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Pollen Analyses from the Deposits of Six Upland Tarns in the Lake District

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POLLEN ANALYSES FROM THE DEPOSITS OF SIX UPLAND TARNS IN THE LAKE DISTRICT

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CONTENTS

The first part of an investigation designed to cover most of the tarns of the English Lake District is described. This investigation was planned as an application of the techniques of Quaternary research to a detailed analysis of the late-Quaternary history of a single limited area which forms a clearly defined geographical region.

The primary concern of the investigation is the relationship between stratigraphy and pollen content of the lake deposits, in an attempt to reconstruct the history of deposition in each tarn in relation to late- and post-Glacial changes in climate, and consequent changes in soil and vegetation in the drainage basins. In the account of pollen analysis of the sediments of six tarns at various altitudes in the south-western quadrant of the Lake District, comparisons between these various pollen diagrams from a fairly small area serve to emphasize the contrast between those widespread regional changes due to climatic change on which the pollen zonation is based, which are common to all the diagrams, and local changes due to local topography and human history, which differ in a consistent way from one tarn to another.

The differences between the late-Glacial deposits of the six tarns are related to topography, and the probable limits of the last corrie glaciation of the Lake District. Evidence from pollen analysis suggests very strongly that in the early post-Glacial period forest extended over the Lake District hillsides up to the altitude of the highest tarn investigated (1800 ft.). The first indication of disturbance of the primary forest occurs at the zone boundary VII*a*/*b*, the elm decline (which, as Godwin showed in his Croonian lecture of 1960, has been established to be broadly synchronous in north-west Europe at *ca.* 3000 B.C.).

Evidence is put forward suggesting that destruction of the elm in the Lake District during the early Neolithic period was particularly pronounced round tarns near to the sites of the stone-axe factories. The next phases of forest clearance are shown to be most clearly demonstrated in those tarns around which are abundant remains of upland settlement of Bronze Age type. The relation between the successive phases of forest clearance, post-Glacial soil degradation, peat formation and soil erosion is discussed, in relation to chemical investigations by F. J. H. Mackereth (at the Windermere laboratory of the Freshwater Biological Association) which suggest that the lake deposits are derived mainly from soils in the drainage basins.

1. Introduction

This paper describes the first part of an investigation designed to cover most of the tarns of the English Lake District. It is concerned with the relationship between stratigraphy and pollen content of the lake deposits in an attempt to reconstruct the history of deposition in each tarn in relation to late- and post-Glacial changes in climate, and consequent changes in soil and vegetation in the drainage basins. In the following account of pollen analysis of the deposits of six tarns in the south-western quadrant of the Lake District, comparisons between these various pollen diagrams from a fairly small area will serve to emphasize the contrast between those regional changes due to climatic change on which the pollen zonation is based, which are common to all the diagrams, and local changes due to local topography and human history, which differ in a consistent way from one tarn to another.

This work has been carried out in co-operation with the Freshwater Biological Association's Windermere laboratory, and is particularly associated with the chemical investigations of F. J. H. Mackereth. In a recent paper on the sediments of a number of the larger lakes of the Lake District, Mackereth (1964) concludes on purely chemical evidence that 'the sediments of these lakes represent a sequence of soils derived from the drainage basins...changes in the concentration of major components in the post-Glacial sequence of sediments are related to changes in the rate of erosion of the drainage basin rather than to changes in organic productivity in either the soils or the lake itself'. If this hypothesis is true, then there is preserved in the lake sediments a continuous record of soil changes in the drainage basin.

Pollen analysis of the sediments provides a time-scale for these changes, by fixing the position of the zone boundaries, which are known to be broadly synchronous and therefore presumably climatically determined, up to the time of the zone VII *a/b* boundary at *ca.* 3000 B.C. (Godwin 1960). Though lake sediments have not as yet been found suitable material for radiocarbon dating, the zone boundaries can be dated by reference to the dates obtained at Scaleby Moss, north Cumberland, by Godwin, Walker & Willis (1957), and this is the source of the dates given on the pollen diagrams. After 3000 B.C. it is doubtful whether any synchronous horizon, depending on climatic change alone, is perceptible in pollen diagrams from northern England, unless it is accompanied by a stratigraphic response to climatic change comparable with the major recurrence surfaces in the raised bogs. After 3000 B.C., therefore, only direct radiocarbon analysis can provide dates for the deposits, but ecological interpretation of the pollen diagrams can provide data on the vegetational history of the drainage basins, and by integrating this with the record of soil changes preserved in the lake deposits (as revealed by the chemical analyses) a continuous ecological history of the lakes and their drainage basins can be built up. This is the aim of the present investigation.

The present paper records one stage in the process of obtaining the required data from all the small lakes or tarns. Mackereth's (1964) observations on the large valley lakes, Windermere, Ennerdale and Esthwaite Water, could be related to zoned pollen diagrams from the sediments of these lakes which had already been published (Pennington 1947, 1959; Franks & Pennington 1961). In addition to his results from these lakes, he discusses observations on Devoke Water, one of the upland tarns. In the present paper, pollen diagrams and stratigraphic details from the Devoke Water deposits will be given first, followed by similar data for five other upland tarns, presented comparatively. Parallel chemical investigations of the deposits of these other tarns are in progress, and will be published at a later stage.

The stratigraphy and total depth of sediment are similar in all the large valley lakes which have been investigated, and synchronous horizons lie at comparable depths in the profiles. These lakes can be regarded as expansions of the rivers in whose course they lie, and must represent an integration of conditions in the many small drainage basins which make up the river system. It seemed reasonable to suppose that the smaller lakes, or tarns, each in its small drainage area, would present a simpler ecological picture, from which the various factors which had controlled soil erosion and vegetational change during the post-Glacial period could be unravelled. Accordingly, the joint investigation was carried out on Devoke Water, an upland tarn of about half the size of Esthwaite Water, with similar morphometry, but having a small drainage basin and only small inflows. As Mackereth (1964) records it was striking to discover that the curve for total carbon, which he regards as the most significant single variable, bore exactly the same relation to the pollen zone boundary VII *a/b* as in the large lakes, though in them this horizon lay 3 m below the mud surface, whereas in Devoke Water it lay 5 m below the mud surface. This meant that the rate of sedimentation, and hence according to Mackereth's theory, soil erosion, must have been many times more rapid during the second half of the post-Glacial period, since 3000 B.C., than in the first half, at Devoke Water, and considerably more rapid than in the large valley lakes during the period since 3000 B.C.

This raised certain basic questions about the process of sedimentation in a lake, and made clear the necessity for more data from other tarns. The only time-scale which had been constructed for lake deposits before the development of radiocarbon analysis had been based on Hutchinson's (1940) assumption that unit mass of mineral material was deposited in unit time. Knowing the current rate of deposition of mineral material in Windermere, it was possible to use this assumption of Hutchinson's to construct a tentative time-scale for that lake (Pennington 1943), and when the first radiocarbon dates for zone boundaries became available, this tentative time-scale was seen to be in reasonably good agreement with them.

Speculations on the ecological history of the Lake District had shown that the dates suggested by this time-scale for the major periods of deforestation in the Lake District were in agreement with what was then known of the human history (Pearsall & Pennington 1947). The results from Devoke Water showed that Hutchinson's assumption was certainly not true for that lake, so it was clearly necessary to re-examine this limnological hypothesis

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in the light of the exact time-scale provided by radiocarbon dates, and in relation to Mackereth's conclusion. It was also necessary to re-examine ideas on forest clearance and ecological history in the light of the volume of work published since 1940 on the subject of man's effect on natural vegetation (Iversen 1941; Troels-Smith 1960; Turner 1962, etc.), and also in relation to recent archaeological discoveries in the Lake District (Bunch & Fell 1949).

The pollen diagrams from the five other tarns illuminate certain other problems presented by the results from Devoke Water. The interpretation of them attempted here will accept Mackereth's hypothesis of derivation of lake sediments from soils in the drainage basin (with the necessary corollary that derived pollen from the washed-in soils must be expected in the lake sediments), and will show that up to the time of the zone boundary VII *a*/*b*, both stratigraphical changes and vegetational succession appear to follow a comparable course in all the tarns and are explicable as the direct results of the known climatic changes during the first half of the post-Glacial period, i.e. all the diagrams indicate closed forest from soon after the end of the late-Glacial period until the end of zone VII *a*, the composition of the forest changing after the usual pattern for England and Wales. The first indications of human interference with the forest appear at or shortly above the zone boundary VII *a*/*b*, and it is significant that this is one of the horizons of greatest change in the chemical curves from all the lakes as yet investigated.

Above the VII *a*/*b* boundary, i.e. from *ca.* 3000 B.C. onwards, not only do the vegetational changes differ from one tarn to another, but stratigraphical differences show that the course of deposition and rate of accumulation of lake sediments followed a very different pattern in the various tarns. On Mackereth's hypothesis, this indicates soil changes of differing types in the various drainage basins, and if the tarns are grouped according to the type of deposition since 3000 B.C., the vital factor is seen to be the human history of their drainage basins, since those tarns with a similar history of human settlement in their locality resemble each other in stratigraphical and vegetational succession. This suggests a strong correlation between human influence on the vegetation, in the form of forest clearance and agriculture, and soil changes resulting in changes in erosion rate.

2. Geology, topography and soils in relation to stratigraphy of lake deposits

All six tarns and their drainage basins lie on Ordovician rocks of the Borrowdale Volcanic series, the tarns occupying hollows dammed by glacial deposits. The drift deposits are of local origin and derived from similar Borrowdale Volcanic rocks. The age of the tarns in relation to the final stages of glaciation of the Lake District will be discussed in a later paper covering the whole district; here the late-Glacial deposits will be briefly described but not discussed. The tarns all lie in upland drainage areas which are now almost completely treeless, except for a small plantation beside Blea Tarn. Grassland of the various types described by Pearsall (1950) covers most of the area, but there are patches of Callunetum and of bog, which is chiefly dominated by *Sphagnum–Eriophorum* vegetation. *Pteridium* is common up to about 1000 ft. on the deeper soils.

Much of the peat underlying the areas of bog is shallow, being less than 1 m deep. In a few areas, mostly on nearly flat land or over relatively impermeable drift, blanket peat has accumulated to a depth of nearly 2 m, and wood, often birch, is buried at the base of this peat, showing that trees once grew there.

Though exposed surfaces of Borrowdale Volcanic rocks, and the present soils derived from them, are non-calcareous, freshly exposed rock surfaces can be shown to contain sufficient calcium carbonate to effervesce with hydrochloric acid. During the late-Glacial period, the freshly exposed rock debris would therefore be expected to have been rich in calcium, and Mackereth has shown that the laminated clays of zone I in the larger lakes have a high calcium content. This agrees with the botanical evidence, from the presence of calcicole species of diatoms and land plants, that during the late-Glacial period the lake waters and soils of the district had a comparatively high base-status, which thereafter declined. The process of continuous leaching out of bases by rainfall is discussed in detail by Mackereth (1964), in relation to the composition of lake deposits, and by Pearsall (1950) in relation to soil changes in upland areas of high relief. Pearsall emphasizes how the continuous leaching of upland soils in an oceanic climate results in increasing acidity, by podsolization and paludification, of all soils except those in which the base supply is maintained by flushing or by continuous rock breakdown. This process of continuous increase in soil acidity tends to bring about the formation of peat in areas of impeded drainage or of particularly high rainfall, and so brings about a *natural* replacement of forest by ericaceous heath or bog. Conway (1954) has shown in detail how this occurred in the South Pennine region. Iversen (1958) summarizing the glacial–interglacial–glacial climatic cycle which has been several times repeated during the Pleistocene, shows that this process is a normal feature of the second part of an interglacial climatic sequence, after the climatic deterioration has set in, and that the retrogressive change from mesocratic climax forest to telocratic acid woodland or heath is not only widely known from the recent vegetational history of north-west Europe but can be recognized in Jutland pollen diagrams from the corresponding state of the previous interglacial (Andersen 1957). One question to be answered by this investigation of the Lake District is, therefore, to what extent the changing vegetation of land and water through the post-Glacial period has been the response to purely natural processes. As Iversen (1941, etc.) was one of the first to demonstrate convincingly, in our present interglacial the cycle was 'interrupted by the appearance of a new factor; agricultural man began to clear the forest and till the soil...degradation of the soil was speeded up by destruction of the forest' (Iversen 1958). Recent work in many countries of north-west Europe has all tended towards the conclusion that the time at which the activities of agricultural (Neolithic) man first affect the vegetation is at the zone boundary VII *a*/*b*, at about 3000 B.C. (Troels-Smith 1960; Smith 1961). The present investigation will show that this is the horizon at which, first, chemical changes in the lake muds are initiated or intensified, and secondly, the individual small basins begin to diverge in their history.

Of the processes controlling the deposition of sediment in a lake, Mackereth has shown that in these Lake District lakes, organic production within the lake is of minor importance and this is borne out by the work of Fogg & Belcher (1958) on plant pigments in the deposits. Most of the sediment is derived from outside the lake, either by erosion of the land surface or from land plants. The usual type of post-Glacial sediment is a dark brown mud containing about 20% organic matter, a 'detritus gyttja'. Periods of

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rapid erosion of the land surface—i.e. periods of soil instability—result in a different type of sediment, which is minerogenic in periods (such as the late-Glacial) when the soils were predominantly mineral; this accounts for the characteristic clay layer of zone III in the tarns outside the limits of the corrie glaciation of zone III, because the severe climate of the period of the corrie glaciation caused solifluction and other phenomena of soil instability, and the moving soil material was almost entirely mineral. In this area of high relief and much outcropping rock, periods of intense soil erosion would continue to add much minerogenic sediment to the tarn deposits, throughout the post-Glacial period, but as the spread of vegetation over the land surface began to add humus to the soils in the early post-Glacial, material eroded from the land surface and deposited in the lake basins would contain organic as well as mineral matter. At whatever time the process outlined in the previous paragraph led to peat formation in the drainage basin, there began to be the possibility that periods of erosion would begin to add highly organic matter in the form of peat to the lake deposits (on the other hand, of course, if local topography favoured the development of a continuous skin of peat over the land surface, the latter would then be protected from further erosion, as long as the peat remained intact). Remains of land plants can be expected in the lake deposits both as formless humus, cellular fragments from soils, and as large cellular fragments from peat, but observation shows that when trees grow near the lake the major contribution of organic matter to lake deposits comes from comminuted deciduous leaves of forest trees. Undecomposed bryophyte remains are commonest in late-Glacial zones and after deforestation, and when the species of Bryophyta can be identified, the habitat throws some light on the place of origin of the washed-in material. In addition to these sources of the accumulating sediment, marginal wave action in a lake causes redistribution of material from round the shores. The tarns described here are all stony round their present shores, but any change in water level would be expected to lead to redeposition in the central deposits of material either from the surrounding soil (if the water level were raised) or from littoral muds newly subject to wave erosion (if the water level were lowered). Bands of minerogenic sediment within the brown organic muds can therefore be interpreted as indications of *either* increased erosion of mineral soils *or* of changes in water level. Pollen analysis can help to decide which explanation is the true one for each sample.

