous herbs in significant amount can be described as follows:

(*a*) Reduction of the forest canopy by branch pruning, bark-peeling, defoliating disease, or tree felling.

(*b*) Reduction of shrub growth by disease or cutting and clearing.

(*c*) Maintenance of an unshaded area in which heliophilous herbs (and often grasses) flourished.

(*d*) Regeneration of shrub growth in an area formerly cleared or over which the forest canopy has been reduced.

(*e*) Regeneration of forest trees over an area formerly clear or occupied by shrubs.

The 'Ulmus' decline

Independent evidence of climatic change, with which the reduction of *Ulmus* during Zone C16 (VIIa) would be consistent, is lacking in the Cumberland Lowland. The

TABLE 12.

zone		number of sites represented	number of samples analysed	number of samples containing *Hedera*	percentage of samples containing *Hedera*
	C23	1	7	3	43
	C22	1	25	3	12
	C21	1	5	2	60
	C20	2	12	3	25
VIIb,	C19	6	54	20	37
	C18	5	28	7	25
	C17	5	39	9	23
VIIa	C16	5	22	2	9
	C15	5	20	6	30
	C14	5	35	11	31
	C13	5	20	8	40
VI	C12	6	16	6	37
	C11	3	9	4	44
	C10	3	14	1	7

frequency of samples in which pollen of *Hedera helix* occurs, expressed as percentages of the total number of samples analysed for each zone at all the sites at which that zone is represented, shows a significant decrease in Zone C16 (table 12).

Values of an order comparable with that of Zone C15 recur in Zones C17, C18 and later, however, so that, if climatic change is invoked to explain the fall in C16, its effects must have been both short-lived (about 1000 years) and reversible. This is far from being impossible, but it would be difficult to suppose what kind of climatic change could so affect *Hedera helix* in a region so intensely oceanic, yet allow its recovery soon after. In view of this, and of Troels-Smith's (1960) contentions about the use of ivy as a fodder plant in the European Neolithic, the further consideration of this problem is best deferred.

The first unequivocal evidence of established clearings in the forest occurs in the following Zones:

Ehenside Tarn	Zone C16 (VIIa)	Oulton Moss	Zone C18
Bowness Common	Zone C16 (VIIa)	Scaleby Moss	Zone C19
Abbot Moss	Zone C17 (VIIb)		

The processes resulting in these clearings were initiated some time before at each site and took a greater or lesser time to complete.

At Ehenside Tarn the initiation of the first clearing (clearance A, part IV) took place with the opening of the forest canopy at the beginning of Zone C16 (figure 49). *Ulmus* and *Quercus* were both reduced and *Corylus* flowered abundantly whilst *Fraxinus* also became established. Subsequently the shrubs were reduced and an open, herb-dominated, clearing established. There is some slight evidence that, in the later stages, *Ulmus* was destroyed preferentially to *Quercus*; the latter certainly played some part in subsequent regeneration which *Ulmus* did not.

In the ecotone between oak and elm forest patches, seedlings of each would grow up beneath the other. Edaphic conditions would not permit the young elms to survive beneath the oaks. Nor is it likely that, in spite of the developing soil conditions there, the oak seedlings would persist long beneath the shade of the elms, reduced in vigour though the latter may have been. It seems unlikely, therefore, that the natural replacement of elm by oak was the result of established young oaks growing upwards into trees continuously as the elm canopy deteriorated. A much more likely sequence of events would be that the dying of an elm would allow the growth of pioneer shrubs, such as *Corylus*, beneath it. New seedlings of elm and oak would compete there and under such conditions, where light was no longer a limiting factor favouring the elm, the edaphic conditions would encourage the growth of the oaks. Heliophilous herbs would play no significant part in this process, although they might find temporary places in it in the earliest stages. Otherwise, this process would be impossible to identify pollen-analytically from a clearance of the forest by human agency in which elms were preferentially felled.

To explain the sequence of events at Ehenside as the results of a disease would demand that the pathogen first attacked the forest trees and only subsequently the shrubs and that it then so reduced the woody vegetation as to allow herbs to dominate the clearing without deleteriously affecting them. Such a situation, although not impossible, seems fairly unlikely.

At Bowness Common, isolated records for heliophilous herbs (e.g. *Artemisia*, *Plantago coronopus*) could be attributed to the low coastal position of the site. The expansion of herbs as the coast receded is difficult to interpret similarly, however, and the establishment of a forest clearing late in Zone C16 (VIIa) seems probable. As at Ehenside, the tree felling which initiated the clearance (figure 50) affected both *Ulmus* and *Quercus* together but subsequently in Zones C17 and C18 *both* regenerated. A climatic explanation for this behaviour would be difficult to find.

At Oulton Moss (figure 51) and Scaleby Moss (figure 52) much of the diminution in *Ulmus* is totally unaccompanied by positive evidence of nearby clearances although, at the latter site, isolated occurrences of heliophilous herbs are recorded. On the whole, *Ulmus* and *Quercus* curves run parallel, equally affected by, or themselves influencing, the generally rising *Corylus* values. Finally, at the C16–C17 border, *Ulmus* is preferentially reduced and, being low already, falls to zero. At Oulton Moss this event can rather uncertainly be associated with the beginnings of clearance culminating in Zone C18. A peak in *Ulmus* values in the middle of Zone C17 at Oulton Moss is probably the effect of falling *Corylus* values only but the rise across the C17 to C18 border which is paralleled by the *Corylus* curve must imply elm regeneration there. Similarly, although the apparent beginnings of its recovery early in Zone C17 at Scaleby Moss might be entirely the results of changes in *Corylus* frequency, this cannot be true of its maintenance through the rest of that Zone. If the primary hypothesis on which these diagrams are based is correct, the '*Ulmus*' decline at these two sites during Zone C16 cannot be *only* the result of the replacement of *Ulmus* by *Quercus*. It could be that clearances of the type recorded at Ehenside and Bowness Common, although not directly affecting the local component of the pollen rain at Oulton Moss and Scaleby Moss, so increased the abundance of *Corylus* in the regional pollen rain as to lead to the records made there. The already low levels of *Ulmus* pollen would lead to its relatively early disappearance from the pollen diagrams and so enhance the proportional representation of *Quercus* regionally in the remaining woodlands. The fact of the later regeneration of *Ulmus* at all save Ehenside Tarn, suggests that neither a major climatic change nor the ultimate development of podsols over all the area was responsible for the temporary disappearance of *Ulmus* in C16 and C17. It could reasonably be supposed, however, that the very disturbance of the soil associated with forest clearance might temporarily have restored the edaphic balance in favour of elm regeneration.

The reason for the big fall in *Ulmus* pollen frequency early in Zone C16 at Abbot Moss (figure 53) cannot be hazarded. Immediately afterwards the values rise somewhat and subsequently falling *Ulmus* and *Corylus* curves accompany a steady rise in *Quercus*. This can be explained as the continuing replacement of elm by oak on the sandy soils of the Eden Valley. But the final reduction of the elm at the beginning of Zone C17 is also associated with a fall in *Quercus* and a rise in *Corylus*. After some confused interaction between the curves positive evidence of forest felling leading to clearings in the immediate vicinity of Abbot Moss is found. It is probable, therefore, that the events at the beginning of Zone C17 represent the changes in regional pollen rain resulting from clearings immediately outside the Abbot Moss basin.

