Post-glacial vegetational and climatic changes in part of south-east Scotland as indicated by the pollen-analysis and stratigraphy of some of its peat and lacustrine deposits.

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INTRODUCTION.

Late Quaternary time is divided into the Late-glacial and the Post-glacial. The Late-glacial refers to the stage immediately preceding the Post-glacial in which an interruption in the amelioration of climate at the end of the last Glacial resulted in a re-advance of glaciers in the Highlands called the Moraine Glaciation by Charlesworth (1956) or the Highland Readvance by Donner (1957). The Post-glacial commenced with the final recession of the glaciers that had advanced along Highland valleys during the Late-glacial re-advance. The general climatic improvement which ensued and which begins the Post-glacial has been correlated with the Fini-glacial stage in Scandinavia, the formation of the Yoldia sea, and the large-scale glacier recession in north-western North America. According to the Radiocarbon dating of Scottish deposits the Post-glacial commenced at ca.8,300 B.C.

The Post-glacial period was characterised by a series of changes in the physical geography of the British Isles which embraced physiography, climate and vegetation and which included the later anthropogenic phases of alteration in the vegetation. These phenomena have been studied in many parts of the British Isles by the methods of macro-stratigraphy and pollen-analysis and correlated with changes which took place in Europe. Early in the development of palynology it was established by von Post (1916) that the Post-glacial period had been characterised by a three-fold climatic sequence: following the final wasting of Late-glacial valley glaciers there had been an early period of increasing warmth; this had been followed by a period of maximum warmth, the climatic optimum or hypisthermal; then, the latter had given place to conditions of decreasing temperature or climatic revertence in the later stages of

the Post-glacial which embraced historic time. This climatic sequence was accompanied by a succession of changes in the natural vegetation and was expressed most directly by the rise and expansion of forest trees.

The British Isles are characterised geographically by the existence of areas of varying size which display marked contrasts in their geomorphology, climate and soil. Tansley (1939) suggested a broad geographical division of the British Isles, based upon climate and modern vegetational features, into northern, western and south-eastern regions and pollen-analyses have indicated that differences existed between these regions during the development of their vegetation throughout Post-glacial time. It is, however, evident that much smaller natural regions exist and in these the sequence of Late-Quaternary climatic change gave rise to patterns of vegetational development which followed a distinctive course, yet in which the changes were synchronous. As Godwin (1956) has pointed out, the changes took a parallel course yet one that was regionally distinctive. The study of vegetational development by palynology is establishing the existence of such natural regions; thus the vegetational history of the north-west Highlands contrasts with that of the southern Highlands and both differ from that of south-west England.

The objective of this investigation was to determine the character of these Late-Quaternary changes and the distinctive pattern which they followed within a region of Scotland that has a well-marked regional individuality, namely, the eatern part of the Midland Valley, south of the Forth. The key to the changes was found in the stratification of peat mosses and lake deposits and in the macro and

micro-fossils incorporated in these deposits. The aim was to use these data to obtain a picture of vegetational succession and from this to interpret climatic, physiographic and biotic change. The method was to obtain a number of vertical sequences of these deposits from sites located at different points in the region; data from these could be correlated to illustrate both the regional pattern of development and the relative chronology.

PART I.

PREVIOUS INVESTIGATIONS OF THE DEVELOPMENT OF VEGETATION IN SCOTLAND.

Previous Investigations of the Development of Vegetation in Scotland.

Introduction:

Two stages may be distinguished in the development of the study of the past vegetation of Scotland. Prior to the pollen researches of G. Erdtman first published in 1923, a series of studies had been based upon the macro-remains and the macrostratigraphy of peat mosses in various parts of Scotland. Some of the earliest of these were made in the early 19th century; they consisted of observations of the larger fragments of plants preserved in peat and of speculations upon the characteristics of the former vegetation and the changes that had taken place in it. In 1869, James Geikie in an important paper which marked the turning point in these early investigations, showed that the stratified structure of peat mosses was related to changes in climate during the late-Quaternary period. This work of Geikie deeply influenced F. J. Lewis (1905-11) who made a detailed investigation of the macrostratigraphy of many Scottish peat mosses; he attempted a complete correlation of the climatic changes postulated by Geikie with the stratification of the mosses. Lewis was followed by G. Samuelsson (1910) who also based his investigations upon fossil remains that could be identified in the field or after simple laboratory preparation; the research included some study of pollen grains in peats in addition to the macro-remains. Samuelsson correlated climatic, vegetation and physiographic changes in Scotland with those of Scandinavia.