3. Human history

Since the publication of earlier speculations on the relation between human settlement and ecological history of the Lake District (Pearsall & Pennington 1947) major advances in archaeology have necessitated a revision of the views held at that time, which were derived from the work of R. G. Collingwood (1933 *a*). Application of radiocarbon dating to archaeology has revised opinions on dates, notably for the early Neolithic, a culture now known to have been established in the British Isles by about 3000 B.C., much earlier than had hitherto been supposed (Clark & Godwin 1962). These authors note that 'The pattern of radiocarbon dates...renders untenable the notion of the primacy of a Windmill Hill culture centred on Wessex and Sussex; on the contrary it suggests that the new (Neolithic) economy spread over the whole region between western Ireland and East Anglia comparatively rapidly and that it perhaps followed a drift from west to east.' The discovery of Neolithic stone-axe factory sites in the central Lake District, at Pike of Stickle, Great Langdale (Bunch & Fell 1949) and on Scawfell (Houlder, personal communication) has shown that there must have been much human activity in the Lake District at some stage in the Neolithic period.

Great Langdale axes were found at the Ehenside Tarn settlement, West Cumberland (Piggott 1954), and a wooden artifact from this site gave a radiocarbon date of 3010 B.C. which is in good agreement with other dates for the early Neolithic in the British Isles (Clark & Godwin 1962), though two other dates from wood found at Ehenside Tarn gave dates of nearly 1000 years later (Evens, Grinsell, Piggott & Wallis 1962). Comparable Graig Lwyd axes have been dated to *ca.* 2900–2700 B.C. (Clark & Godwin 1962). These dates for the stone axes early in the third millennium B.C. are significant in relation to the facts about disturbance of the original forest at the time of the elm decline, the zone VII *a*/*b* boundary, which will be presented in this paper. This disturbance appears to have been more intense, and to have involved stratigraphical changes in the lake deposits, in the two tarns which lie very near to the Great Langdale axe-factory site. All radiocarbon dates for the elm decline in north-west Europe lie close to 3000 B.C. (Godwin 1960; Clark & Godwin 1962).

The next cultural phase of which traces are present in this area is that of the great stone circles, the distribution of which is shown in figure 1. Collingwood regarded these as Neolithic, not Bronze Age, in type, so they may perhaps be compared with the Secondary Neolithic period in the construction of Stonehenge, for which a radiocarbon date of 1848 B.C. was obtained (Atkinson 1960).

These Neolithic phases are quite distinct from the tumuli, burial cairns and stone hut circles which are very common in the south-west Lake District between 700 and 1500 ft. These remains have not been dated by modern methods. Those which have been excavated have yielded burials of Bronze Age type, but no metal objects. The distribution of these 'barrows' is shown in figure 1, and it can be seen that they are very frequent around the two tarns Devoke Water and Seathwaite Tarn, and on the Coniston fells below Blind Tarn and Goatswater, and are absent from the central mountainous area including the Langdales. These remains appear to indicate the presence of a considerable resident upland population, during the period following the introduction of Bronze Age burial customs but before the use of metal had reached the inhabitants of the Lake District. The relation of the upland burial sites to the stone hut settlements is not quite clear, but in Collingwood's opinion the two belong to a continuous occupation, even if not contemporaneous; he would attribute some, if not all, of the stone-built hut settlements to 'not many centuries before the coming of the Romans', and thought that the builders of them cultivated small fields and followed a way of life attributable to the Late Bronze Age. Settlements of this type are found on the north shore of Devoke Water, and at Barnscar, a mile west of Devoke Water, and at other sites on the Dunnerdale and Coniston fells. The question of the dates of this upland occupation, which brought about major changes in the vegetation round Devoke Water and Seathwaite Tarn, is one of the most urgent to be answered by radiocarbon analysis of organic material from lake muds. It is probably related to the settlements and 'Celtic fields', with associated barrows, at

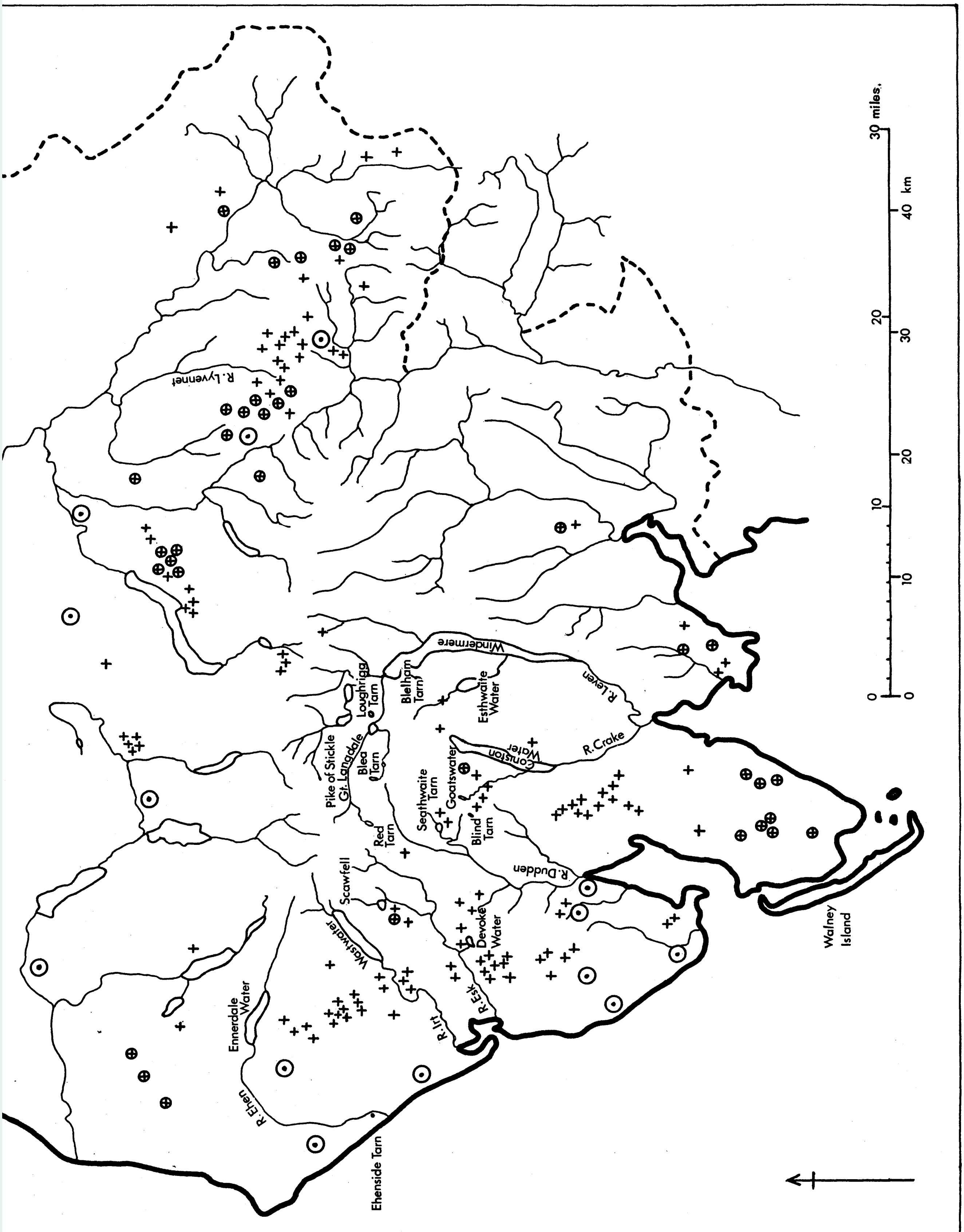

FIGURE 1. Map of the southern Lake District, showing the distribution of (*a*) burial cairns (+), (*b*) those proved to be Bronze Age in type by excavation (⊕), (*c*) great stone circles (⊙). Tarns and lakes mentioned in the text are named on the map. Distributions reproduced from Collingwood (1933 *a*).

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Ewe Close and other sites round the head of the Lyvennet valley in east Westmorland (R. G. Collingwood 1933 *b*).

There is little information about the population of the area during the Iron Age and Roman times, and nothing to add to the summary presented in the previous survey (Pearsall & Pennington 1947). Collingwood's view was that 'the old population, living in much the old way, survived the Anglian settlement and lingered even into the Viking period.' There is no archaeological evidence for the date at which occupation of the hill settlements such as Barnscar ceased. Pearsall (1961) has shown how the place-names of the central Lake District include almost none of Anglian derivation, but give a consistent picture of an area sparsely populated by the descendants of the old upland population when the Viking settlers began to penetrate and clear the valleys and to give names to their farms, about 900 to 1000 A.D. The elder Collingwood (1925) believed that by Norman times, the central Lake District was cleared of woodland and comprised deer forest and rough sheep pasture.

4. Pollen analysis—technique and interpretation

Sampling

The tarns accessible by road were sampled with the Mackereth corer (Mackereth 1958), and those to which it was possible to carry a portable dinghy were sampled by the Livingstone type of piston corer (Livingstone 1954). For the sample from Goatswater I am indebted to Mr B. Walker, who explored the bed of the tarn using diving apparatus, and obtained a core by pushing a Perspex tube into the soft deposits.

The cores were transported to the laboratory and sampled there. The comparatively large diameter of the cylinder of mud obtained with these samplers reduces very much the risk of contamination, when the sample to be analysed is taken from the middle of the cylinder.

Methods

The samples were prepared for counting by the methods recommended in Faegri & Iversen's text-book (1950). Some samples required prolonged boiling with hydrofluoric acid to remove mineral matter.

In most of the work, a pollen sum of about 150 grains of tree pollen was counted. In late-Glacial layers which were poor in pollen, a total of 100 grains was used.

Interpretation

Faegri & Iversen (1950) recommend the use of lake sediments, where available, for pollen analysis, in preference to peats, because where, as in five of the six tarns described here, there are stony shores and no emergent vegetation, no local pollen component complicates the pollen record, and no local hydroseral changes obscure more general vegetational changes. On the other hand, it is clear that not all the pollen in a lake mud comes from the atmospheric pollen rain. The analysis of the sources of a lake deposit outlined in the preceding section emphasizes that derived pollen may enter the lake as part of an eroded soil or peat, and contemporary pollen may enter the lake via the land surface or via inflow streams overhung by trees—this last is a possible source of over-representation of alder pollen.

The amount and nature of the derived, secondary pollen would be expected to vary with conditions. In the early post-Glacial period of continuous forest the land surface below the altitudinal tree limit was probably comparatively stable, and also these forest soils would be expected to contain relatively little pollen because of a neutral or higher pH and oxidizing conditions. As the soils became more acid, however, the chances of pollen preservation in them would increase; Dimbleby (1957) reports that pollen is well preserved in soils of pH 5 and lower. Therefore it would be expected that comparatively recent deposits, resulting from soil erosion, would contain more secondary pollen than deposits of the early post-Glacial period.

Examination of soil samples from the drainage areas of these tarns has shown that they contain large quantities of pollen and spores. The soil samples were predominantly of the mor type, the dark surface accumulation of humus being anything from 2 to 30 or more centimetres deep. Some soils, particularly from beneath *Pteridium*, were of the brown earth type, with no dark surface humus. The mineral soil of the lower parts of the profiles was glacial drift, varying from large stones to pure clay in composition.

The transition from very deep mor soils to true peat is in appearance a continuous one. Here the term 'peaty soil' is used for these deep accumulations of mor humus. The term 'peat' is here restricted to deeper organic deposits where there is some evidence for the presence of *Sphagnum* spp., living or fossil.

In all samples from the dark mor humus layers, and in the surface few centimetres of the brown earth soils sampled, *Calluna* pollen was by far the most abundant, followed by that of grass and sedge. *Plantago lanceolata* and other clearance indicators were also present in these soils, and tree pollen was either absent or infrequent, except in a profile from a field beside Blea Tarn, where tree pollen was abundant in the surface layers. In some soil profiles, *Alnus* pollen was frequent in the deeper layers where the mor humus was in contact with the underlying more-or-less leached drift, usually clayey; in the purely mineral soils at deeper levels, fern spores were frequent, with little other recognizable pollen except *Corylus*.

Fern spores seem to be particularly characteristic of the deeper, mineral layers of some soil profiles, and Dimbleby (1957) found this in some podsols. In counting pollen preparations from these lakes, it was noticed that in samples where fern spores were abundant, nearly always there were fragments of sporangia with annulus cells present; these latter cannot have been air-borne, so it is possible that isolated peaks of fern spores represent secondary deposition from soils of mineral type.

Zonation of the pollen diagrams

The zone boundaries were drawn according to the criteria of Godwin (1956) and Godwin, Walker & Willis (1957). Up to the VII *a/b* boundary, no difficulty was found in recognizing the changes in forest composition on which the zonation scheme of Godwin for England and Wales is based.

Above this horizon, no attempt has been made to draw any zone boundary, on the assumption that, as recognized for England and Wales, a zone boundary indicates a synchronous horizon, and there is no evidence for the actual date of any horizon above the elm decline at the VII *a/b* boundary in these diagrams.

In those tarns in which a steep rise in *Calluna* pollen, accompanied by a steep fall in *Isoetes* spores and a stratigraphic discontinuity occurs, this horizon has been indicated by a line labelled *Calluna* horizon, but this is not intended to denote a synchronous horizon; at this stage there is insufficient evidence to decide whether or not this horizon is synchronous in all the tarns where it occurs.

The pollen of *Myrica* has not been distinguished from that of *Corylus* in the diagrams, because of the large number of grains of intermediate type. 'Coryloid' pollen, while predominantly that of *Corylus*, includes some grains of *Myrica*.

For the sake of clarity, some of the non-tree pollens recorded have not been represented on these diagrams. Aquatic plants have been omitted, except for *Isoetes*. This, and the grouping of the following genera as 'grassland herbs' in some diagrams, has made it possible to represent all the pollen curves on a single diagram: grassland herbs = *Plantago lanceolata* + *Rumex acetosella* + Compositae (except *Artemisia*) + *Galium* type + *Potentilla*.

5. Descriptions of the six tarns

The position of each tarn is shown on the map in figure 1. The stratigraphy of each core analyzed is included with the pollen diagram, and the symbols used for the stratigraphy are shown in figure 2. For each tarn the National Grid reference and the height in feet above sea level according to the one-inch O.S. maps are given.