The difficulty of attributing a climatic cause to the early clearings at Ehenside Tarn and Bowness Common has already been remarked above. They are better interpreted as the result of positive human interference. The results from Scaleby Moss and Oulton Moss do not exclude climatic interpretation but are more readily explicable as the regional effects, along the more coastal strip, of the processes more closely documented at the other two sites. They cannot represent the culmination of edaphic changes already well developed. But these edaphic changes did continue in some parts of the Eden Valley where the natural processes were largely unaffected by Man's activities until the beginning of Zone C17. In general, therefore, the '*Ulmus* decline' of Zone C16 in the Cumberland Lowland was probably due in the uninhabited areas to progressive edaphic depauperation but the effects of this process were totally overshadowed by human activities over considerable parts of the area, and it is to these that the total extinction of the elm for a time at any locality must be attributed.

The early clearances

Clearing of the forest, almost certainly attributable to human activity, is recorded during Zones C16 and C17 near all sites other than Oulton Moss and Scaleby Moss. The pollen diagrams from the latter sites, however, exhibit the regional effects of such clearances. It seems likely that, although this process began along the coastal strip at the beginning of Zone C16 (*ca.* 4000 B.C.), it was not common in the northern Eden Valley until the beginning of Zone C17 about a thousand years later. This would be consistent with a spread of people or techniques from the Irish Sea basin inland across the coastal areas and up the greater valleys. There is no archaeological material stratified into any of the organic deposits of this period so it is impossible certainly to correlate a particular material culture with this first impact on the forest. Watts (1960) has shown that at least some Larnian people in Ireland adopted Neolithic techniques before 3000 B.C. and it may well have been through people of the same material culture that these first spread to the north-west of England (part I).

The sequence of events in these early clearances seems always to have been the same. First the high forest trees, both *Ulmus* and *Quercus*, were either felled or defoliated. As a result the undershrub *Corylus*, joined sometimes by *Fraxinus* and probably by some *Betula*, spread and flowered freely. Rare plants of *Plantago* spp., *Rumex* and *Artemisia* took advantage of the slight ground disturbance and Gramineae usually increased their cover or flowering. The dominance of this 'undergrowth' seems often to have lasted for some time as if the reduction of the large trees was not so much the initial stage in the purposeful development of a particular clearing, but part of a more general process perhaps carried far beyond the human habitations of the time. Troels-Smith (1960) has advocated the collection and utilization of *Ulmus* twigs and young foliage as an explanation of the '*Ulmus*' decline (Heybroek 1963). Although there is no evidence for or against this hypothesis in the present data, it is hardly likely to have applied equally to the oak, and actual felling of the forest trees for timber and firewood and the collection of bark for building and clothes seems at present to be the simpler explanation of events. That such activities could be carried on far beyond the limits of actual settlement is to some extent borne out by observations of the great distances travelled by peoples living under somewhat analogous conditions at the present day (e.g. some New Guinea highlanders) in order to extract timber. The fairly long time periods over which these effects are indicated in any one pollen diagram could also be explained in this way.

The second stage involved the clearance of the now luxuriant shrub growth and its replacement by open herbaceous sward from which *Plantago lanceolata* and the Gramineae contributed most characteristically to the pollen rain. *Rumex* sp. also became significant at Ehenside Tarn but was absent elsewhere. *Plantago coronopus*, presumably readily available from coastal salt marshes, was important at Bowness Common whilst at Abbot Moss *Plantago major* was the commonest herb represented. At all three sites *Pteridium* increased significantly with the clearance of the shrubs and at this stage probably flourished mainly around the margins of the clearings.

There is no positive evidence for the habitual use of fire during these felling or clearing operations.

A clearing was maintained in much the same state as that described above for a variable period of time, the only consistent change being the steady increase in the importance of *Pteridium*. Subsequently, regeneration of woody plants took place, greatly reducing or entirely replacing the herbs and *Pteridium*. Regeneration usually began with the recolonization of the clearing by *Corylus*, presumably accompanied, or slightly preceded, by *Betula*. *Fraxinus* was evidently important near both Ehenside Tarn and Bowness Common but not on the lighter soils around Abbot Moss. Indeed, at the latter site, regeneration of *Corylus* was not at all pronounced, whereas the increased contribution of *Betula* to the pollen rain was very marked: a further example of the edaphic control of vegetational development. Regeneration of the forest trees then took place near Abbot Moss and Bowness Common, the evidence for regeneration of *Ulmus* at this stage being somewhat equivocal at the latter. At these sites the success of *Corylus* and *Betula* was reduced as a result of the forest growth. Near Ehenside Tarn it seems unlikely that a forest period intervened between a rather substantial time of shrub dominance and the renewal of clearing activities.

The flora of the clearances gives little indication of the purpose for which they were used. Their creation represented major works on a scale exceeding that which might have been necessary simply for human habitation sites. Some kind of husbandry or agriculture therefore seems to have been likely. No crop plants are recognized in the flora. Grasses, whilst present in considerable quantity, were not so ubiquitous as to prevent the establishment of ruderals in breaks in the sward. This evidence, such as it is, is consistent with the suggestion that each clearing carried but a few domestic animals and that these were of a kind, such as cattle, whose trampling was less conducive to the establishment of a continuous grassy sward than that, say, of sheep. The spread of *Pteridium* into such clearings would be facilitated by overgrazing and not seriously discouraged even by the collection of its fronds for litter (cf. Tansley 1939). Troels-Smith (1960) has emphasized the importance of collected twigs and leaves of elm and ivy in maintaining animal populations greater than could be supported entirely by the grass of the early Neolithic clearings. Using Sjobeck's estimate (in Clark 1952) of 1000 kg of leaves and twigs per prehistoric cow per winter for survival, several square miles of forest must have been utilized in this way for the maintenance of a single cow. The effect of this on the general forest cover of the region could have been prodigious and might have contributed considerably to the specific reduction of the elm in the forests. The regeneration of shrubs and trees must indicate the removal of these pressures, i.e. the abandonment of the clearing. It suggests, too, that free grazing and browsing by cattle was not common in the forests or on formerly cleared ground for this would have prevented the successful regeneration of the woody plants.

The indications are that husbandmen with cattle, and quite probably with some other domesticated or partly domesticated animals, e.g. pigs, encroached on any particular area first felling the forest trees for wood and collecting the leaves and young shoots for animal fodder and peeling the bark for house building materials (cf. Iversen 1960). Later, they selected and cleared areas of the resulting bush land as bases from which to extend their foresting activities and in which to keep and graze their animals. Encroachment of *Pteridium* into the clearings and the increasing proportion of weeds to grasses there, combined with the ever greater distances to be covered for wood and tree-fodder, finally forced abandonment of each clearing. The time from the beginning of the clearance of the shrubs to the beginning of shrub or forest regeneration seems to have varied from about 200 years near Abbot Moss and 400 years near Bowness Common to about 700 years near Ehenside Tarn.

The striking fall in the frequency of samples containing pollen of *Hedera helix* during Zone C16 cannot be more closely analysed in the diagrams showing evidence of early clearance. At Ehenside Tarn and at Bowness Common there is a superficial suggestion that *Hedera* was rarer during felling, clearing and maintenance than during subsequent regeneration but the absolute number of pollen grains involved is too small fully to substantiate this view. The strong evidence for human interference with the forest during Zone C16 must modify any climatic interpretation of the temporary reduction of *Hedera* in that Zone (cf. Iversen 1960; Troels-Smith 1960; Smith 1961 *a*).

Near Abbot Moss and Bowness Common regeneration of the forest trees followed the earliest clearance and in the restored forest *Ulmus* was less prevalent than it was, say, in the middle of Zone C16 before the steep decline had begun. On the other hand, it was more common than might have been expected had the *general* diminutionary tendencies of Zones C10 to C16 been continued, uninterrupted, through Zone C17. It is therefore possible, indeed likely, that the clearances temporarily favoured *Ulmus* as against *Quercus* in the regeneration phases. *Fraxinus* had also become well established as a woodland shrub.