The statistical study of pollen as an index of vegetational development and chronology was first applied to the study of Scottish Quaternary deposits by Erdtman, a series of papers

appearing in 1923, 1924, 1928. Following the work of Erdtman, Godwin (1940) devised a system of pollen zones based upon work at English sites which could be applied to the Post-glacial vegetation changes of the British Isles. Later research has shown that though a regional differentiation is apparent in Scottish vegetational development, the system of Godwin could be applied to pollen determinations at Scottish sites.

In this review of previous investigations, it is therefore convenient to consider the earlier work prior to the application of pollen-analysis from a chronological standpoint; the more modern work based upon pollen-analysis is then considered and the contribution of each investigator to the study of vegetational development is indicated with relation to the pollen zones.

Geological or botanical evidence of the former vegetation of Scotland has often been revealed in the past by investigations of peat bogs; some of the earliest recorded observations show that wood fragments were abundant in many mosses and commonly lay at the base of the peat. It was obvious that Scotland had once been densely forested. Thus at Pitsligo, in Aberdeenshire, it was noted that 'the greatest part of the county must have been covered with wood, as appears from the roots of very large oaks still existing in the mosses.' (Old Stat. Account, Vol.V). Much speculation was recorded as to the causes of the disappearance of the forest and of its replacement by peat mosses.

It was observed that the altitude and also the latitude of the place had apparently influenced the type of former woodland and also the size of the trees (Walker, 1803). Thus Lochar Moss,

Dumfriesshire, near sea-level, contained very large pieces of oak-wood, whereas mosses at higher altitudes contained smaller fragments, usually of birch. The effect of latitude was shown by the fact that pine was commoner in mosses of the Highlands than in those south of the Forth. Walker explained that these facts established that the timber had been formed in situ and had not been transported and deposited during some marine incursion, as had been held by some authorities. Walker noted also that some mosses contained more than one layer of wood fragments, which he interpreted as indicating that there had been a succession of phases of woodland growth.

Various explanations were offered with regard to the causes of the disappearance of the forest and of its apparent replacement by peat. Rennie (1807) pointed out that as the tree-trunks lay in uniform alignment it was probable that forests had been destroyed by violent storms. Processes of natural decay would also cause trees to fall. Rennie, however, emphasised the importance of forest clearance by human agency; he considered that the Romans had played a principal part in this, for the ancient woodland gave shelter to their native enemies and hence much of it was cut down for strategic reasons. Roman historians had commented upon the thick forests encountered by troops during the campaigns in northern Britain; much of this forest was destroyed during the cutting of the broad 'ways' for troop movements. Rennie suggested that Roman coins and weapons found near tree stumps in the mosses proved that the woodland destruction was Roman. After the trees had been cut down, their remains had become covered by peat. Thus, according to Rennie, the

age of most peat-mosses dated from the Roman period.

Deforestation, in the opinion of the early investigators, was succeeded by the spread of peat-forming mosses which grew over the wood fragments. Aiton (1805) concluded that 'the origin of all moss....may be traced, directly or indirectly, to the overthrow of the forests.' Aiton pointed out that the evidence of place-names showed that peat had originated in historic times, soon after forest destruction; thus, for instance, in Ayrshire, names of areas of peat-moss such as Netherwood or Harewood proved that these had once been wooded. The actual process of moss formation was explained by an observer at Kilbarchan, Renfrewshire (Old Stat. Account, Vol. XV); the fallen trunks impeded surface drainage and in the resultant swampy conditions, mosses developed and grew over the wood, hence an upper layer of peat covered the remains of the forest.

With the work of James Geikie (1866), the study of the geological aspect of Scottish vegetational development entered a new phase. Geikie emphasised the significance of the stratified character of the peat-mosses, consisting often of layers of wood-fragments alternating with layers of peat-forming mosses and other plants. These strata, according to Geikie, were the consequence of past changes in climate and in the distribution of land and sea in north-west Europe.

Examining the evidence of tree-fragments preserved in mosses, Geikie observed that wood-layers had been noted in mosses situated in areas that were treeless as a result of unfavourable climatic conditions, such as the Outer Hebrides or Shetland, or at high

elevations in mountains, above the present tree-line. Tree-fragments had also been found in peat in coastal situations submerged at high tide. All these fragments, according to Geikie, were the remains of an extensive forest which had existed in Scotland during a period in which the British Isles had been influenced by a cold-continental climate with colder winters than at present. In this forest, pines were dominant upon high ground and in situations where soils were poor; oaks occupied heavier soils and lower land. Geikie explained that the more extreme climate was the consequence of an emergence of the land at the end of the glacial period, resulting a retreat of the sea and in the linking of the British Isles with the mainland of Europe.