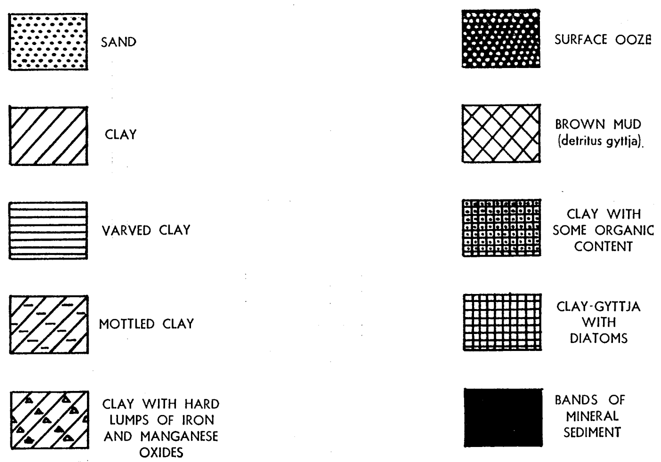

Figure 2. Stratigraphic symbols used in the pollen diagrams.

(1) *Devoke Water*, Cumberland 766 ft. SD/158969

(Diagrams in figures 3*a* and 3*b*)

This tarn, nearly a mile long and one of the largest upland tarns, lies in a hollow in the moorland between the valleys of the Duddon and the Esk. The drainage basin is small, the watershed ringing the tarn about a mile from its shores, following a line of summits reaching 990 to 1500 ft. South and east of the tarn the land is rough rocky *Nardus* grassland with bracken patches; to the north and west, where the rock is intrusive, part of the Eskdale granite complex, it is *Calluna* moorland with small rocky summits resembling tors and an extensive spread of stones around each one, and patches of *Sphagnum* bog wherever the surface is not steeply sloping. On the flattish land round the

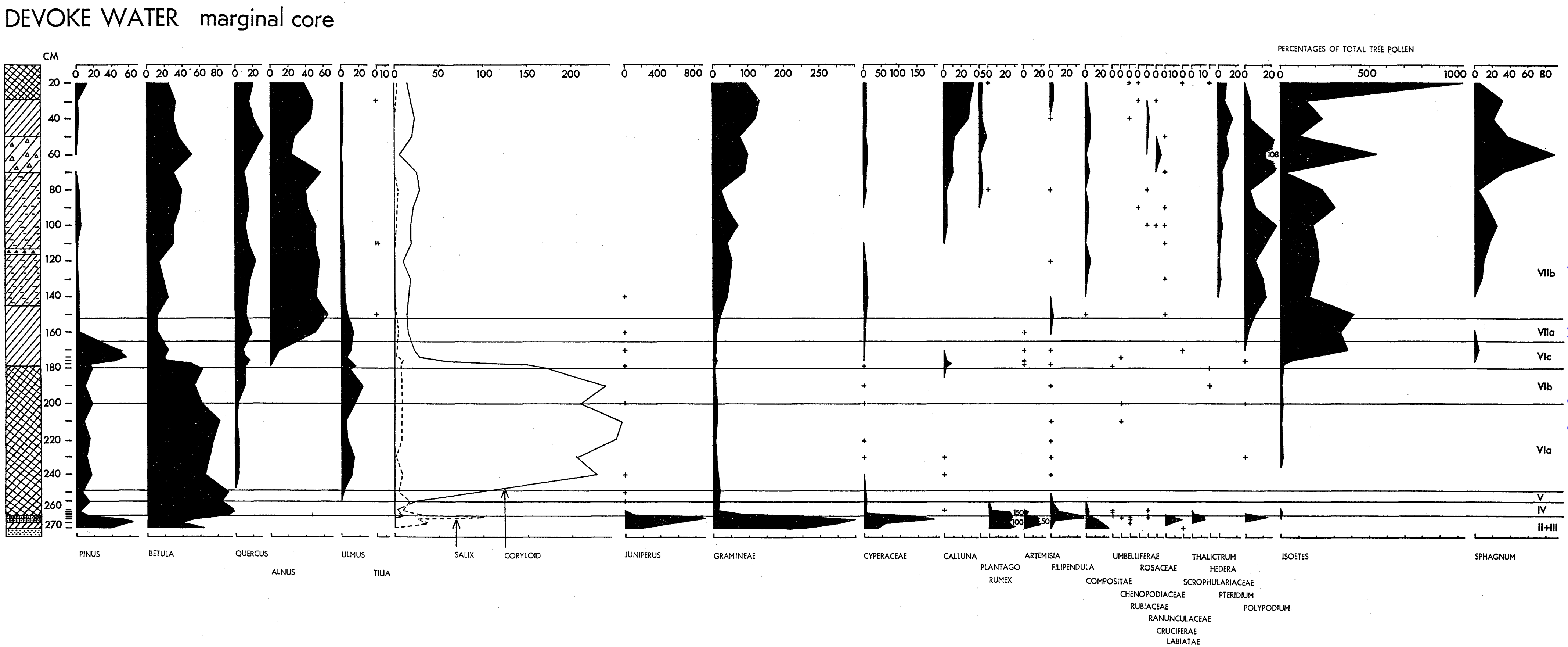

Figure 3 (*a*). Devoke Water pollen diagram: marginal core.

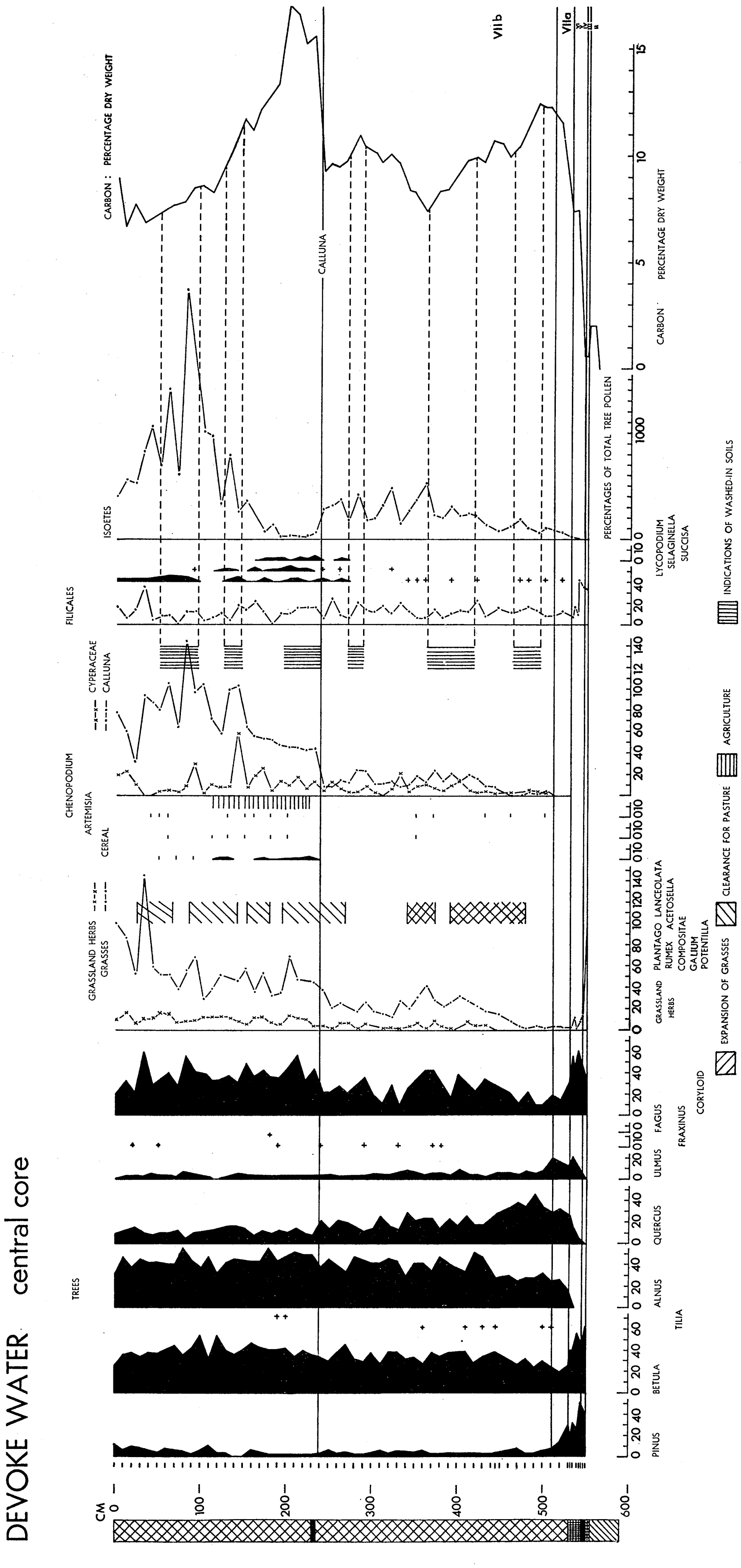

FIGURE 3 (*b*). Devoke Water pollen diagram: central core, including curve for total carbon (percentage dry weight) in this core.

shores of the tarn there are extensive areas of *Sphagnum*, with *Myrica* and *Eriophorum*, but the underlying peat is not more than a metre in thickness, and often much less. The soils under *Calluna* and *Nardus* are shallow and generally black and peaty, with a somewhat leached layer beneath; under the bracken patches the soil is brown earth and oxidizing, and not less than a foot deep. The general appearance of all this moorland is peculiarly desolate, but within a mile or two of the tarn, trees grow well in steep-sided ghylls, and the land enclosed by intake walls produces good pasture and even crops. It would therefore seem likely from observation that the treelessness and generally acid poverty of the moorland soils results from historical rather than climatic factors, and the pollen diagrams support this hypothesis.

There are present in the drainage area a very large number of stone cairns, most of them at altitudes between 600 and 1000 ft. One estimate (Cherry 1961) is that there are 1100 to 1200 cairns, in the area within two miles of Devoke Water in each direction. There was clearly a considerable settlement in the neighbourhood. Excavations at the settlement at Barnscar, a mile west of the tarn, in the last century, yielded two burial urns of Middle Bronze Age type.

The tarn was probed with the Mackereth sampler to discover a representative profile of deposits. Five cores were taken in the central part, where the water is 10 to 14 m deep; several of them appeared to include an unconformity at the junction of late- and post-Glacial deposits, but the core shown in figure 7 presented an apparently conformable succession. The stratigraphy was as follows:

cm	
0– 25	soft black mud, rather wet
25–230	brown fine detritus with occasional narrow black bands
230–231	light brown silty band
231–440	brown fine detritus mud with very occasional narrow black bands
440–530	brown fine detritus mud
530–535	light brown clay mud
535–545	diatom mud
545–550	pink clay without laminations
550–552	dark grey sandy silt
552–557	clay, light brown to yellow in colour
557–590	pink clay without laminations

The dark sandy silt at 550 to 552 cm represents zone II of the late-Glacial, and the pink clay above it, 545 to 550 cm, was deposited during the cold period of zone III. The absence of varves shows that no glacial drainage was entering Devoke Water during zone III, and this corresponds with the absence of high corries or gathering grounds from the drainage area. The change from light-coloured diatom and clay muds to detritus mud corresponds with the Boreal/Atlantic transition at 530 cm, so that the early post-Glacial zones, IV, V and VI are here represented by only 15 cm of deposition. There is no stratigraphic change at the zone VII *a/b* boundary, which comes at 510 cm. The silty band at 230 cm coincides with the *Calluna* horizon. No conclusions were reached about the nature of the black bands.

Exploration of the littoral part of the tarn with a Livingstone corer showed that the basal deposit was a pinkish sand at 280 to 300 cm, with above it a laminated clay, grey and pink in colour and about 15 cm thick. Zone II was represented by a layer of detritus silt no wider than in the central deposits, and it did not contain macroscopic plant remains. It was overlain by a narrow zone III clay, which in some cores was sludged into the zone II silt, as if disturbance had taken place during zone III. The pollen diagram from one littoral core showed a consistent series of changes through zones II and III, but abrupt changes (suggesting unconformity) at the upper boundary of zone III.

The stratigraphy of this littoral core was as follows:

cm	
0– 24	soft black mud
24– 50	transitional, soft clay-mud
50– 70	iron-stained pinkish clay with dark brown lumps of Fe and Mn oxides
70–112	pink and dark grey mottled clay
112–115	lumps of iron oxide forming a hard layer
115–145	pink and dark grey mottled clay
145–179	pale pinkish-grey clay
179–263	brown fine detritus mud; abrupt junction at 263 cm
263–266	mixed clay and muddy silt, in thin wedges
266–281	faintly laminated pink clay with small stones
281–286	pinkish sand

In this core the Boreal/Atlantic transition, as defined pollen-analytically by the expansion of *Alnus*, is placed at 165 cm, about 15 cm above the stratigraphic change from lake mud to clay. This pale clay may well represent the marginal deposits during a period of low water level at the end of the Boreal period, but many complex factors affect the type of deposit accumulating in the marginal areas of lakes. Deposition was much more rapid at this point than in the centre during the early post-Glacial zones IV, V and VI.

(2) *Seathwaite Tarn*, Lancashire 1210 ft. SD/253988

(Diagrams in figures 4 and 9)

This large tarn, $\frac{3}{4}$ mile in length, is a small valley lake in the course of Tarn Beck, a major tributary of the river Duddon. On both sides of the valley, steep grass slopes rise to ridges 2500 ft. in height. Tarn Head Moss, an extensive valley bog, lies in the course of the stream just above the tarn. At the outflow end of the tarn there is a spread of drift boulders plastered across the hillside, on which peat has developed to a depth of between 1 and 2 m. There are many large branches or trunks of birch buried at the base of this peat, now being removed by erosion from an overspill channel. The nearest existing trees are a mile away, and 600 ft. lower, to the south-west.

Seathwaite Tarn was increased in depth in 1904, when Barrow Corporation built a dam across the outflow. This added a minerogenic band to the deposits, but below this they are not affected.

Archaeological remains in the neighbourhood are similar to those near Devoke Water; there are burial cairns and a group of stone-hut circles in the drainage area.