Near Ehenside Tarn, only shrub regeneration followed the early clearance and this was soon cleared once more and a balance of vegetation very similar to that of the height of the early clearance re-established. This was maintained over a long period (about 1100 years from the beginning of the shrub clearance) punctuated by very slight and temporary shrub regeneration. There was virtually continuous occupation of the Ehenside locality, therefore, from the beginning of Zone C16 (*ca.* 4000 B.C.) during which time two significant changes are documented in the economy of the people concerned. The first of these is a slight increase in the contribution of grasses relative to that of broad-leaved herbs in Zone C17. The second is the presence of cereals in small quantity from the end of Zone C17. These and a slight increase in the variety of herbs recorded, including *Chenopodium*, *Pastinaca*, *Plantago maritima* and *Artemisia*, argue a slow change in the economy. Probably this began by greater dependence on the grazing of grassland and less on collected fodder for the maintenance of stock. Then cereal crops were grown in an experimental fashion. Yet there is little evidence for renewed and extensive clearance of the virgin forest during this time. The implication of this, particularly in the light of the possible greater reliance on grazing, is that neither the human nor the stock population increased very much.

Near Abbot Moss, the forest seems to have been substantially undisturbed until the beginning of Zone C19. At Bowness Common there is some evidence of slight and temporary clearance of the regenerated forest early in Zone C18 and subsequent shrub regrowth. At Oulton Moss and Scaleby Moss the indications of changes in the regional forest continue without significant alteration until the middle of Zone C18 in the former and the end of the same zone in the latter. Until the latter part of Zone C18 and the beginning of Zone C19 (2000 B.C. to 1750 B.C.) a people with a slowly changing economy were living more or less permanently at some sites (e.g. Ehenside Tarn) whilst other groups probably of the same people, were more nomadic and conservative in their agricultural habits. Evidence from archaeological sites, with which are associated radiocarbon dates, outside the north-west of England strongly suggests that axes made of Lake District rocks were being exported from the area between 2500 B.C. and 2000 B.C. The people quarrying these stones in the mountains must have been associated with the makers of the early clearances in the lowland forests (Piggott 1962).

The later clearances

Near Ehenside Tarn a new impact on the forest was evidently made early in Zone C19 (*ca.* 1600 B.C.) (Clearance C in part IV). Although the abundance of all herbaceous plants greatly increased as the forest reduced, the grasses seem to have played a relatively less important role in the resulting open sward. Cereal pollen is recorded in considerable frequency from this phase. This would be consistent with an economy in which grazing was relatively less important than formerly and in which agriculture figured largely. Nevertheless, it seems very likely that the absolute numbers of grazed animals and the asolute area of grazing land increased considerably at that time.

At Bowness Common a clearance of shrubs and forest late in Zone C18 led to a balance of herbs in which the grasses at first figured considerably. Above that level it is difficult to separate in the pollen diagram the contribution from grasses growing on the bog surface, but it seems reasonably certain that grasses continued to play an important part in the clearing vegetation. Cereal pollen is commonly recorded, together with a greater variety of weeds than before (e.g. *Chenopodium*, Compositae, Cruciferae and freshly important *Rumex* cf. *acetosella*). The period extended from about 2000 B.C. to at least 1000 B.C., the main impact being roughly contemporaneous with the introduction of cereals at about 1700 B.C.

Near Abbot Moss, forest was cleared in Zone C19 (beginning about 1750 B.C.) on a hitherto unprecedented scale and, in the resulting vegetation, herbs (e.g. *Rumex*, Compositae, *Plantago* spp.) were relatively more important, in their relation to grasses, than had earlier been the case. Records of cereals are hardly significant, however.

The first completely unequivocal indications of clearance in the immediate vicinity of Oulton Moss date from Zone C18 (about 2000 B.C.). This was maintained with a short period of shrub regeneration well into Zone C19 where a pronounced and renewed activity took place at about 1500 B.C., from which time onwards cereals are recorded with some consistency. Cruciferae and Compositae were common throughout this period whilst latterly *Artemisia* and *Succisa* played an increasingly important role.

From Scaleby the record is less detailed, but local clearance of forest evidently began early in Zone C19 (about 1750 B.C.) and continued at a greatly increased rate from about 1400 B.C.

At all these sites *Pteridium* was very important, particularly during the early stages of the later clearances. Later (e.g. at Ehenside) there is some indication of a reduction in *Pteridium* as if some measure of partial control, natural or artificial, had been achieved. At Oulton Moss fragments of charcoal frequently found their way on to the mire at the beginnings of settlement during Zone C18. Similarly, charcoal is very abundant in Ehenside Tarn muds dating from early in Zone C18 until the end of Zone C20. This may be indicative of the use of fire in the actual clearing processes around these two sites, but might equally easily be explained by supposing actual human settlement to have taken place on the banks of the basins. The radiocarbon date of about 2128 B.C. for a 'stake' from the Ehenside Tarn platform confirms the latter view (part IV).

At Oulton Moss, Scaleby Moss, Abbot Moss and Bowness Common some slight regeneration of forest and shrubs seems to have followed this phase but, in so far as the pollen diagrams are reliable when derived from so close to the surface, the cleared area was never totally annihilated, and partial occupation was maintained, to be extended later.

The general indications are, therefore, that further clearing activity spread through the Cumberland Lowland from about 2000 B.C. This was given new impetus during the period 1750 B.C. to 1400 B.C. when a new economy, more sedentary and utilizing cereals widely, became established. Areas of better soil were evidently most early affected whilst impact on the low clay areas (e.g. around Scaleby Moss) was correspondingly delayed. It is evident that, for the greater part of the region, this was the time at which serious irreversible changes in the vegetation balance began. It is tempting to suggest that this was the result of the wide use of the polished stone axes quarried in the nearby Lake District hills (Bunch & Fell 1949; Fell 1954; Plint 1962). The archaeological evidence from Ehenside Tarn (part IV) does not conflict with this view but is still insufficiently good certainly to confirm it. It is clear from the earlier occurrence of cereals at Ehenside Tarn, however, that it was not the introduction of cereals alone which encouraged more extensive settlement. However, given a new means of forest clearing or a critical level in population growth, the availability of cereals would remove some of the former checks on settlement extension. If, as has already been argued (part I), 'Beaker cultures' encroached into the south-east of this area and strongly affected the indigenous Neolithic population as far as the coast, this might also have contributed to the settlement expansion.

After Zone C19 the only pollen analytical evidence for vegetation change derives from Ehenside Tarn (part IV). There the balance initiated early in Zone C19 continued virtually unchanged until early in Zone C21 (about A.D. 100). There is no indication of progressive and wide extension of the cleared area about the site during the greater part of this period (Clearance Stage C) but increased numbers of grass pollen attributed to cereals and increased abundance of *Rumex* cf. *acetosella* might be taken as indications of intensified agriculture, whilst lower frequencies of *Pteridium* spores might equally well suggest better management of grazing lands. The implication of this is that the archaeological developments of the Bronze Age and the Iron Age (in so far as the latter affected this region) did not significantly influence the type of agriculture which had been practised in the lowland since middle Neolithic times. This is in keeping with the archaeological data which indicate that the heaviest Bronze Age settlements were restricted to the higher land and that the Iron Age in the usual sense was hardly represented at all in Cumberland.