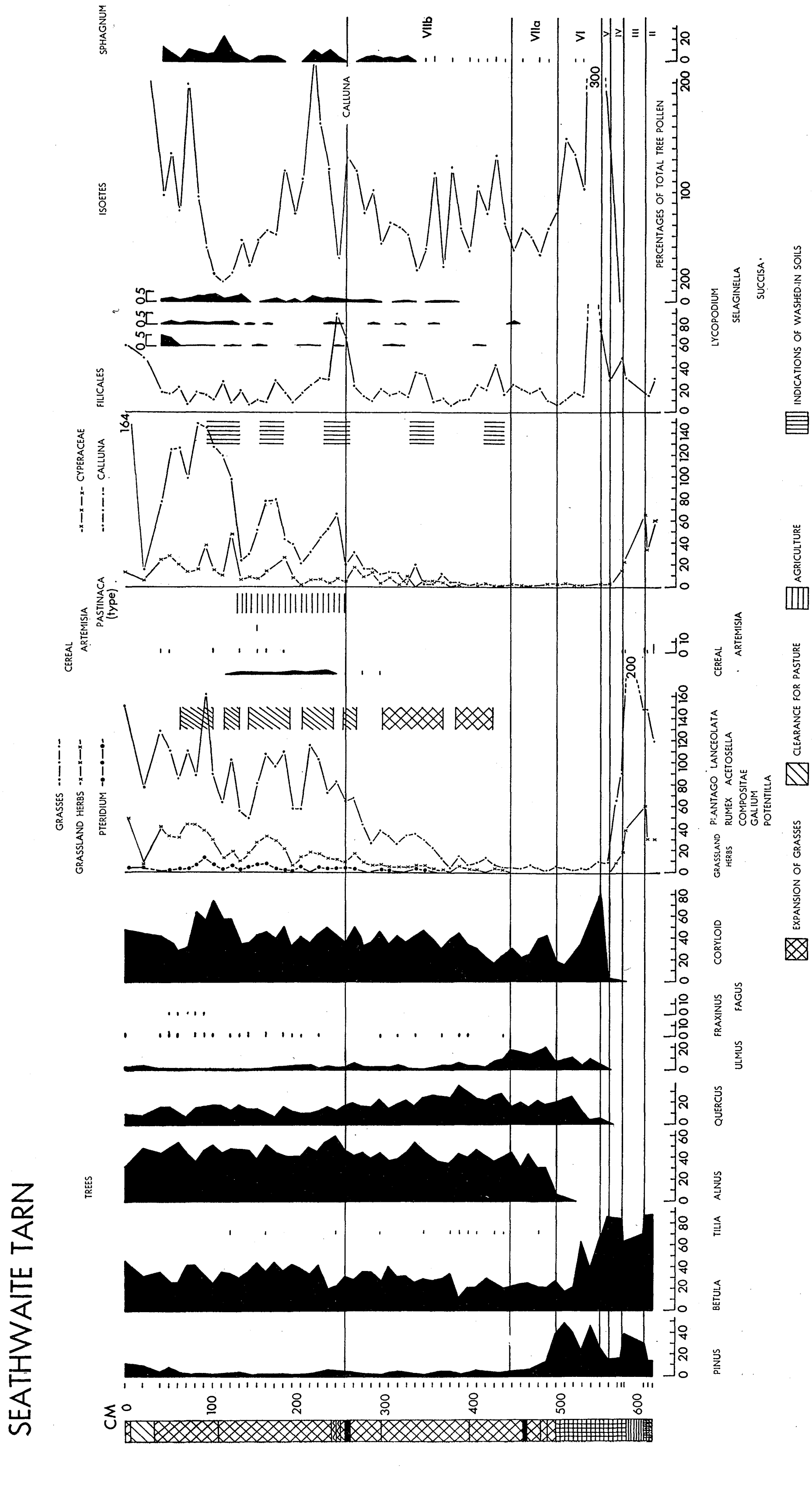

Figure 4. Seathwaite Tarn: pollen diagram from a point somewhat south of the centre, where the water depth is 25 m.

Two cores were obtained from an area of the tarn about halfway between the centre and the outflow, where the water is 25 m deep. The stratigraphy which agreed well between these two cores, was as follows:

cm	
0 – 5	black organic mud
5 – 33·5	brown clay mud, product of marginal soil erosion when level raised in 1904
33·5– 39·5	black organic mud
39·5–230	brown fine detritus mud, with narrow bands of pink clay at 107 and 108 cm
230 –235	pinkish brown fine detritus clay mud
235 –240	pinkish grey clay
240 –244	remains of mosses, very fresh, with sand
244 –250	detritus mud
250 –252	coarse detritus mud
252 –254	detritus mud
254	narrow sand layer
254 –453	brown fine detritus mud with narrow clay bands at 292 and 391 cm
453 –454	pink clay
454 –490	brown fine detritus mud with narrow clay bands at 474 and 479 cm
490 –491	narrow clay band
491 –550	pale brown fine detritus mud becoming gradually clay mud
550 –560	grey clay mud
560 –570	pink clay mud
570 –585	pink clay
585 –590	narrow greyish-pink varved clay
590 –591	pink clay
591 –600	faintly pink grey silty mud

The 9 cm of silty mud at the base of this core was formed during zone II, the Allerød oscillation of the late-Glacial, and the varves in the overlying clay of zone III show that the tarn was in existence at this time and that there was an active glacier in the valley above Seathwaite Tarn during zone III. Above the clay of zone III, clay mud was deposited in the lake until the Boreal/Atlantic transition, which coincides with the stratigraphic change at 490 cm. Above this the deposit is a brown detritus mud interrupted by occasional very narrow bands of clay of uncertain origin. There is no stratigraphic change at the zone boundary VII *a*/*b*, but the very conspicuous band of mosses and sand at 240–252 cm corresponds with the *Calluna* horizon—the first abrupt rise in the *Calluna* curve, as at Devoke Water.

(3) *Goatswater*, Lancashire *ca.* 1650 ft. SD 266977

(Diagram in figure 6)

This is a stony tarn between the precipice of Dow Crag and the ridge of Coniston Old Man. It was supposed by Marr (1916) to be dammed by the screes which have fallen from these two ridges, and its outflow has a short underground course through the large block scree. Much of the drainage basin is bare rock and large scree; the rest is steep montane grassland, except on the col between the two ridges, where thin peat has formed in places and bears a vegetation dominated by *Juncus squarrosus*. Several low grass-covered moraine mounds are present beside the tarn in the north-west angle of the basin.

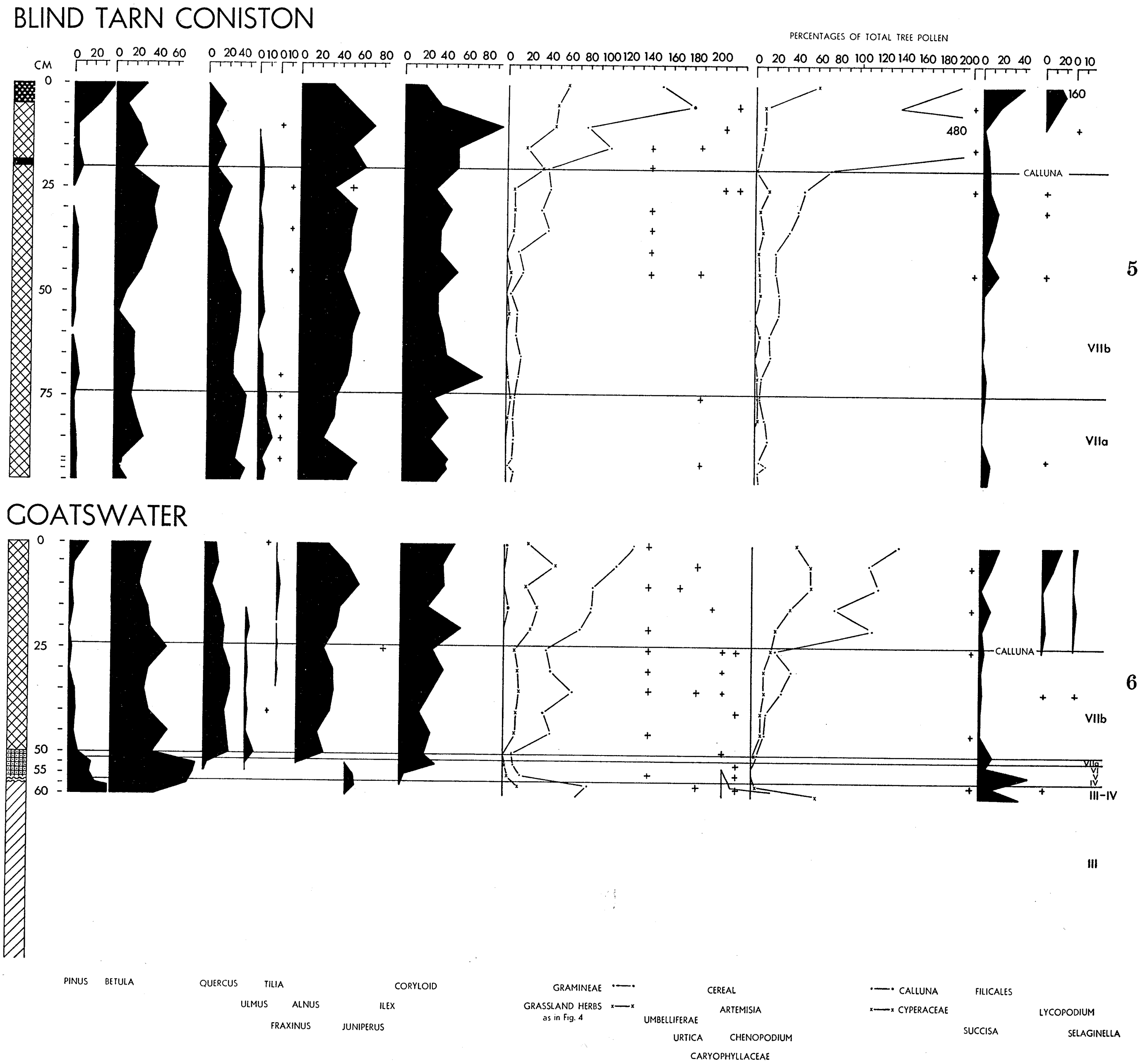

FIGURE 5. Blind Tarn, Coniston: pollen diagram from the centre.

FIGURE 6. Goatswater: pollen diagram from the point where the deposit reaches its maximum thickness.

Goatswater and the next tarn, Blind Tarn, both lie above any trace of human settlement, but in the upland valley to the south-east of them, at 800 to 1000 ft., there are many burial cairns and stone hut circles, and two burial circles, one of which yielded on excavation a cremated burial of Bronze Age type (Collingwood 1925).

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The bed of this tarn was explored by Mr B. Walker, who reports that most of it is stony, with no soft deposit, but that in the north-west quarter there is a conspicuous mound of clay with brown organic sediment on its surface; this must be a submerged moraine, probably associated with the mounds just above the tarn margin at this place. A core 1 m long was obtained from the top of this morainic mound; its stratigraphy was as follows:

cm	
0 – 50	greyish black organic mud
50 – 52·5	small stones in a mixture of pink clay and sand
52·5–57·5	greyish clay
57·5– 60	moss remains in greyish clay
60 –100	pink clay without laminations

This core represents the late- and post-Glacial sequence of sediments in a remarkably contracted vertical thickness. No pollen could be extracted from the clay below 60 cm. At 60 cm, the sample contained a typical late-Glacial pollen spectrum; at 57·5 cm the remains of mosses, *Rhacomitrium* cf. *fasciculare*, *Hylocomium* cf. *splendens* and *Tortula* sp. were identified by Mr J. Dickson, and the rapid fall in herbaceous pollens in this sample fixed the zone III/IV boundary here. The layer of sand and stones at 50 cm coincides with the Boreal/Atlantic transition, above which began the deposition of organic mud. There was no sign of any unconformity in this succession of deposits. On the available evidence it is not possible to determine the age of the late-Glacial sediments with certainty, but it is probable that the submerged and visible moraines represent the deposition of the zone III glaciation in this hollow, and that the thin layer of sediment containing a late-Glacial pollen spectrum and moss remains, which overlies the submerged moraine, represents the debris which accumulated on top of this snow-bed or small corrie glacier during the closing stages of zone III.

(4) *Blind Tarn*, Lancashire *ca.* 1850 ft. SD 263967

(Diagram in figure 5)

This is a very small stony tarn occupying a small corrie in the eastern slope of Brown Pike (2237 ft.). The back wall of the corrie is steep, though not sheer, and the tarn is dammed by a very regular crescentic moraine; there is no outflow. The numerous outcrops on the walls of the corrie bear an association dominated by mountain plants of open habitats, but *Anemone nemorosa* and *Oxalis acetosella* are present on the floor of the corrie, suggesting the presence of former woodland.

Three cores were obtained from the central part of this tarn, though much of the bottom is stony. The longest was 95 cm in length; the other two were shorter and appeared to correspond with the upper portion of the first. The stratigraphy was as follows:

cm	
0– 5	soft black mud
5–20	firmer greyish black fine detritus mud
20–22	coarse detritus mud; a stone 5 cm in diameter occurred at this horizon in the second core
22–95	greyish black detritus mud

28-2

Samples were taken at close intervals at the base of this core, and showed that the basal deposits contain much alder pollen as well as oak, elm and birch. The bottom is therefore in zone VII*a*. It is of course possible that deposition only began in this tarn at this time, but in view of the stratigraphy of the Goatswater deposits, it seems very likely that the Livingstone corer used in Blind Tarn was stopped by a layer of stones at the Boreal/Atlantic transition at the base of zone VII*a*, similar to that which occurs in Goatswater. Therefore no clue to the age of the tarn's moraine is provided by these cores.

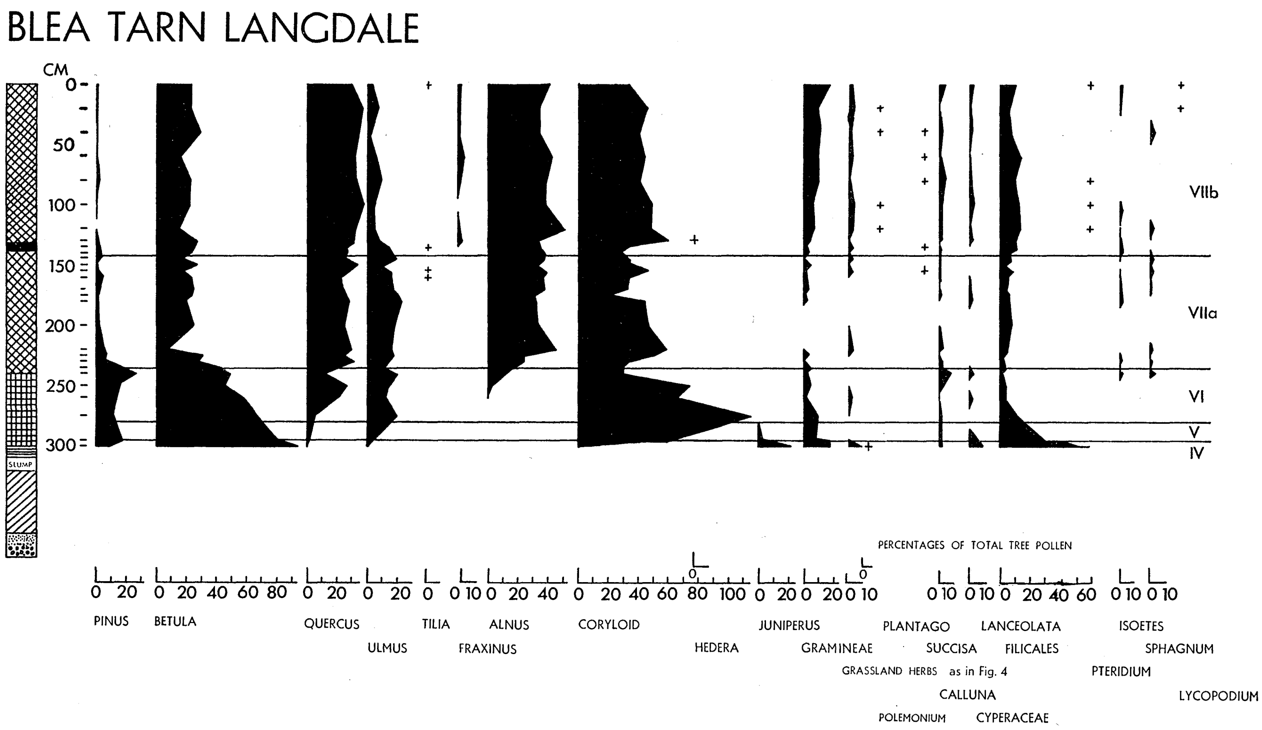

Figure 7. Blea Tarn, Langdale: pollen diagram from the centre.

The layer of coarse detritus and stones at 20 cm corresponds to the abrupt rise in *Calluna* pollen which has been designated the '*Calluna*' horizon in those tarns in which it occurs. The abrupt rise in *Calluna* pollen occurs in Goatswater, but is not accompanied there by any perceptible stratigraphical change.

(5) *Blea Tarn*, Langdale, Westmorland *ca*. 700 ft. NY 293044

(Diagram in figure 7)

This is a fairly shallow tarn, occupying a hollow in the drift in the floor of an upland valley which hangs above Little Langdale to the south, but is connected by a low col to the north-east of the tarn with Great Langdale, to the north. East and west of the tarn are steep slopes leading up to the ridge *ca*. 2000 ft. high, which separates the two Langdales. On the western side of the tarn is some woodland, now mainly planted conifers but including some oak; and scattered trees of oak, ash, larch and birch occur up to about 1000 ft. in the drainage area, and there are extensive patches of juniper. The shores of

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the tarn are stony except in the north, where peat has overgrown part of the open water.

Blea Tarn and the next, Red Tarn, lie quite outside the area of upland archaeological remains of Bronze Age type—the burial cairns and stone hut-circles. The map shows that these are absent from the central mountainous region of the Lake District. These two tarns are, however, very close to the Neolithic axe-factories which have been found in Great Langdale (Bunch & Fell 1949) and on Scawfell.

A core taken from the open water 8 m deep in the middle of the tarn contained *ca.* 3 m of organic mud overlying glacial clay. There was clear evidence of disturbance and unconformity at the junction of mud and clay, and the topmost layers of glacial clay contained a mixture of varved pink clay and organic deposits. This disturbance has been found in several other shallow tarns, and will be discussed in a later paper on late-Glacial sediments in the Lake District. Meanwhile only the post-Glacial stratigraphy will be considered. This was as follows:

cm	
0–135	brown fine detritus mud
135–140	reddish clay mixture in above mud
240–300	lighter brown fine detritus mud
300–	top of disturbed layer of pink glacial clay with some admixture of organic mud

The layer with a high proportion of mineral matter, at 135 to 140 cm, corresponds to the zone boundary VII *a*/*b*. No stratigraphic change at the Boreal/Atlantic transition was found in the cores from this tarn. The sample at 300 cm contained a pollen spectrum characteristic of zone IV.

This tarn is unique among the six in having no stratigraphic change above the zone boundary VII *a*/*b*. This corresponds with the absence of the *Calluna* horizon from the pollen diagram.

(6) *Red Tarn*, Langdale, Westmorland 1700 ft. NY 267037

(Diagrams in figures 8 and 9)

This is a small and very shallow tarn, occupying a hollow in the drift cover of the floor of a high valley in the ridge west of Blea Tarn. Several smaller hollows around it are entirely or partially overgrown, and the normal hydrosere is apparently in process of filling in Red Tarn. Blanket peat has developed on the ground west and south of the tarn, to a depth of 1 to 2 m and can be seen to be encroaching round the morainic mounds with their interspersed filled-in hollows. Much of this peat is now deeply dissected, and a layer of wood including branches of birch is visible near the base of most of the exposed sections.

On the slopes above the floor of this high valley, the vegetation is montane grassland with *Lycopodium* spp., much *Calluna* in places, and occasional *Empetrum*.

Over much of the bottom of the tarn there is a very thin deposit, but in one part, nearly 4 m of organic mud was found. The water at this point is less than 1 m deep, and the

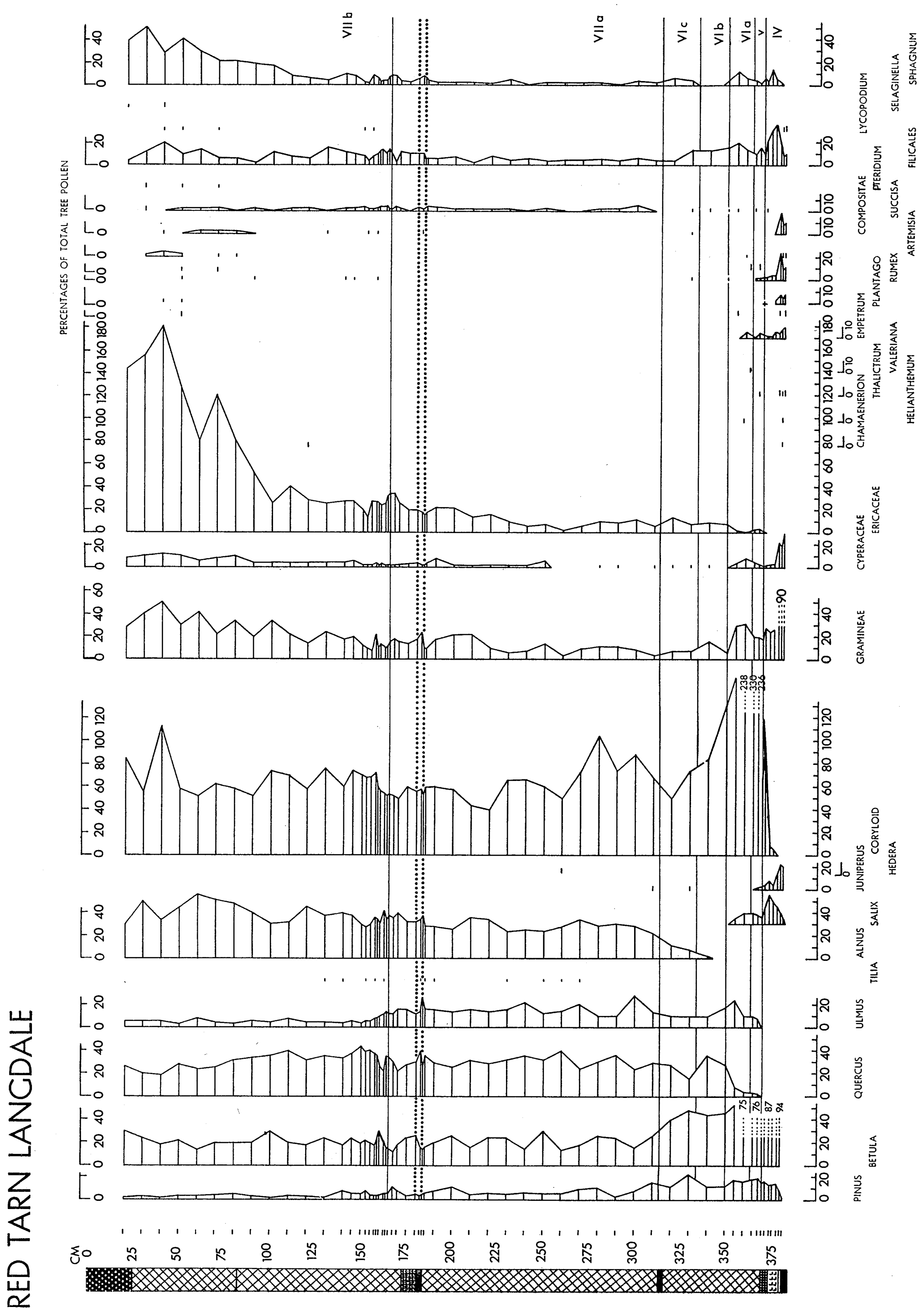

FIGURE 8. Red Tarn, Langdale: pollen diagram from the centre. The dotted lines indicate the horizon where sudden fluctuations in the pollen curves suggest the inwash of soil containing pollen.

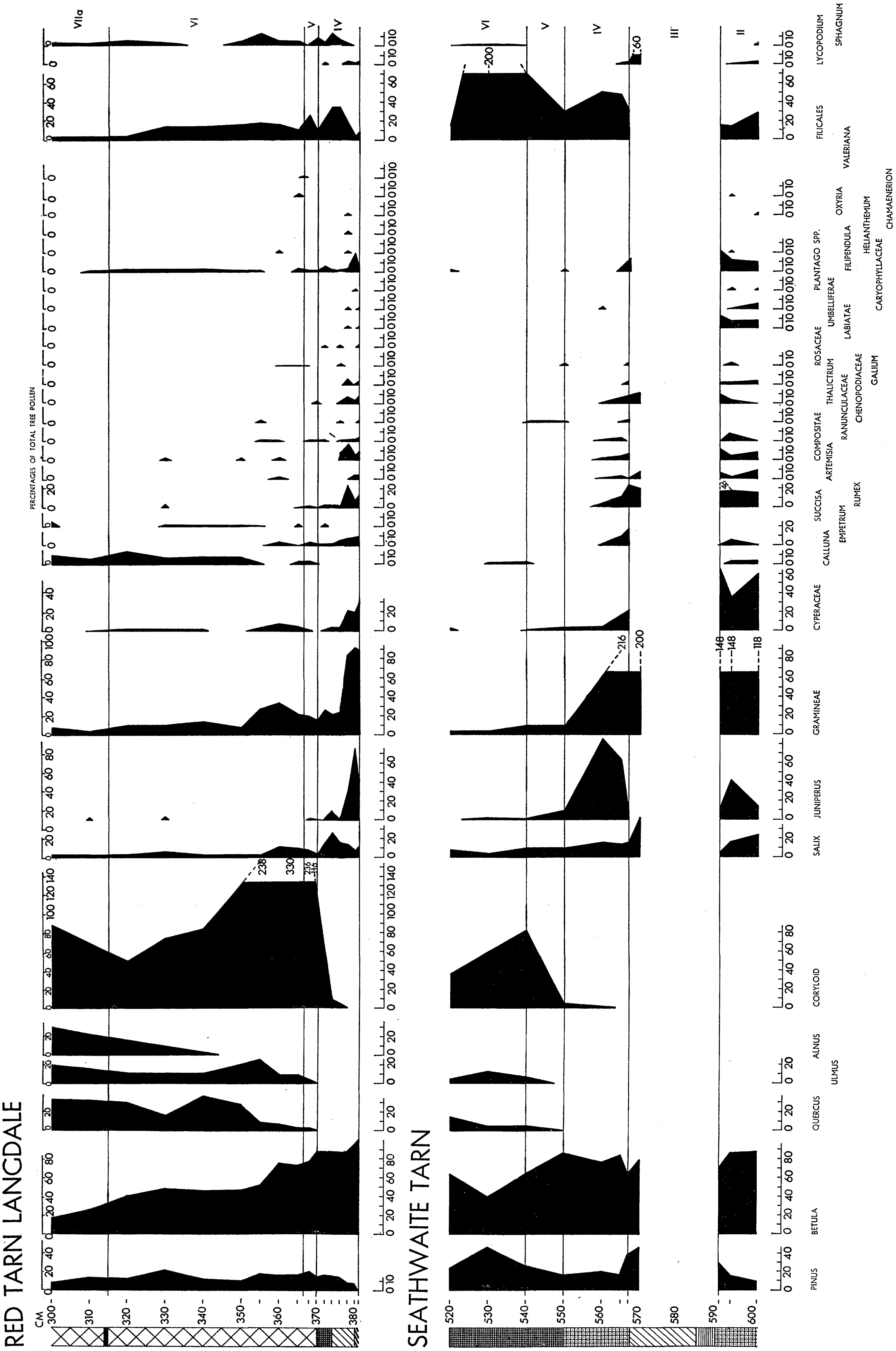

FIGURE 9. Seathwaite Tarn and Red Tarn, Langdale: late-Glacial pollen diagrams compared.

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best core was obtained by pushing a Livingstone sampler through a hole in the ice when the tarn was frozen. The stratigraphy was as follows:

cm	
0– 12	soft black ooze
12– 59	brown coarse detritus-mud
59– 70	paler, silty organic mud
70– 79	brown coarse detritus-mud, rather dark
79– 84	mixture of pale silty mud with dark coarse detritus-mud
84–*ca.* 170	dark brown coarse detritus-mud, becoming gradually more silty from 170 cm
*ca.*170–182	silt content gradually increasing downwards
182–184	silty mud of higher density
184–224	fine detritus-mud, pale brown
224–274	dark brown coarse detritus-mud
274–310	fine detritus-mud, pale brown
310–312	band of red clay
312–*ca.* 370	medium brown fine detritus-mud, becoming reddish and clayey towards 370 cm
ca. 370–374	reddish-fawn clay-mud
374–380	brick-red crumbly clay
380–382	disturbed horizon; mixture of deposits above and below
382–385	very stiff plastic brick-red clay containing haematite, and no pollen

The layer at 380 to 382 cm contains a pollen-spectrum characteristic of the late-Glacial period, but there is no indication of the threefold division, nor of the organic layer of zone II. Therefore this high hollow may well have been occupied by ice during zone III, as Manley supposes, and the disturbance at 380 cm may in that case represent the results of melt phenomena.