There followed a period of about 300 years (Stage *Cc*), roughly equivalent to Zone C21, when the abundance of all dry-land herbs was somewhat reduced and regeneration of forest trees took place in which *Ulmus* and to a lesser extent *Pinus* played a significant part. The cleared areas were certainly not abandoned entirely and cereals continued to be grown, but some temporary recession in agricultural activity took place. If the chronology of the Ehenside Tarn deposits is dependable, this recession must have taken place at about the time of the Roman occupation of the Cumberland Lowland. It might reflect the disturbance wrought by the early Brigantean wars followed by urbanization and the employment of local people in the Roman forces and administration during the occupation.

Post-Roman land utilization

The Roman occupation certainly did not exterminate farming in Lowland Cumberland and it may well be that in many parts, for which pollen analytical data are not available, there was a positive stimulus to crop and animal production at this time to meet the needs of the Roman garrisons. Immediately afterwards, however, a new impetus was given to agriculture. The evidence from Ehenside Tarn indicates renewed and vigorous forest clearance at least until about A.D. 800 and the expansion of farming similar in kind but considerably greater in extent than that which had preceded the Roman invasion. There is a strong temptation to attribute the initiation of this movement to the reduction in available urban and military employment after the Roman withdrawal, and its extension and success to the new materials and techniques which the Romans had introduced and the new freedom of movement, both into and within the region, which their road system had provided. Under these conditions, with untouched woodland still to be cleared, a considerable population increase was almost inevitable. The historical and archaeological evidence suggests that both Anglian and Scandinavian settlement of Cumberland was predominantly peaceful and that the latter, in the main, settled the valleys and upland areas beyond the region of established occupation. There they made their farms based on extensive upland grazing. On the lowlands a slow increase in agriculture, as distinct from husbandry, probably took place under English influence. Even on the lowlands, however, clearance of forest and scrub and grazing of cattle were the predominant farming methods of the pre-Monastic period.

In the absence of pollen diagrams covering these periods from any site other than Ehenside Tarn it is difficult to achieve a more dependable generalization about the development of land utilization than has already been elaborated from historical data (part I). Moreover it is likely that by about the height of Clearance Stage D i.e. about A.D. 800, the area around Ehenside Tarn itself was virtually deforested, making the usual techniques of detailed interpretation inapplicable. Thus, whilst *Linum* and *Cannabis* (or *Humulus*) were introduced a short time before this, they reached their maximum in a subsequent period during which the heliophilous herbs were but poorly represented in the pollen rain. This may indicate a local change in the farming economy rather than a reduction of the area being farmed. It would be consistent with the increasing influence of the monasteries during the twelfth and thirteenth centuries. Nevertheless, the Ehenside deposits of this and subsequent periods have yielded formidable evidence of open environments and disturbed soil, e.g. *Ulex*, *Juniperus*, *Centaurea nigra*, *Chrysanthemum segetum*, *Descurainia sophia*, *Petroselinum segetum* and *Trifolium scabrum* (part IV).

The causes of vegetational change

The series of events which led up to the early clearances and the manner in which the later clearances were maintained was such as can be explained only with extreme difficulty in terms of climatic or edaphic determination. On the other hand they are consistent with reasonable views about probable human activities and their chronology can easily be harmonized with archaeological and historical evidence for settlement of the region. The clearances are therefore positively attributed to human activity.

The decline of *Ulmus* during Zone C16 (VIIa) is attributable to progressive replacement of elm by oak resulting from the long established trend towards soil depauperation but the suddenness with which the elm was virtually annihilated, particularly in the coastal areas, was the result of forest clearance by human agency. Minor regeneration of the elm afterwards may have been due to the aftermath of the clearances themselves but the maintained success of the elm and pine from the beginning of Zone C22 onwards at Ehenside Tarn is difficult to explain in a similar manner. It may simply be the result of selective felling of oak in the post-Roman period but there is no factual evidence of this from the region. A climatic cause cannot be ruled out.

The behaviour of *Fraxinus* was clearly related to clearance phenomena, particularly in its early stages. No attempt is made to explain its late arrival in the north-west of England but it evidently owed its widespread establishment on the boulder-clay areas to human destruction of the high forest.

On many occasions *Betula* can be shown to have reacted strongly at times contemporary with the abandonment of a clearing. It is also true, however, that podsolization progressed so far in many localities that *Betula* woodlands probably formed the edaphic climax there and on cut and drained bogs. Edaphic and human effects therefore encouraged the expansion of *Betula* and there seems no reason to invoke climatic change in explanation of its success.

The possible evidence for climatic change since the beginning of Zone C16 (*ca.* 4000 B.C.) in the area is therefore limited to the recurrence surfaces of Scaleby Moss and the revertance of *Ulmus* and *Pinus* in the Ehenside Tarn pollen diagram. Less certainly significant are the water-level changes recorded at Oulton Moss and Ehenside Tarn. These data cannot readily be fitted to a single hypothesis of climatic change but they none the less urge caution in dismissing the possibility of any such changes in the north-west of England since 4000 B.C. It is reasonably clear, however, that during the past 5000 years or more the dominant determinant of vegetation has been human activity with edaphic and climatic factors playing but a secondary role.

The climatic optimum

The concept of a period of post-Glacial climatic optimum is difficult to apply in the face of increasing knowledge of the autecologies of different species. In the Cumberland Lowland itself there were no vegetation changes certainly indicative of 'improved' thermal conditions after about 6000 B.C. In the region immediately south of the Lake District hills, however, the occurrence of *Tilia cordata* on base-rich soils (Smith 1958, 1959; Oldfield 1960*b*; Walker 1955*a*) cannot be similarly dismissed. The pattern of the spread of *T. cordata* through Great Britain (Godwin 1956) certainly suggests that its extension was slowed by competition from the existing closed forests of oak and elm and that it did not reach the north-west until very late, possibly long after the region became climatically suited to it. Its very establishment at the limit of its range in Zone VIIa under these conditions argues a change in the factors determining forest composition which is difficult to attribute to anything other than climate. The virtual absence of *Tilia* in Cumberland at the time may have been due to the absence of suitable soils but it might equally have been true that any climatic change failed to transgress the threshold of tolerance for *Tilia* in that region.

The humidity of the region was evident already in late-Glacial time (part VI). There is no pollen analytical evidence for a dry period at any time in the post-Glacial. The extension of *Alnus glutinosa* in Zones C12 (Boreal-Atlantic Transition) is attributed to an effective increase in rainfall which may have been going on for some time already (part VII). At Ehenside Tarn and at Scaleby Moss there are stratigraphic indications which might be interpreted as evidence of increased precipitation affecting one of these sites in Zones C16 (*ca.* 3500 B.C.), C18 (*ca.* 1900 B.C.) and C21–C22 (*ca.* A.D. 0–1000). A fuller understanding of the causes of recurrence horizons is necessary before these suggestions can be substantiated (Conway 1948; Godwin 1954; Walker 1961). It is certain, however, that evidence of increased precipitation is more likely to be preserved in organic deposits than is evidence of desiccation, so that a lack of evidence for dryer periods does not preclude their having occurred.

As far as it goes, therefore, the evidence suggests that a thermal 'optimum' might have been achieved early in the post-Glacial and that increases in precipitation:evaporation ratio occurred from time to time throughout the period.

REFERENCES

Andersen, A. 1954 Two standard pollen diagrams from South Jutland. *Danm. geol. Unders.* II, **80**, 188.

Armstrong, A. M., Mawer, A., Stenton, F. M. & Dickins, B. 1952 *The Place-names of Cumberland*, **22**, III. Cambridge University Press.

Arnold, J. J. & Libby, W. F. 1951 Radiocarbon dates. *Science*, **113**, 111.

Atkinson, R. J. C. 1956 *Stonehenge*. London: Hamilton.