Figure 9 shows the base of this profile in detail. At 380 cm, the lowest horizon at which pollen was present, the pollen-spectrum is one characterizing an open vegetation with some birch, and contains the juniper maximum characteristic of the base of zone IV in many diagrams. The red crumbly clay and the clay-mud therefore belong to zone IV, the IV/V boundary being drawn, as customarily, at the beginning of the rise in *Corylus*, which occurs at 370 cm. This is taken to indicate that at this altitude solifluction continued throughout zone IV, producing the minerogenic deposit between 370 and 380 cm. The changeover to true organic deposit was delayed in this tarn until midway through zone V, and still more interesting, the plants of open habitats (*Empetrum*, *Helianthemum*, *Rumex*, *Artemisia*, etc.) continued to be represented into zone VI*a*, if the V/VI boundary is drawn as usual at the first expansion of *Ulmus*.

The clay-band at 310 to 312 cm can be interpreted as due to reworking of marginal muds in the period of low water level just before the B.A.T. (though the slow expansion of *Alnus* in this diagram makes it difficult to draw an exact line for the VI/VII*a* boundary).

The silty mud at 182 cm occurs just before the zone boundary VII*a*/*b*, and coincides with some evidence for redeposited pollen. It is very significant that this tarn and Blea Tarn show a stratigraphic change at the *Ulmus* decline, the VII *a*/*b* boundary.

The mixed layer at 84 cm coincides with an expansion of *Calluna* pollen which almost certainly indicates the beginning of severe erosion and secondary deposition.

6. Pollen zonation and stratigraphic changes

(i) *Late-Glacial; zones I, II and III*

It is proposed to discuss late-Glacial deposits in more detail in a later paper, when evidence has been obtained from tarns in all parts of the Lake District. Here it can be stated briefly that the evidence from these six tarns is in general agreement with Manley's conclusions as to the height of the late-Glacial snow-line in the Lake District—conclusions based on geomorphological and climatological grounds. At Seathwaite Tarn, the presence of an organic Allerød (zone II) layer, overlain by varved clay, shows that there was an active glacier in the drainage basin during zone III, but it did not extend as far down the valley as the tarn (1200 ft.). Manley considered it likely that there was a snowbed in the Goatswater hollow during zone III, and the evidence from Goatswater has been shown to support this. It is unfortunate that the cores from Blind Tarn, Lancashire, appearing as they do to be incomplete, cannot provide any evidence as to the age of the crescentic moraine of that corrie. Manley's supposition that Red Tarn, Langdale (1700 ft.), lay within the gathering ground of a zone III snowfield, is fully supported by the absence there of any trace of a zone II (Allerød) layer. The cores from Red Tarn appear to be complete and conformable, and the lowest deposit, apparently lying on the rock, is a brick-red plastic clay with no pollen, which passes upwards into a crumbly clay, and the pollen spectrum at the base of the crumbly clay is characteristic of the boundary between zone III and zone IV. This suggests that the plastic clay, like the clay mound in Goatswater, was deposited during zone III by ice or snow of sufficient erosive power to have removed the deposits of zone II.

Blea Tarn and Devoke Water both lie below 800 ft. and so beyond any possible direct influence of the corrie glaciers of zone III. The thin unlaminated zone III clay in the middle of Devoke Water resembles the corresponding deposit in Esthwate Water (Franks & Pennington 1961); both drainage basins lack any possible sites for zone III glaciers. In Blea Tarn it is as yet impossible to date the clays which lie below the post-Glacial organic mud, because there is clear evidence of disturbance of the clay, with incorporation of organic mud which may be either Allerød (zone II) or early post-Glacial (zone IV) in age. This type of disturbance at the late-Glacial/post-Glacial boundary has been found in other shallow tarns, e.g. Blelham Tarn, Lancs. and Loughrigg Tarn, Westmorland, and further investigation of it is in progress.

(ii) *Early post-Glacial; zones IV, V and VI*

These three zones cover the period from *ca.* 8300 B.C. to *ca.* 5500 B.C. and thus represent the deposition of nearly 3000 years. Proportionately to the whole profile, these zones are contracted, showing that deposition was relatively slow, in all the profiles except Red Tarn, Blea Tarn and the shallow-water core from Devoke Water. (Evidence from the large valley-lakes had already shown that these early post-Glacial zones are represented by a greater thickness of sediment in shallow water than in the deep central parts of the lakes, possibly because much of the accumulated material was derived from marginal erosion.) In all the tarns, the sediment of this early post-Glacial period, though more organic than the deposit of zone III, is less organic than later sediments, and the stratigraphic change coincides with the zone boundary VI/VII*a*, the Boreal/Atlantic transition.

In zone IV, Red Tarn differs from the others in that the change to a more organic limnic sediment is delayed until the end of zone IV (the zone being defined pollen-analytically); the deposit of zone IV is a minerogenic crumbly clay, deriving its brick-red colour from haematite present there both in the rock and in the drift, so that it appears that solifluction remained active at this altitude (1700 ft.) throughout zone IV. In Goatswater (1650 ft.) the sediment of these zones is so thin that it is impossible to distinguish clear zone boundaries, but much minerogenic sediment is present at the base of the post-Glacial and the major change to an obviously more organic mud coincides with the Boreal/Atlantic transition. At Seathwaite Tarn (1200 ft.) there is a pink clay (similar to the zone III clay) incorporated in the mud of zone IV, and the colour change due to its disappearance corresponds with the pollen-analytic zone IV/V boundary. It seems clear that though organic muds began to accumulate at the zone III/IV boundary (except perhaps at Red Tarn), around all the lakes above 1000 ft. solifluction remained active for some time, adding much mineral material to the lake deposits.

The organic muds which began to accumulate at the beginning of the post-Glacial were diatom-muds. The diatom shells represent the non-oxidizable residue of organic production, and above the limit of solifluction activity in the cores, diatom shells make up the bulk of the deposit of zones V and VI. Once solifluction has ceased it seems that little allochthonous material, either organic or inorganic, was deposited in the lakes in these early post-Glacial zones; this supposition agrees with the known dry climate of the Boreal period, and corresponds with Mackereth's period of minimum erosion and rapid leaching of soluble bases. This accounts for the low rate of deposition shown by the thinness of deposit in these zones.

In nearly all the lakes and tarns, the change to a more organic mud at the Boreal/Atlantic transition is preceded by a band of minerogenic deposit, clay or silt or, as at Goatswater, small stones. This suggests lowered water levels accompanied by marginal reworking of muds during zone VI*c* as found, e.g. at Hockham Mere (Godwin 1956), and Haweswater (Oldfield 1960).

(iii) *The Atlantic period, zone VIIa, and the zone VIIa/b boundary* (Ulmus *horizon*)

In all the lakes and tarns (excluding littoral deposits) the muds above the Boreal/Atlantic transition are more organic than those below, and in those lakes which have been investigated, there are pronounced changes in diatoms and cladoceran remains in the muds at this horizon. It is clearly a horizon which marks a considerable change in conditions in some lakes, and it is not yet possible to decide how far these changes were a direct consequence of the climatic change to a more oceanic climate, and how far they were due to changes in water level. It has already been shown that a stratigraphic change to minerogenic sediment in zone VI*c* in some lakes, e.g. Devoke Water littoral core, can be explained as a response to a lowered water level in late Boreal times. With the increased rainfall of the Atlantic period, water levels must have risen again, and possibly it is this rise which produced the stony layer in the Goatswater muds at this horizon. In the littoral area of Devoke Water, as in parts of the littoral of Windermere and Esthwaite Water, minerogenic sediment was deposited during zone VII*a* and later, with the precipitation of ferric and manganese hydroxides, but the complexities of littoral deposition will not be pursued further.

In figure 3*b* the curve for percentage of total carbon per unit dry weight in the central core from Devoke Water is shown alongside the pollen diagram, by permission of F. J. H. Mackereth. It indicates clearly the rise in organic content of the muds above the VI/VII*a* boundary. In zone VII*a* the muds are very rich in both diatoms and pollen grains, and all these factors agree in indicating a comparatively small proportion of mineral sediment. Mackereth has, on purely chemical evidence, deduced that the erosion rate during the Atlantic period was low, and this is in agreement with the above facts. The very low figures for herbaceous pollens during zone VII*a* indicate that the forest cover was practically complete, and presumably the low erosion rate in this period, when the climate is known to have been oceanic, shows that a continuous forest cover protects even steep land surfaces from erosion by rainfall.

The thickness of the zone VII*a* deposit is greatest at Red Tarn and Blea Tarn, where it is about 1 m thick, and least at Goatswater, where it is only 5 cm. There is no obvious correlation between these very different deposition rates during this zone and any morphometric factor differentiating the various tarns. The organic mud shows little change from the base to the top of the zone, and only at Seathwaite Tarn is it interrupted by any minerogenic deposits. There are three narrow clay bands within this zone at Seathwaite; no explanation of these can be put forward at this stage.

The *Ulmus* horizon, the steep fall in the *Ulmus* pollen curve which marks the upper boundary of zone VII*a*, is accompanied by a stratigraphic change in Blea Tarn and in Red Tarn, where there is a band of mineral silt at this horizon. Samples were analyzed at close intervals in both profiles and established that the stratigraphic change coincides exactly with the first disturbance of the tree-pollen curves. On the reasoning used to explain stratigraphic changes at the Boreal/Atlantic transition, this might indicate a rise or fall in water level, and hence a climatic change at the *Ulmus* horizon could be postulated, but the absence of any stratigraphic change at the *Ulmus* horizon in other tarns makes this unlikely. There is strong evidence from continental sites for an anthropogenic origin for the *Ulmus* decline (Troels-Smith 1960) and the various manifestations of this change in these six tarns can be explained more easily by an anthropogenic causal factor than by a climatic change (which would be expected to bring about similar changes in all the tarns). It will be explained in more detail in the next section how the pollen curves suggest that the vegetational changes at the *Ulmus* decline were more intense in the neighbourhood of Red Tarn and Blea Tarn, and how they indicate a real alteration in the composition of the local vegetation at the time of the decrease in elm. It can be seen clearly in all the pollen diagrams that some increase in fern spores occurs at or just above

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the *Ulmus* decline. It has been shown by Dimbleby (1957) that fern spores are very characteristic of the deeper layers of soils, suggesting preservation from the early post-Glacial period in soils. These features of the pollen diagrams are therefore believed to indicate increased soil erosion accompanying the vegetational changes at the elm decline, varying from tarn to tarn in a manner readily explicable if human interference with the virgin forest was the cause. Red Tarn and Blea Tarn lie near each other, in an area where there is evidence for local activity of early Neolithic inhabitants, and it is very suggestive that these are two tarns where the vegetation changes at the elm decline were apparently sufficiently intense to produce a stratigraphic change in the deposits.

(iv) *Post-*Ulmus *horizon; forest clearance and stratigraphic change*

The *Ulmus* horizon has been dated to *ca.* 3000 B.C. by radiocarbon analyses from many parts of north-west Europe (Clark & Godwin 1962; Godwin 1960). This puts it almost exactly midway between the opening of the post-Glacial period and the present day. In the profiles from Red Tarn and Blea Tarn, this horizon falls approximately midway between the surface of the mud and the top of the late-Glacial deposits, showing that the rate of accumulation throughout the post-Glacial 10,000 years has been approximately uniform. In the other four tarns, the *Ulmus* horizon is much deeper in the profile than halfway, showing that the accumulation rate has been much more rapid since 3000 B.C. At Devoke Water the accumulation rate during the 5000 years since the *Ulmus* horizon has been ten times as rapid as during the preceding 5000 years.

It is known that the rate of accumulation on the floor of a lake depends partly on the supply of material for deposition, and partly on hydrographic conditions which determine how much of the deposited material remains in place at any point on the lake floor. There is no hydrographic factor common to Red Tarn and Blea Tarn and differentiating them from the other tarns, so that the position of the *Ulmus* horizon in the sediment profile is strong evidence for lower deposition rates in these two tarns during the last 5000 years compared with the other four. On the assumptions discussed in the introductory section, this implies that in the Langdale area, around Red Tarn and Blea Tarn, soil erosion has not been more rapid during the period since the elm decline than during the early post-Glacial period, but in the Coniston–Duddon area, on the other hand, soil erosion has been up to ten times more rapid since the elm decline than it was before. At Blea Tarn and Red Tarn the episode of the elm decline itself was more intense than round the other tarns, but after that episode there was, on the evidence of the lake deposits, no sustained increase in soil erosion in the upper Langdale area.

In three of the tarns where the deposition rate was so much accelerated after the *Ulmus* horizon, Devoke Water, Seathwaite Tarn and Blind Tarn, the organic muds of the post-elm decline period are interrupted by a band of minerogenic sediment with organic debris immediately above it. This band occurs at comparable levels in the profiles from these three tarns, and is possibly contemporaneous, but as yet there is not sufficient evidence to decide this point. The organic debris in Seathwaite Tarn includes many moss plants, including species common in mountain grassland—species of *Rhacomitrium*, *Hylocomium*, etc. In one core from Blind Tarn a stone 5 cm across was included in the minerogenic band. This layer is interpreted as indicating a period of very rapid inwash from the land surface. In all three tarns it coincides with a very steep rise in *Calluna* pollen, and since this pollen occurs in great quantity in many Lake District soils, this supports the hypothesis of the derivation of this layer from inwash. The curve for total carbon in the Devoke Water muds shows that in the 30 cm of deposit immediately above the minerogenic layer (230 cm) the values for total carbon are higher than at any other horizon in the whole profile. It seems possible that this is due to inwash of organic material (though in the Devoke Water core analyzed there were no visible moss plants, unlike the corresponding layer at Seathwaite Tarn). The evidence from the pollen diagrams that this layer resulted from inwash of humic material will be discussed in the following section.

The topmost stratigraphic change is the transition to blacker and wetter mud which occurs about 20 cm below the mud surface in all the tarns. At Seathwaite Tarn, the black surface mud of before 1904, when the dam was built, is visible underneath the 30 cm of minerogenic sediment resulting from the rise in water level, and the 5 cm of black mud which lies on top of the minerogenic layer presumably represents the deposition of the last 50 years, since the new shoreline of the deepened tarn became stabilized. The abundance of fern spores in the 30 cm layer of minerogenic sediment here is an interesting confirmation of the presence of these spores in the mineral soils around the original shoreline which were eroded and redeposited when the level was raised.

Summarizing this section, it can be said that the zone boundaries which are recognized as denoting major climatic changes correspond with stratigraphic changes in most, if not all, of the tarns and lakes. This can be explained by the effect of low temperatures on soil movement, by the stabilizing effect on soils of a continuous vegetation cover (particularly forest) which was the response to a more favourable climate, and by changes in water level in response to rainfall. The stratigraphic changes after the zone VII *a*/*b* boundary are not so readily explicable, because they result from both climatic change and human interference with the continuous forest cover.

All the evidence which has been presented in this section is in agreement with Mackereth's conclusion (which was based on purely chemical evidence) that the tarn sediments represent a sequence of soils derived from the drainage basins, and that changes in the type of sediment reflect changes in rates of soil erosion.

7. Vegetational history in relation to climatic change and human influence

The evidence from these tarns, combined with that from the valley lakes, presents the picture of an open late-Glacial vegetation of grasses, sedges and herbs, with varying proportions of birch woodland during zone II plus willow and juniper, followed by the spread of forest during zone IV with an abrupt fall in the pollen of herbs and shrubs, leading up to a closed forest even at the highest altitude explored here (1800 ft.). This period of closed forest lasted until 3000 B.C., after which progressive deforestation led to the bare fell-sides of the present day and depressed the tree limit to its present level of 600 to 800 ft.

The three major factors determining the course of ecological history were climatic, edaphic and human. The climatic changes (together with the sequence of post-Glacial immigration of species) determined the changes in forest composition on which the pollen zonation is based, and the consistent behaviour of the pollen curves during the early post-Glacial period shows that a similar development and succession of dominant vegetation took place all over the southern Lake District. The edaphic factor was the influence on vegetation succession of progressive soil changes as post-Glacial time went on—the change from immature soil profiles of the late-Glacial period to mature soil profiles, in this region of high relief, oceanic climate, and hence rapid leaching. The third factor was the effect on vegetation and soils of human exploitation, beginning with the Neolithic revolution. The differences between one tarn and another since 3000 B.C. suggest that the third factor may have been dominant during the last 5000 years, but the known climatic deterioration which set in during the last millennium B.C. must have affected both the natural climatic climax vegetation and, even more, the course of soil changes and the operation of the edaphic factor, particularly in the greatly accelerated rate of peat formation. Because no direct radiocarbon dates are available for the lake deposits, it is not at this stage possible to identify with certainty the horizon of the climatic deterioration. Arguments for and against the identification of this event with the *Calluna* horizon will be stated briefly.

In late-Glacial zones and after deforestation, the values for herbaceous pollen reach several times the total tree pollen sum, and in the surface mud of these tarns there is very little tree pollen at all. This is in complete contrast to the forest period of zones V, VI and VII*a*, during which no herbaceous pollen at all was found at Devoke Water and at Blea Tarn (below 800 ft.) and less than 10% herbaceous pollen at Seathwaite, Blind Tarn and Goatswater (1200 to 1800 ft.). Only at Red Tarn (1700 ft.) did the curves for grass and *Calluna* pollen remain at *ca.* 10% of the total tree pollen throughout the forest period of zones VI and VII*a*, and this can probably be explained as at least partly due to local hydroseres, as marshy hollows in the surface of the drift filled in and passed through a stage of willow-sedge fen to *Calluna–Sphagnum* associations, such as can be seen there today (see diagram in figure 9).

It is not yet possible to estimate how far the pollen grains in peats or muds have travelled from their place of origin, so it is clearly not possible to obtain an accurate estimate of the amount of forest around each tarn from the pollen diagrams alone. However, where no herbaceous pollen at all was recorded, forest cover must have been complete. The considerable differences between the various tarns in the later post-Glacial period imply that the pollen incorporated into the deposits of each tarn was of local origin. So it is likely that the individual features of the pollen diagrams from these six tarns reflect mainly the local vegetational changes, within the regional trends determined by climate. Before 3000 B.C. local differences would be due to topography; after 3000 B.C. the topographical differences were accentuated by different human history.

The late-Glacial vegetation in relation to altitude will be discussed in a subsequent paper. Unfortunately no macroscopic remains of late-Glacial vegetation, other than bryophytes, were found in these cores, and as the deposits of zone III are entirely minerogenic there is no evidence as to the vegetation during the period of the corrie glaciation. Figure 9 shows details of the late-Glacial/post-Glacial transition at Red Tarn and Seathwaite Tarn. At the stratigraphic transition from minerogenic deposit to pollen-bearing muds, grass, sedge, *Empetrum* and *Rumex* pollen exceed the tree birch sum; juniper and willow are both present. The zone boundary III/IV, defined pollen-analytically by the decline in *Artemisia* and Cyperaceae, and a *Rumex* peak as in Western Ireland (Watts 1963), coincides with the stratigraphic change, and immediately precedes first the juniper maximum and then the spread of birchwood in the area, indicated by the abrupt decline in grass pollen. Iversen (1960) regards the juniper phase as a pioneer stage in the forest succession, due to the immediate response of juniper already present in a stunted form to the rise in temperature. In the Red Tarn diagram, the zone boundaries IV/V and V/VI *a* can be drawn with reference to the curves for *Corylus* and *Ulmus*, which follow the usual course, and it is striking to see how the plants of open habitats, *Empetrum*, *Succisa*, *Rumex*, *Artemisia* and *Helianthemum*, persist into zone VI *a* and then disappear, indicating that the closing of the forest was delayed until about 7000 B.C. at this altitude. None of the drainage areas include cliff refugia of the type described by Godwin at Cwm Idwal (1955) where plants of open habitats persisted throughout the forest period.

There are three interesting features in the regional forest succession. The Boreal hazel maximum is lower in these upland tarns than in the valley lakes; only at Red Tarn and in the diagram from the margin at Devoke Water do values for *Corylus* exceed the total pollen of other trees. Iversen's (1960) explanation of the forest succession in the Boreal is that the newly immigrated *Corylus* displaced *Betula* by preventing regeneration; possibly some altitudinal factor enabled birchwoods to survive in many places in the uplands, but this would not explain the larger hazel maximum at Red Tarn. *Ulmus*, which appears at the zone boundary V/VI, expands faster and further at Red Tarn, Blea Tarn and to a lesser extent at Seathwaite, than in the others or in the valley lakes. The species is most likely to have been *Ulmus glabra*, and it appears to have found favourable conditions in the central mountains of the Lake District—a further suggestion that soils on the Borrowdale Volcanic series, and drifts derived from them, had a higher base-status in the early post-Glacial than now. In sub-zone VI *c*, a *Pinus* maximum appears in the profiles from Devoke Water (see figure 3 *a*) and Blea Tarn, accompanied by small peaks of *Calluna* and *Sphagnum*. It seems most likely that this represents a local succession of ill-drained marginal areas during the phase of lowered water levels in zone VI *c*, but the presence of *Sphagnum* is surprising in this dry period. Any possibility that this *Pinus–Calluna–Sphagnum* phase belongs to the subsequent oceanic Atlantic zone VII *a* would imply that the expansion of *Alnus* was not contemporaneous at these various tarns (since the rise in the *Alnus* curve has been used to determine the VI *c*/VII *a* boundary). After discussions with Professor Godwin, I believe that this hypothesis of *Pinus–Calluna–Sphagnum* colonization of ill-drained marginal areas during zone VI *c* is more likely than non-synchroneity of the *Alnus* expansion, but the horizon needs further investigation. The expansion of *Alnus* is sudden and coincides with a stratigraphic change, in all the tarns except Red Tarn. Here the expansion is long-drawn-out and the zone boundary difficult to draw. In this shallow tarn there is a marginal hydrosere, and this may be related to the absence of sudden stratigraphic change.

During the Atlantic forest period of zone VII *a*, there is evidence for regarding *Alnus* as predominantly the tree of basin swamps, up to high altitudes. Alder wood is common in this period in upland basin peat, and the high percentage of *Alnus* at Blea Tarn and Seathwaite can be explained by the presence of adjoining marginal swamps. There is also much *Alnus* pollen at Blind Tarn, and this may have come from the valley bog Cove Moss, which is quite near though 600 ft. lower, and has much alder wood in its zone VII *a* peat. Devoke Water, the tarn with no deep valley swamps in its drainage area, has a conspicuously lower percentage of *Alnus* pollen than the other tarns.

The Atlantic forest on dry ground consisted of oak, elm and birch. Elm seems to have been more abundant in the Langdale area, and to a lesser degree at Seathwaite, than in the area south and west of the central mountain mass, but this must be confirmed by analyses from other tarns. Birch is noticeably more frequent in Goatswater, the drainage basin in which soils are conspicuously shallower than in any other.

Tilia is never more than 1 % of the tree pollen. It seems most likely that it never grew in this area, but the occasional grain was blown from the limestone region of South Westmorland. Donner's Scottish diagrams (1963) show a similar absence of *Tilia*.

In the upland basins of Red Tarn, Blea Tarn, Devoke Water and Seathwaite Tarn, *Ulmus* pollen reached 20 % of the total tree pollen in zone VII *a* and the elm decline at the end of this zone is seen as a sudden drop from this figure to between 2 and 4 %. In the large lakes the percentage of *Ulmus* before the decline is smaller and the decline not so sudden. In nearly all the tarns, *Fraxinus* pollen appears shortly above the elm decline, and at Blea Tarn and at Goatswater *Fraxinus* forms a continuous curve from the elm decline upwards. In the large lakes, *Fraxinus* pollen is rare. It seems that the decline of the elm provided an opportunity for ash to enter the upland woods, and it is difficult to postulate a climatic change which would account for this.

The changes in other pollen curves which accompany the elm decline are seen in most pronounced form in the diagrams from Red Tarn and Blea Tarn, and these are the two where a stratigraphic change accompanies the elm decline. It is significant that these two tarns are close to the Neolithic axe-factory sites in Great Langdale. Closely spaced counts at the elm decline in these two profiles (cf. figures 7, 8) show that the first disturbance of the tree pollen coincides with a change to a more silty mud. At Red Tarn, just below the main fall in the *Ulmus* curve, there are sudden fluctuations in the pollen curves, accompanying the change to silty mud, which can be interpreted as due to secondarily deposited pollen originating in pollen-containing woodland soil humus, like that now found preserved under the later blanket peat in Red Tarn Moss. Both the secondary pollen and the silt could have reached the tarn as the result of soil erosion accompanying the changes in forest composition; peaks of fern spores at the same horizon confirm the supposition that mineral soils entering the tarn produced the silty bands at this horizon. These changes are all consistent with the anthropogenic explanation of the elm decline put forward by Troels-Smith (1953). If the first Neolithic farmers utilized the elm for fodder for domestic animals, as suggested by Troels-Smith, this would open up the virgin forest, and could well have made it possible for the light-demanding ash to gain a foothold for the first time. Increases in grass and hazel pollen just at the elm decline support the theory of an opened-up forest, and at these two tarns especially, transient peaks of birch pollen just above the elm decline, soon replaced by increasing oak, suggest phases in recolonization of opened-up parts of the forest. As yet, the counts are not sufficiently large to be critical for distribution of the herbaceous pollens at the elm decline, and so do not permit detailed comparison with Morrison's Primary Deforestation phase in Northern Ireland (Morrison 1959).

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After the elm decline at the zone boundary VII *a*/*b* the elm pollen never again rises above 2 to 3 %, in any of these tarns. This is in contrast to Morrison's sites in Antrim, and Oldfield's in Lowland Lonsdale, but corresponds with what happened on poor soils in Ireland (Smith 1961). This agrees with the interpretation of *Ulmus glabra* as a species of the early post-Glacial in the Lake District hills, a base-demanding species whose status must have become more precarious as the retrogressive soil changes of the post-Glacial progressed, but whose very sudden end must surely have been caused by a more catastrophic phenomenon than the slow diminution in base-status of the soil. Twenty years ago it would have seemed most unlikely that vegetation and soil changes in the Lake District dated to 3000 B.C. could have been anthropogenic in origin, but the conclusions quoted earlier from Clark & Godwin (1962), not only on the dates for the early Neolithic, but on the assumed rapid spread of the new culture (of stock-keeping) from west to east (so that the Lake District cannot be regarded as a backward area at this time) are in support of this interpretation.

The pollen diagram from Blea Tarn shows that after the episode of the elm decline, no pronounced vegetational change took place there until very recent times—i.e. only in the surface mud do the indications of deforestation appear. The phenomena responsible for the *Calluna* horizon in other tarns were totally absent from this drainage basin, and this corresponds with the absence from it of any relics of the long upland settlement of Bronze Age character. In the samples taken from surface soils in the existing plantation on one side of the tarn, and from grassland with scattered trees on the other sides, tree pollen of oak, birch and alder was quite frequent and this contrasts strongly with the Devoke Water area, where very little tree pollen could be found in soil samples. In significant agreement with this evidence for the long persistence of forest and soils containing tree pollen at Blea Tarn is the absence of any acceleration of deposition in the tarn; after the short episode of the deposition of silt at the time of forest disturbance at the elm decline, no further evidence of soil erosion is present. This agrees with the present appearance of the drainage basin, where quite deep exposed sections of brown drift soils are frequent, especially east of the tarn. The persistence of forest in one drainage basin is evidence that changes in climate and soil are unlikely to have been the *main* cause of deforestation in the Lake District.

The strongest contrast with Blea Tarn is found at Devoke Water and Seathwaite Tarn. In these pollen diagrams (figures 3 *b* and 4) the vegetation changes at the elm decline follow the pattern already outlined but are less intense. The *Quercus* maximum just above the elm decline suggests that oak replaced elm to some extent in the disturbed forest, and the rise in grass pollen which begins at the elm decline in Seathwaite probably indicates the beginning of a grassy ground flora in the higher woods at this time. The first main clearance at these two tarns begins about 25 cm above the elm decline, and the rest of the diagrams, covering between 4 and 5 m of lake deposits, records a progressive deforestation, with the *Calluna* horizon about midway between the elm decline and the surface.

In the pollen diagrams in figures 3 *b* and 4, an attempt has been made to group the various taxa according to their ecological significance. The tree pollens are shown on separate vertical axes in the usual way; the next section to the right includes on a common vertical axis the pollen indicating forest clearance together with, on separate vertical axes, cereal pollen and the pollen of weeds of cultivation (i.e. the operation of the human factor), and in the next section to the right are shown the pollens which it is considered indicate soil changes (or the operation of edaphic factors)—mainly by the indication of secondary deposition of soil in the lake. It is assumed that the curve for grass pollen indicates mainly the extension of grasses in response to destruction of forest; on the same axis the curve for 'grassland herbs' includes the total of pollen of *Plantago lanceolata*, *Potentilla*, cf. *erecta*, *Galium* type, *Rumex acetosella*, and Compositae other than *Artemisia*. It can be seen that this curve follows closely the curve for total grasses. *Pteridium* is plotted on the same vertical axis in the Seathwaite Tarn diagram, and its maxima correspond. These three curves are considered to indicate the amount of open ground, cleared of trees but capable of bearing trees if human pressure were relaxed. In the next section to the right on the diagram, that indicating soil changes, curves for *Calluna* and for Cyperaceae are plotted on the same vertical axis, and the total for fern spores (other than *Pteridium*) on the next axis. Evidence has already been presented for the view that these pollens reach the lake deposits by secondary deposition of soils rather than as entirely air-borne fresh pollen. Some of the peaks on these curves for these three indicators—*Calluna*, Cyperaceae and fern spores—are so steep, consisting only of a single maximum, that it seems very unlikely that they indicate changes in composition of the pollen rain due to ecological changes in vegetation, and more likely that these sudden peaks indicate inwash of soil containing quantities of these pollens. (This interpretation would explain the otherwise puzzling discrepancy between the values for *Calluna* in the marginal and central profiles from Devoke Water—washed-in *Calluna* pollen would be deposited in the centre but not round the margins.) Fern spores characterize the older, deeper mineral layers of soil profiles (Iversen, personal communication, believes this is because of their great resistance to oxidation). *Calluna* and sedges, especially *Eriophorum*, are characteristic plants of podsolized soils and peat, and their pollen is known to be abundant in such soils and peats, so the pollen curves will indicate initially the spread of these plants on to soils which could no longer bear trees, and will go on to a stage when the curves indicate both the spread of these plants on the surface *and* secondary wash-in of soils on which they have grown, including peat.