Averdieck, F. R. & Döbling, H. 1959 Das Spätglazial am Niederrhein. *Geol. Rheinland und Westf.* **4**, 341.

Bailey, J. & Culley, G. 1797 *A general view of the agriculture of the County of Cumberland*. London.

Barker, H. & Mackey, J. 1961 British Museum natural radiocarbon measurements. III. *Radiocarbon*, **3**, 39.

Barnes, F. & Hobbs, J. L. 1951 Newly discovered flint-chipping sites in the Walney Island locality. *Trans. Cumb. West. Ant. Arch. Soc.* (N.S.), **50**, 15.

Bellhouse, R. L. 1958 Roman sites on the Cumberland coast 1956. *Trans. Cumb. West. Ant. Arch. Soc.* (N.S.), **57**, 18.

Benninghoff, W. S. 1952 Interaction of vegetation and soil frost phenomena. *Arctic*, **5**, 34.

Blackburn, K. B. 1952 The dating of a deposit containing an elk skeleton found at Neasham near Darlington, County Durham. *New Phytol.* **51**, 364.

Blake, B. 1955 *The Solway Firth*, London: Hale.

Bradley, D. E. 1958 The study of pollen grain surfaces in the electron microscope. *New Phytol.* **57**, 226.

Bunch, B. & Fell, C. 1949 A stone-axe factory at Pike of Stickle, Great Langdale, Westmorland. *Proc. Prehist. Soc.* **15**, 1.

Carruthers, R. G. 1939 On northern glacial drifts; some peculiarities and their significance. *Quart. J. Geol. Soc. Lond.* **95**, 299.

Carruthers, R. G. 1947 The secret of the glacial drifts. *Proc. Yorks Geol. Soc.* **27**, 43.

Casparie, W. A. & van Zeist, W. 1960 A Late-glacial lake deposit near Waskemeer (Prov. of Friesland). *Acta Bot. neerl.* **9**, 191.

Charlesworth, J. K. 1926 The readvance marginal kame moraine of the south of Scotland and some later stages of retreat. *Trans. roy. Soc. Edinb.* **55**, 25.

Charlesworth, J. K. 1957 *The Quaternary era.* London: Arnold.

Cherry, J. 1961 Cairns in the Birker Fell and Ulpha Fell area. *Trans. Cumb. West. Ant. Arch. Soc.* (N.S.), **61**, 7.

Clapham, A. R., Tutin, T. G. & Warburg, E. F. 1952 *Flora of the British Isles.* Cambridge University Press.

Clark, J. G. D. 1952 *Prehistoric Europe.* London: Methuen.

Clark, J. G. D. 1955 A microlithic industry from the Cambridgeshire Fenland and other industries of Sauveterrian affinities from Britain. *Proc. Prehist. Soc.* **21**, 3.

Collingwood, R. G. 1933 An introduction to the prehistory of Cumberland, Westmorland and Lancashire North-of-the-Sands. *Trans. Cumb. West. Ant. Arch. Soc.* (N.S.), **33**, 163.

Conolly, A. P. 1961 Some climatic and edaphic indications from the Late-glacial flora. *Proc. Linn. Soc. Lond.* **172**, 56.

Conolly, A. P., Godwin, H. & Megaw, E. M. 1950 Studies in the Post-glacial History of British Vegetation. XI. Late-glacial deposits in Cornwall. *Phil. Trans.* B, **234**, 397.

Conway, V. M. 1948 von Post's work on climatic rhythms. *New Phytol.* **47**, 220.

Dahl, E. 1951 On the relation between summer temperature and the distribution of alpine vascular plants in the lowlands of Fennoscandia. *Oikos*, **3**, 22.

Dakyns, J. R., Tiddeman, R. H. & Goodchild, J. G. 1897 The geology of the country between Appleby, Ullswater and Haweswater. *Mem. Geol. Surv. U.K.* Sheet 102 SW.

Daniel, G. 1958 *The megalith builders of Western Europe.* London: Hutchinson.

Darbishire, R. D. 1874 Notes on discoveries in Ehenside Tarn, Cumberland. *Archaelogia*, **44**, 273.

Dickinson, W. 1852 On the farming of Cumberland. *J. Roy. Agric. Soc.* **13**, 207.

Dixon, E. E. L., Maden, J., Trotter, F. M., Hollingworth, S. E. & Tonks, L. H. 1926 The geology of the Carlisle, Longtown and Silloth District. *Mem. Geol. Surv. U.K.* Sheets 11, 16 and 17.

Donat, A. 1928 Die Verbreitung einiger Isoëtiden. II. *Die Pflanzenareale* (1), **8**, K79.

Donner, J. J. 1957 The geology and vegetation of Late-glacial retreat stages in Scotland. *Trans. Roy. Soc. Edinb.* **63**, 221.

Donner, J. J. 1958 Loch Mahaick, a Late-glacial site in Perthshire. *New Phytol.* **57**, 183.

Donner, J. J. 1959 The Late- and Post-glacial raised beaches in Scotland. *Ann. Acad. Sci. fenn.* (3A), **53**, 1.

Donner, J. J. 1960 Pollen analysis of the Burn of Benholm peat-bed, Kinkardineshire, Scotland. *Soc. Scient. Fennica. Comm. Biol.* **22**, 1.

Druce, G. C. 1932 *The Comital flora of the British Isles.* Arbroath: Buncle.

Du Rietz, G. E. 1942 De svenska fjällens växtvärld. *Ymer*, **62**, 169.

Eastwood, T. 1930 The geology of the Maryport District. *Mem. Geol. Surv. U.K.* Sheet 22.

Eastwood, T., Dixon, E. E. L., Hollingworth, S. E. & Smith, B. 1931 The geology of the Whitehaven and Workington district. *Mem. Geol. Surv. U.K.* Sheet 28.

Elliott, G. 1960 The system of cultivation and evidence of enclosure in the Cumberland open fields in the sixteenth century. *Trans. Cumb. West. Ant. Arch. Soc.* (N.S.), **59**, 85.

Elliott, G. 1961 The decline of the woollen trade in Cumberland, Westmorland and Northumberland in the late 16th century. *Trans. Cumb. West. Ant. Arch. Soc.* (N.S.), **61**, 112.

Erdtman, G. 1952 *Pollen morphology and plant taxonomy. Angiosperms.* Stockholm: Almqvist and Wiksell.

Fair, M. C. 1932 A reconsideration of the lakeside site at Ehenside Tarn. *Trans. Cumb. West. Ant. Arch. Soc.* **32**, 57.

Fell, C. I. 1950 The Beaker period in Cumberland, Westmorland and Lancashire North-of-the-Sands. *The early cultures of north-west Europe* (H. M. Chadwick Memorial Studies). Cambridge University Press.

Fell, C. I. 1954 Further notes on the Great Langdale axe-factory. *Proc. Prehist. Soc.* **20**, 238.

Firbas, F. 1949 *Spät- und nacheiszeitliche Waldgeschichte Mitteleuropas nordlich de Alpen I.* Jena: Fischer.

Firbas, F. 1954 Die Vegetationsentwicklung im Spätglazial von Wallensen im Hils. *Nachr. Akad. Wiss. Götingen* (IIb), **5**, 37.

Firbas, F., Müller, H. & Münnich, K. O. 1955 Das warscheinliche Alter der späteiszeitlichen 'Bolling'—Klimaschwankung. *Naturwissenschaften*, **42**, 509.

Fletcher, W. 1958 Grey Croft stone circle, Seascale, Cumberland. *Trans. Cumb. West. Ant. Arch. Soc.* (N.S.), **57**, 1.

Florin, M. B. 1957 Pollen-analytical evidence of prehistoric agriculture at Mogetorp neolithic settlement, Sweden. *Kungl. Vitterhets Historie och Antikvitets Akadamiens Monografi.* Stockholm, 3.

Fries, M. 1958 Vegetationsutveckling och odlingshistoria i Varnhemstrackten. *Acta phytogeogr. Seuc.* **39**, 1.

de Geer, E. H. 1954 Skandinaviens geokronologi. *Geol. Foren. Stockh. Forh.* **76**, 299.

Godwin, H. 1954 Recurrence-surfaces. *Danm. geol. Unders.* (II), **80**, 22.

Godwin, H. 1955 Vegetational history at Cwm Idwal: a Welsh plant refuge. *Svensk bot. Tidskr.* **49**, 35.

Godwin, H. 1956 *The history of the British flora.* Cambridge University Press.

Godwin, H. 1959 Studies of the Post-glacial history of British vegetation. XIV. Late-glacial deposits at Moss Lake, Liverpool. *Phil. Trans.* B, **242**, 127.

Godwin, H. 1960 The Croonian Lecture. Radiocarbon dating and Quaternary history in Britain. *Proc. Roy. Soc.* B, **153**, 287.

Godwin, H. & Clapham, A. R. 1951 Peat deposits on Cross Fell, Cumberland. *New Phytol.* **50**, 167.

Godwin, H., Suggate, R. P. & Willis, E. H. 1958 Radiocarbon dating of the eustatic rise in ocean-level. *Nature, Lond.* **181**, 1518.

Godwin, H. & Tallentire, P. A. 1951 Studies in the Post-glacial history of British vegetation. XII. Hockham Mere, Norfolk. *J. Ecol.* **39**, 285.

Godwin, H., Walker, D. & Willis, E. H. 1957 Radiocarbon dating and post-glacial vegetational history: Scaleby Moss. *Proc. Roy. Soc.* B, **147**, 352.

Godwin, H. & Willis, E. H. 1959*a* Cambridge University natural radiocarbon measurements I. *Amer. J. Sci. Radiocarbon Supplement*, **1**, 63.

Godwin, H. & Willis, E. H. 1959*b* Radiocarbon dating of the Late-glacial Period in Britain. *Proc. Roy. Soc.* B, **150**, 199.

Godwin, H. & Willis, E. H. 1960 Cambridge University natural radiocarbon measurements II. *Amer. J. Sci. Radiocarbon Supplement*, **2**, 62.

Godwin, H. & Willis, E. H. 1961. Cambridge natural radiocarbon measurements. III. *Radiocarbon*, **3**, 60.

Goodchild, J. G. 1875 The glacial phenomena of the Eden Valley and the western part of the Yorkshire Dale district. *Quart. J. Geol. Soc. Lond.* **31**, 55.

Grainger, F. & Collingwood, W. G. 1929 The register and records of Holm Cultram. *Cumb. West. Ant. Arch. Soc. Rec. Series*, **7**. Kendal: Wilson.

Greenwood, C. & Greenwood, J. 1823 *Map of the County of Cumberland, from an actual Survey made in the years 1821 and 1822 (Scale 1 inch to 1 mile)*. London: Greenwood.

Gresswell, R. K. 1958 The post-glacial raised beach in Furness and Lyth, North Morecambe Bay. *Trans. Inst. Brit. Geogr.* **25**, 79.

Gross, H. 1957 Die geologische Glienderung und Chronologie des Jungpleistozans in Mitteleuropa und den angrenzenden Gebieten. *Quatär*, **9**, 1.

Hafsten, U. 1956 Pollen analytical investigations on the Late Quaternary development in the inner Oslofjord area. *Univ. Bergen Arb. 1956 naturv. R.* **8**, 1.

Hafsten, U. 1958*a* Finds of subfossil pollen of *Koenigia islandica* from Scandinavia. *Bot. Notiser*, **3**, 333.

Hafsten, U. 1958*b* Jordbrukskulturens Historie i Oslo og Mjøstrakten belyst ved pollenanalytiske Undersøkelser. *Viking*, **22**, 51.

Hagerup, O. 1942 The morphology and biology of the *Corylus* fruit. *Biol. Medd. Kbh.* **17**, 6, 1.

van der Hammen, T. 1952*a* Late-glacial flora and periglacial phenomena in the Netherlands. *Leid. geol. Meded.* **17**, 71.

van der Hammen, T. 1952*b* Dating and correlation of periglacial deposits in Middle and Western Europe. *Geol. en Mijnb.* (N.S.), **14**, 328.

van der Hammen, T. 1957*a*. The stratigraphy of the Late-glacial. *Geol. en Mijnb.* (N.S.), **19**, 250.

van der Hammen, T. 1957*b*. A new interpretation of the pleniglacial stratigraphical sequence in middle and western Europe. *Geol. en Mijbn.* (N.S.), **19**, 493.

Hedberg, O. 1946 Pollen morphology in the genus *Polygonum* L. *s.lat.* and its taxonomical significance. *Svensk bot. Tidskr.* **40**, 371.

Hegi, G. 1919 *Illustrierte Flora von Mittel-Europa.* IV: 1. München: Lehmann.

Hegi, G. 1924 *Illustrierte Flora von Mittel-Europa.* IV: 3. München. Lehmann.

Helbaek, H. 1953 Early crops in Southern England. *Proc. Prehist. Soc.* **18**, 194.

Helbaek, H. 1959 Notes on the evolution and history of *Linum. Kuml.*

Heybroek, H. M. 1963 Diseases and lopping for fodder as possible causes of a prehistoric decline of *Ulmus. Acta bot. neerl.* **12**, 1.

Hodgson, K. S. & Harper, K. 1951 The prehistoric site at Broomrigg near Ainstable: the excavations of 1948–49. *Trans. Cumb. West. Ant. Arch. Soc.* (N.S.), **50**, 30.

Hodgson, W. 1898 *Flora of Cumberland.* Carlisle: Meals.

Hollingworth, S. E. 1931 The glaciation of Western Edenside. *Quart. J. Geol. Soc. Lond.* **87**, 281.

Hollingworth, S. E., Carruthers, R. G., Lewis, W. V., Odell, N. E. & King, W. B. R. 1950 Discussion on the origin of glacial drift. *J. Glaciol.* **1**, 430.

Hulten, E. 1950 *Atlas of the distribution of vascular plants in N.W. Europe.* Stockholm: Generalstabens Lithografiska Anstalt.

Hunter Blair, P. 1956 *An introduction to Anglo-saxon England.* Cambridge University Press.

Iversen, J. 1940 Blütenbiologische Studien. I. Dimorphie und Monomorphie bei *Armeria. Biol. Medd. Kbh.* **15** (8), 1.

Iversen, J. 1941 Landnam i Danmarks Stenalder. *Danm. geol. Unders.* II, 66, 1.

Iversen, J. 1942 En pollenanalytisk Tidsfaestelse af Ferskvandslagene ved Nørre Lyngby. *Medd. fra Dansk Geol. Foren.* **10**, 130.

Iversen, J. 1944 *Viscum, Hedera* and *Ilex* as climate indicators. *Geol. Fören. Stockh. Förh.* **66**, 463.

Iversen, J. 1949 The influence of prehistoric man on vegetation. *Danm. geol. Unders.* (IV), **3**, 1.

Iversen, J. 1954 The Late-glacial flora of Denmark and its relation to climate and soil. *Danm. geol. Unders.* (II), **80**, 87.

Iversen, J. 1960 Problems of the early Post-glacial forest development in Denmark. *Danm. Geol. Unders.* (IV), **4**, 3.

Jessen, K. 1949 Studies in the Late Quaternary deposits and flora-history of Ireland. *Proc. R. Irish Acad.* **52** B, 85.