Phases of forest clearance are indicated in figures 3*b* and 4 by diagonal shading. The two phases occurring in the 2 m of deposit above the elm decline appear in both tarns, and in both the expansion is of grasses only, with only small quantities of herbaceous pollen, but accompanied by a steady fall in the relative amount of oak in the tree pollen. *Corylus* expands in both diagrams as *Quercus* falls. These phases would appear to have been attacks on the oak forest, including pasturing animals within it, with extension of the grassy ground flora, and spread of hazel. In the same sections of the diagrams, the two phases of wash-in of secondary pollen indicators have been indicated by vertical shading. In the Devoke Water diagram, Mackereth's curve for carbon content of the mud has been drawn beside the pollen diagram, and it can be seen clearly how these wash-in phases correspond with levels of steeply falling organic content. This suggests that mineral soils were washed into the tarn, with their included fern spores, as a result of soil erosion following destruction of part of the original oak forest. If burning accompanied forest destruction as is very likely, this would remove humus and cause the washed-in soil to be almost entirely mineral. The low levels of *Calluna* and Cyperaceae through this phase suggest that there was at this time comparatively little podsolized soil or peat in these two drainage basins.

At the top of the second clearance phase at Devoke Water, corresponding with the top of the second wash-in horizon, there is evidence of forest regeneration. The grass and *Corylus* curves decline steeply, *Plantago lanceolata* disappears, while oak shows some recovery, and this phase is accompanied by a continuous rise in carbon content, probably indicating a period free from erosion of mineral soils. At Seathwaite this phase of regeneration is less clear, and the deposits of it much thinner, than at Devoke Water.

It is not possible to give a date to this post-elm decline period of clearance for pasture, and subsequent forest regeneration. Its very similar manifestation at these two tarns, 5 miles apart, suggests that the clearances were not purely local and temporary, but were the result of a widespread settlement. The diagrams from Blind Tarn and Goatswater, quite near to Seathwaite on the other side of the high Coniston ridge, show indications of a comparable rise in grass and herb pollen and progressive decline in oak during the period between the elm decline and the *Calluna* horizon, but the slow rate of deposition in these tarns makes the sequence compressed and difficult to compare. No trace of this phase appears in the deposits of Red Tarn or Blea Tarn. Very tentatively, it might be suggested that the pasture clearance may correspond to the later Neolithic peoples who built the megalithic circles near the mouth of the Duddon, on the western side of Black Combe, and further north on the Cumberland coast. Nothing is known of their dwelling-places, and they may have been nomadic but pasture was probably part of their economy. The regeneration of oak at Devoke Water after this phase suggests that it antedated the main occupation there, but there is no clear evidence, until radiocarbon dates are obtained.

After the regeneration phase, the most intensive and permanent clearances at Devoke Water and Seathwaite Tarn cover the layer of their deposits between *ca.* 260 and 100 cm. The grass curve, with corresponding peaks for grassland herbs and *Pteridium*, shows four main peaks of the clearance indicators in this section of the deposits of both tarns, and a continuous curve for cereal pollen covers the same section, with the weeds of cultivation *Artemisia* and *Chenopodium*. If the percentages of pollen are recalculated on the basis of total pollen of flowering land plants instead of on total tree pollen, it is clear that all the tree genera decline over this section, whereas the previous clearance for pasture affected only the oak. The picture presented by this long period of clearance, with indications of cereal cultivation, corresponds to Collingwood's description of the people who interred their dead in cremation burials under the upland cairns and lived in stone hut villages near which were small stone-walled fields for tillage.

Collingwood visualized this upland occupation as lasting many centuries, and it has already been pointed out that nothing is known about how long the stone-hut villages such as Barnscar were inhabited. It is striking that the two tarns showing this comparatively early complete deforestation are the two around which the remains of this upland settlement are most abundant.

Blind Tarn and Goatswater are near to cliffs, such as Dow Crag, and very steep slopes which would be unsuitable for pasture, still less agriculture. The rise in grass pollen in their deposits probably indicates clearance by this same upland population of the high valley which runs almost from Duddon estuary to Coniston and contains many cairns, hut circles and a Bronze Age burial circle. At Blind Tarn the main clearance came somewhat later; this tarn's basin lay above the Bronze Age settlements and may have remained a small pocket of woodland until one of the later phases of clearance. The great expansion of *Lycopodium* spp. indicates the return of species of open habitats there, comparatively recently.

The *Calluna* horizon is clear in the diagrams of all these four tarns, as the major and very steep rise in *Calluna* pollen accompanied by a fall in *Isoetes* spores and by a stratigraphic horizon indicating wash-in of material from the land surface, i.e. mosses, sand and stones. It coincides with the beginning of the cereal pollen curve at Devoke Water and Seathwaite Tarn. The carbon curve for Devoke Water shows that exactly at the *Calluna* horizon is a very steep rise in the carbon curve, carrying it up to the highest peak of the whole profile. The high values for carbon cover the 50 cm above the *Calluna* horizon, after which the curve declines steadily to the surface of the mud. This carbon peak is found at a comparable horizon in relation to the grass pollen curve in the larger lakes—i.e. just above the main rise in grass which is attributed to clearance by the upland population. (This is the culture referred to in general terms as 'megalithic' in Pearsall & Pennington (1947).) At Seathwaite Tarn the *Calluna* horizon is accompanied by a large peak of fern spores. There are therefore many indications that the *Calluna* horizon represents a major wash-in of material from the land surface, changing the nature of the accumulating sediment in the lakes. A rapid increase in silting would explain the sudden decline in *Isoetes*. The washed-in material must have contained much *Calluna* pollen, and apart from the sand and stones it must have been so highly organic as to raise the value for total carbon to the maximum for the whole profile; the wash-in coincided with the beginning of the major forest clearance around the four tarns in which it appears. One further clue is that at Devoke Water the pollen of *Succisa* is found only in the deposits corresponding to the carbon peak; *Succisa* has a very large heavy pollen grain and it is possible that it is only found in lake deposits where washed in during periods of unstable soil (this would explain its frequency in late-Glacial zones). The washed-in material was not older than the elm decline, because the tree pollen curves show no sign of disturbance by deposition of secondary pollen from earlier zones. At this stage it is not possible to say whether this ecologically important horizon should be regarded as anthropogenic or as a result of some major flood. There is no trace of it in the deposits of Blea Tarn, so it is not *purely* a result of natural soil changes or a climatic event such as the deterioration at *ca.* 500 B.C. Nor does it appear in its typical form at Red Tarn; the more gradual increase in *Calluna* there may correspond with the beginning of erosion of the blanket peat around that tarn, so is different from these other four tarns where there is no blanket peat. In these four tarns the *Calluna* horizon seems linked in some way with the clearance activities. One possibility is that earlier clearances in the basins of these four tarns, between 3000 B.C. and the arrival of these farming settlers, had accelerated podsolization by replacing trees by *Calluna*, and that the first activities of the upland farmers led to the wholesale deposition in the lake of the A-horizon of these podsols. Such truncated soil profiles are known to have resulted from human activity, e.g. the frydd soils of upland Wales (Pearsall 1950).

The term 'Bronze Age' is used in the broad sense for this upland occupation, because of its burial customs, but its dates are still vague. Collingwood thought that some of the stone hut villages were begun 'not many centuries before the coming of the Romans', i.e. in the second half of the last millennium B.C. In view of the known climatic deterioration during this millennium, which led to the flooding of raised bog surfaces, it is a little difficult to accept the possibility that this was the time at which tillage of cereals began on the seaward margin of the Lake District. Only radiocarbon dates will make it possible to date this phase of cereal cultivation with certainty.

In south Westmorland, the curve for cereal pollen begins just below the main change in humification of the raised bog peat which is dated as 800 to 400 B.C. (Oldfield & Statham 1963, Statham, M.Sc. thesis). The sites are, however, too far from those discussed here to suggest, as yet, any correlation.

In the meantime, the data from these tarns suggest that forest disturbance by the earliest Neolithic settlers, at the time of the elm decline, 3000 B.C., had only transitory effects on the soil and did not destroy the forest, but only changed its composition, removing the elm and allowing ash to enter. This secondary forest continued at Blea Tarn until quite recently, and for a long period at Red Tarn. At the other four tarns, which lie near to relics of later Neolithic and Bronze Age Settlements, extension of grasses and decline in oak began shortly after 3000 B.C., indicating clearance for pasture, which diminished the secondary forest and led to erosion of forest soils; the appearance of *Calluna* and Cyperaceae pollen in this period probably indicates the development of acid soils and podsols, which followed the first serious clearance and erosion phases. From the position in the profiles of these phases, and by analogy with the human history of the area, which suggests a population large enough to construct five megalithic circles of Neolithic type in south-west Cumberland, 1500 to 2000 B.C. could be taken as a very approximate date for this phase. The forest regeneration which follows this pasture clearance phase at Devoke Water indicates that soil degradation had not taken place over all the cleared area.

The climatic deterioration known to have occurred at the opening of the Sub-Atlantic period, which is associated with pronounced recurrence surfaces in British raised bogs for which radiocarbon dates of 900 to 450 B.C. have been obtained (Godwin 1960), would be expected to have hastened the process of leaching and erosion of soils already deforested. At Blea Tarn, where the pollen diagram indicates no clearance of the forest at this time, there is no stratigraphic or pollen-analytic evidence for any change at this time. In the drainage areas of three of the tarns, peat profiles which have been examined show that the basal peat must younger than 3000 B.C., since it contains no appreciable elm pollen but *Plantago lanceolata* is present. The profile at Red Tarn Moss, adjoining the tarn, shows that the blanket peat began to form after a birchwood phase, and that the pieces of birch wood entombed in the basal peat lie on top of *ca.* 40 cm of accumulated humus which contains tree pollen in clear temporal succession (cf. Iversen 1963) and clearly represents the soil of the forest of zones VII *a* and VII *b*. In the valley of Seathwaite Tarn there are several small areas of blanket peat which show a similar succession from a basal birchwood phase, and the pollen content of the peat resembles the succession in Red Tarn Moss. The only peat deeper than 75 cm found in the Devoke Water drainage basin, two small valley bogs in the course of the main inflow, similarly contained no elm pollen and had *Plantago lanceolata* to its base. This evidence suggests that most of the peat in this part of the Lake District is Sub-Atlantic in age, and that older peat is found only in basin swamps.

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This contrasts with the Pennines, where blanket peat began to form at the beginning of the Atlantic period (Conway 1954; Johnson & Dunham 1963).

In the drainage basins of these six tarns, the areas of Sub-Atlantic blanket peat are of very limited extent, probably because of the high relief. The most pronounced effect of increased rainfall at the opening of the Sub-Atlantic would therefore be expected to be erosive; therefore it is arguable that an indication of increased erosion at some time after 3000 B.C. is likely to mark the horizon of increased oceanicity between 900 B.C. and 450 B.C. Such an indication of increased erosion is found in the *Calluna* horizon, with its clear evidence of large-scale wash-in of sand, stones, highly organic soil humus and *Calluna* pollen. This occurs in the four tarns where a 'Bronze Age' occupation followed a 'Neolithic' pasture phase in the same area; it is not found at Blea Tarn, nor in its characteristic form in Red Tarn, so is unlikely to be a simple response to increased rainfall. It is suggested tentatively that the *Calluna* horizon in Devoke Water, Seathwaite Tarn, Goatswater and Blind Tarn appears to be the result of increased erosion of already partly deforested soils. Its position at comparable depths in the profiles of these four tarns suggests a synchronous, and therefore most probably climatic, cause, but if this were the onset of a wetter climate, between 900 and 450 B.C., it is difficult to understand why it marks the beginning of a phase of cereal cultivation. The archaeological evidence for the date of the 'Bronze Age' occupation is very indefinite; the burial cairns may date from any time after the introduction of cremated urn burials, and there is no real evidence to relate the stone hut circles and small enclosed fields of the upland sites to the burial cairns. Presumably the small enclosed fields, to be seen at Crosbythwaite, south-east of Devoke Water, can be related to the phase of cereal cultivation. Clearly much further work is necessary to unravel the ecological history of the successive stages of the 'Bronze Age' occupation of the uplands of the south-west Lake District and its relation to the climatic deterioration at the opening of the Sub-Atlantic period.

After the end of the cereal phase at Devoke Water, there are two phases of wash-in with *Calluna* peaks and steeply falling carbon, which probably indicate rapid erosion of abandoned land colonized by *Calluna*. There are traces in soil profiles in the Devoke Water basin of major erosion horizons, with spreads of sand and stones incorporated in the black mor humus layer of the soil profiles. Much of the stony desolation of the moorland today, particularly on the granite, is probably the result of unchecked erosion since the forest cover was completely removed by the long 'Bronze Age' upland settlement. At both Devoke Water and Seathwaite Tarn, pollen is very scarce in the top metre of lake deposit, and is predominantly herbaceous. The spread of *Lycopodium* spp. in the post-clearance grassland is very clearly shown.

In the valley lakes the main forest clearance comes higher in the profile, and has been attributed to the Viking farmers of the ninth and tenth centuries. This phase is not clearly apparent in any of these tarns, but it may be that the topmost clearances at Devoke Water and at Seathwaite Tarn (and even more probably the late clearance at Blind Tarn) may represent the activities of Norse sheep farmers clearing residual pockets of woodland. The contrast between these upland tarns of the south-west Lake District, where the main clearance was apparently over before the Norse invasions, and lowland tarns such as Blelham Tarn, Windermere, and Out Dubs Tarn, Esthwaite (Franks 1957) which show a clear Landnam phase and then recovery of the forest until the main clearance high in the profile—the Norse—will be increasingly apparent as other pollen diagrams are published. All the evidence confirms the hypothesis that the large lakes such as Windermere show an integration of many different vegetation histories, which can be elucidated separately from the deposits of the tarns.

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