Jessen, K. & Milthers, V. 1928 Interglacial freshwater deposits in Jutland and northwest Germany. *Danm. geol. Unders.* (II), **48**, 1.

Jones, E. W. 1959 Biological flora of the British Isles. *Quercus* L. *J. Ecol.* **47**, 169.

Kendrick, T. D. 1930 *A history of the Vikings*. London: Methuen.

Kirby, D. P. 1962 Strathclyde and Cumbria: a survey of historical development to 1902. *Trans. Cumb. West. Ant. Arch. Soc.* (N.S.), **62**, 77.

Kubitzki, K. 1961 Zur Synchronisierung der nordwesteuropäischen Pollendiagramme (mit Beiträgen zur Waldgeschichte Nordwestdeutschlands). *Flora, Jena*, **150**, 43.

Lacaille, A. D. 1954 *The stone age in Scotland*. London: Oxford University Press.

Lambert, J. M. 1951 Alluvial stratigraphy and vegetational succession in the region of the Bure Valley Broads. III. Classification, status and distribution of communities. *J. Ecol.* **39**, 149.

Lang, G. 1952 Zur späteiszeitlichen Vegetations- und Florengeschichte Südwestdeutschlands. *Flora, Jena*, **139**, 243.

Lindquist, B. 1932 Om den vildväxande skogsalmens raser och deras utbredning i Nordvesteuropa. *Acta phytogeogr. Suec.* **4**, 1.

McVean, D. N. 1953 Biological flora of the British Isles. *Alnus glutinosa* (L.) Gaertn. *J. Ecol.* **41**, 447.

McVean, D. N. 1955 Ecology of *Alnus glutinosa* (L.) Gaertn. II. Seed distribution and germination. *J. Ecol.* **43**, 61.

McVean, D. N. 1956*a* Ecology of *Alnus glutinosa* (L.) Gaertn. III. Seedling establishment. *J. Ecol.* **44**, 195.

McVean, D. N. 1956*b* Ecology of *Alnus glutinosa* (L.) Gaertn. VI. Post-glacial history. *J. Ecol.* **44**, 331.

Manley, G. 1951 The range of variation in British climate. *Geogr. J.* **117**, 43.

Manley, G. 1953 Reviews of modern meteorology, 9. Climatic variation. *Quart. J. R. Met. Soc.* **79**, 185.

Manley, G. 1959 The Late-glacial climate of north-west England. *Liverpl Manchr Geol. J.* **2**, 188.

Meusel, H. 1943 *Vergleichende Arealkunde*. Berlin: Borntraeger.

Mitchell, G. F. 1948 Late-glacial deposits in Berwickshire. *New Phytol.* **47**, 262.

Mitchell, G. F. 1952 Late-glacial deposits at Garscadden Mains, near Glasgow. *New Phytol.* **50**, 277.

Mitchell, G. F. 1953 Further identification of macoscopic plant fossils from Irish Quaternary deposits especially from a Late-glacial deposit at Mapastown, Co. Louth. *Proc. R. Irish Acad.* **55**B, 225.

Mitchell, G. F. 1954 The Late-glacial Flora of Ireland. *Danm. geol. Unders.* (II), **80**, 73.

Mitchell, G. F. 1956 Post-Boreal pollen diagrams from Irish raised bogs. (Studies in Irish Quaternary deposits: no. 11.) *Proc. R. Irish Acad.* **57**, B, 185.

Mitchell, G. F. 1958 A Late-glacial deposit near Ballaugh, Isle of Man. *New Phytol.* **57**, 256.

Morrison M. E. S. 1959 Evidence and interpretation of 'Landnam' in the North-east of Ireland. *Bot. Notiser*, **112**, 185.

Morrison, M. E. S. & Stephens, N. 1960 Stratigraphy and pollen analysis of the raised beach deposits at Ballyhalbert, Co. Down, Northern Ireland. *New Phytol.* **59**, 153.

Movius, H. J. 1942 *The Irish Stone Age*. Cambridge University Press.

Müller, H. 1953 Zur spät- und nacheiszeitlichen Vegetationsgeschichte des mitteldeutschen Trockengebietes. *Nova Acta Leop. Carol.* (N.F.), **16**, 1.

Nickson, D. & Macdonald. J. H. 1956 A preliminary report on a microlithic site at Drigg, Cumberland. *Trans. Cumb. West. Ant. Arch. Soc.* (N.S.), **55**, 17.

Oldfield, F. 1960*a* Late Quaternary changes in climate, vegetation and sea-level in Lowland Lonsdale. *Trans. Inst. Brit. Geogr.* **28**, 99.

Oldfield, F. 1960*b* Studies in the Post-glacial history of British vegetation: Lowland Lonsdale. *New Phytol.* **59**, 192.

Osvald, H. 1923 Die Vegetation des Höchmoores Komosse. *Svenska Växtsoc. Sallsk. Handl.* **1**, 1.

Pearson, M. C. 1960 Muckle Moss, Northumberland. I. Historical. *J. Ecol.* **48**, 647.

Pearson, M. C. & Rogers, J. A. 1962 Biological flora of the British Isles. *Hippophaë rhamnoides* L. *J. Ecol.* **50**, 501.

Pearson, R. G. 1962 The Coleoptera from a Late-glacial deposit at St Bees, West Cumberland. *J. Anim. Ecol.* **31**, 129.

Pigott, C. D. 1958 Biological flora of the British Isles. *Polemonium coeruleum*. *J. Ecol.* **46**, 507.

Piggott, C. D. & Pigott, M. E. 1959 Stratigraphy and pollen analysis of Malham Tarn and Tarn Moss. *Field Studies*, **1**, 84.

Piggott, C. M. 1955 Milton Loch Crannog I. A native house of the 2nd Century A.D. in Kirkudbrightshire. *Proc. Soc. Ant. Scotland*, **87**, 134.

Piggott, S. 1954 *Neolithic cultures of the British Isles.* Cambridge University Press.

Piggott, S. (In Evens E. D., Grinsell, L. V., Piggott, S. & Wallis, F. S.) 1962 Fourth report of the subcommittee of the south-western group of museums and art galleries on the petrological identification of stone axes. *Proc. Prehist. Soc.* **28**, 1.

Plint, R. G. 1962 Stone axe factory sites in the Cumbrian fells. *Trans. Cumb. West. Ant. Arch. Soc.* (N.S.), **62**, 1.

Polunin, N. 1959 *Circumpolar Arctic Flora.* Oxford: Clarendon Press.

Poore, M. E. D. & Walker, D. 1959 Wynbunbury Moss, Cheshire. *Mem. Manchr. Lit. Phil. Soc.* **101**, 72.

Precht, J. 1953 On the occurrence of the 'Upper forest layer' around Cold Fell, N. Pennines. *Trans. Nth. Nat. Un.* **2**, 44.

Prevost, W. A. J. 1961 A journie to Carlvle and Penrith in 1731. *Trans. Cumb. West. Ant. Arch. Soc.* (N.S.), **61**, 202.

Proctor, M. C. F. 1956 Biological flora of the British Isles. *Helianthemum chamaecistus*. *J. Ecol.* **44**, 683.

Proctor, M. C. F. 1958 Ecological and historical factors in the distributions of the British *Helianthemum* species. *J. Ecol.* **46**, 349.

Raistrick, A. 1931 Bronze Age settlement of the north of England. *Archaeologia Aeliana.* (4), **8**, 149.

Raistrick A. 1934 The distribution of Mesolithic sites in the north of England. *Yorks. Archaeol. J.* **31**, 141.

Raven, J. E. 1952 *Koenigia islandica* L. in Scotland. *Watsonia* **2**, 188.

Richmond, I. A. 1963 *Roman Britain.* London: Cape.

Richmond, I. A. (ed.) 1958 *Roman and native in north Britain.* London: Nelson.

Ridley, H. N. 1930 *The dispersal of plants throughout the world.* Ashford: Reeve.

Robinson, T. 1709 *An essay towards a natural history of Westmorland and Cumberland.* London: Freeman.

Rubner, K. 1953 *Die pflanzengeographischen Grundlagen des Waldbaues.* Berlin: Neumann.

Salisbury, E. J. 1952 *Downs and dunes.* London: Bell.

Samuelsson, G. 1934 Die Verbreitung der höheren Wasserpflanzen in Nordeuropa. *Acta phytogeogr. suec.* **6**, 1.

Sauramo, M. 1955*a* On the nature of the Quaternary crustal upwarping in Fennoscandia. *Acta Geogr., Helsingf.* **14**, 334.

Sauramo. M. 1955*b* Land uplift with hinge-lines in Fennoscandia. *Ann. Acad. Sci. fenn. A*, (3) **44**, 1.

Shetelig, H. (ed.) 1940 *Viking antiquities in Great Britain and Ireland.* Oslo: Aschehoug.

Simpson, I. M. & West, R. G. 1958 On the stratigraphy and palaeobotany of a Late-Pleistocene organic deposit at Chelford, Cheshire. *New Phytol.* **57**, 239.

Smith, A. G. 1958 Two lacustrine deposits in the south of the English Lake District. *New Phytol.* **57**, 363.

Smith, A. G. 1959 The mires of south-western Westmorland: stratigraphy and pollen analysis. *New Phytol.* **58**, 105.

Smith, A. G. 1961*a* The Atlantic-Sub-boreal Transition. *Proc. Linn. Soc. Lond.* **172**, 38.

Smith, A. G. 1961*b* Cannons Lough, Kilrea, Co. Derry: stratigraphy and pollen analysis. *Proc. R. Irish Acad.* **61**, B, 369.

Smith, B. 1931 Borings through the glacial drifts of the northern plain of the Isle of Man. *Summ. Progr. Geol. Surv., Lond.* **3**, 14.

Smythe, J. A. 1912 The glacial geology of Northumberland. *Trans. Nat. Hist. Soc. Northumb.* (N.S.), **4**, 86.

Spence, J. E. 1937 A tumulus in Mecklin Park, Santon Bridge. *Trans. Cumb. West. Ant. Arch. Soc* (N.S.), **37**, 104.

Suggate, R. P. & West, R. G. 1959 On the extent of the Last Glaciation in eastern England. *Proc. Roy. Soc.* B, **150**, 263.

Tansley, A. G. 1939 *The British Islands and their vegetation.* Cambridge University Press.

Tauber, H. 1960 Copenhagen radiocarbon dates. IV. *Amer. J. Sci. Radiocarbon Supplement*, 2, 12.

Terasmäe, J. 1951 On the pollen morphology of *Betula nana. Svensk bot. Tidskr.* **45**, 358.

Troels-Smith, J. 1960 Ivy, mistletoe and elm. Climate indicators—fodder plants. *Danm. geol. Unders.* (IV), **4**, 4.

Trotter, F. M. 1929 The glaciation of eastern Edenside, the Alston Block and the Carlisle Plain. *Quart. J. Geol. Soc.* **85**, 549.

Trotter, F. M. & Hollingworth, S. E. 1932*a* The glacial sequence in the north of England. *Geol. Mag.* **69**, 374.

Trotter, F. M. & Hollingworth, S. E. 1932*b* The geology of the Brampton district. *Mem. Geol. Surv. U.K.* Sheet 18.

Trotter, F. M., Hollingworth, S. E., Eastwood, T. & Rose, W. C. C. 1937 The geology of the Gosforth district. *Mem. geol. Surv. U.K.* Sheet 37.

Trow-Smith, R. 1957 *A history of British livestock husbandry to 1700.* London: Routledge and Kegan Paul.

Tullie, I. 1840 Narrative of the Siege of Carlisle in 1644 and 1645. Carlisle: Jefferson.

Valentin, H. 1953 Present vertical movements of the British Isles. *Geogr. J.* **119** (3), 299.

de Valera R. 1961 The 'Carlingford Culture', the Long Barrow and the Neolithic of Great Britain and Ireland. *Proc. Prehist. Soc.* (N.S.), **27**, 234.

Walker, D. 1955*a* Studies in the Post-glacial history of British vegetation. XIV. Skelsmergh Tarn and Kentmere, Westmorland. *New Phytol.* **54**, 222.

Walker, D. 1955*b* Late-glacial deposits at Lunds, Yorkshire. *New Phytol.* **54**, 343.

Walker, D. 1956 A Late-glacial deposit at St Bees, Cumberland. *Quart. J. Geol. Soc. Lond.* **112**, 93.

Walker, D. 1961 Peat stratigraphy and bog regeneration. *Proc. Linn. Soc. Lond.* **172**, 29.

Walker, D. 1964 Post-glacial deposits at Tarn Wadling, Cumberland. *New Phytol.* **63**, 232.

Walker, D. 1965*a* Excavations at Barnscar, 1957–58. *Trans. Cumb. West. Ant. Arch. Soc.* (N.S.), **65**, 53.

Walker, D. 1965*b* The post-Glacial period in the Langdale Fells, English Lake District. *New Phytol.* **64**, 488.

Walker, D. 1966 The glaciation of the Langdale Fells. *Livr. Manchr Geol. J.* **5**, 208.

Walker, D. & Godwin, H. (In Clark, J. G. D.) 1954 *Excavations at Star Carr.* Cambridge University Press.

Walters, S. M. 1953 *Montia fontana* L. *Watsonia*, **3**, 1.

Wardle, P. 1961 Biological flora of the British Isles: *Fraxinus excelsior* L. *J. Ecol.* **49**, 739.

Watts, W. A. 1960 C-14 dating and the Neolithic in Ireland. *Antiquity*, **34**, 111.

Watts, W. A. 1961 Post-Atlantic forests in Ireland. *Proc. Linn. Soc. Lond.* **172**, 33.
West, R. G. & Godwin, H. 1958 The Cromerial Interglacial. *Nature, Lond.* **181**, 1554.
Willett, F. 1957 The Ruthwell and Bewcastle crosses. *Mem. Manchr. Lit. Phil. Soc.* **98**, 95.
Wilson, A. 1938 *The flora of Westmorland.* Arbroath: Buncle.
Wilson, A. 1956 *The altitudinal range of British plants.* Arbroath: Buncle.
Woldstedt, P. 1956 Über die Gliederung der Wurm-Eiszeit und die Stellung der Losse in ihr. *Eiszeitalter und Gegenwart.* **7**, 78.
Young, A. 1770 *A six-months tour through the north of England.* 3. (Letter 17). London: Strahan.

FIGURE A. Aerial photograph of the Ehenside Tarn region viewed from the north-east. The old tarn basin, with its two ponds, is in the left fore-ground. Similar features, Hollas Moss and Silver Tarn occupy the middle-right of the picture, and the coast is in the background. The distance from the immediate foreground to the coast on this line is 1 km. (*Phot.* J. K. St Joseph. Crown Copyright Reserved.)

FIGURE B. Archaeological excavation trench 1 at Ehenside Tarn, photographed from the south-western (lakeward) end. The upper surface of the timber and boulder layer has been cleaned of mud but other, underlying, timbers are not yet exposed. The surveying pole is graduated in feet. (*Phot*. B. Blake. Copyright.)