Considering the question of the destruction of the forest, Geikie suggested that although some of it was doubtless cut down by the Romans, their part in the deforestation of Scotland might probably have been exaggerated by previous investigators. In fact, at the time of the Roman invasions, the ancient great forest had already become reduced by a spread of Sphagnum and other mosses which was a consequence of an altered climate. Geikie suggested that the climate had become more insular as a result of a rise in sea-level which had cut the British Isles off from the Continent. The upper peat-moss layer commonly observed lying above the wood-layer in our mosses was therefore the result of a wetter climate. Bog-mosses had spread downwards from higher altitudes, or had extended inland from coastal areas and had destroyed forest trees and finally overwhelmed them. Human influence upon the vegetation of Scotland thus did not begin until after this last climatic change had already

restricted woodland growth, according to Geikie. For this reason, the Romans found in north Britain much marshland and bog, though considerable forest remained; part of this they cut down for strategic reasons. In summarising the historical evidence of forest destruction in Scotland, Geikie showed that although much forest was still standing until the Middle Ages, a steady encroachment took place during the wars with England; much forest was cleared later because of the need for agricultural land and of the use of timber for building and for fuel. From the time of the early Stewarts, Acts of Parliament were passed prohibiting tree-felling, but these had little effect so that by the end of the 15th century very little woodland remained.

Considering the present appearance of peat-mosses, Geikie pointed out evidence of another and more recent climatic change. Peat development in many mosses was no longer in progress; instead, active weathering and erosion of the peat could be observed resulting in the formation of deep gullies and channels.

These, Geikie considered, were the effects both of a decrease in humidity of the climate and of drainage operations for agriculture. He pointed out that the disintegration of peat was taking place faster in low-lying mosses than in those at higher levels where humidity was greater.

In his later work, Geikie (1894) outlined a sequence of correlation of climatic and vegetation changes and related these to glacial events and to changes in land and sea level. He pointed out the link between the macro-stratigraphy of peat-mosses and that

of post-Glacial marine deposits, both of these geologically recent deposits being the consequence of a series of changes in the late-Quaternary geography of Britain. Thus the regional glaciation of Scotland had been followed by a late-Glacial stage during which tundra conditions had prevailed in lowland Scotland whilst ice-sheets and valley glaciers still existed in the Highlands and Southern Uplands respectively; at this time the sea stood 100 feet higher than at present, depositing a well-marked beach along the coasts. A steady improvement of climate followed, according to Geikie, associat[illegible] with a rise of the land and a retreat of sea which united the western and northern islands of the British Isles to the mainland, and which linked the British Isles to the continent. This land-bridge permitted the migration of flora and fauna from Europe; forests of oak and pine spread into Britain, oak covering the lowland regions and extending into valleys in highland regions. Geikie assumed that the climate of that time was 'not less genial than it is to-day'. As this period was represented by the lowest of the layers of tree-stumps in the Scottish mosses, Geikie referred to the latter as the Lower Forest. This forest-phase ended with a slow submergence of the land, associated with colder and wetter climatic conditions; this more oceanic climate gave rise to the spread of bog-mosses which destroyed and overwhelmed the woodland situated at high elevations; at the same time, the returning cold produced a return of glaciation, thus 'post-glacial glaciers' appeared in valleys of the Highlands and the Southern Uplands. In the valleys of the Forth and Tay, a transgression of the sea took place, forming the deposits of marine clays, sands and muds known as the Carse Clays.

After the deposition of the Carse Clays, Geikie assumed that again the climate changed; a retreat of the sea was accompanied by a rise in temperatures which again favoured the spread of forest trees; forests of oak and pine readvanced upon hills and grew over drying bog surfaces. Forest advanced also upon the clays of the river estuaries. This period was considered by Geikie to be represented stratigraphically by a layer of wood-fragments observed in some mosses in a position nearer to the surface than that of the Lower Forest, and therefore he named the higher woody horizon the Upper Forest. The period represented by the Upper Forest ended with another submergence of the land, accompanied by a further climatic change towards lower temperatures and increased moisture. Small glaciers were formed in the Highlands and bog-mosses again advanced over woodland reducing the latter in area; this was the condition of the vegetation of Scotland at the beginning of the historical period. Sea-level again rose slightly, resulting in the formation of the later raised beaches. A recent climatic change had, however, taken place, as explained by Geikie in his previous paper; the climate had become less moist resulting in the cessation of growth of bog-mosses so that they had begun to disintegrate.

In a later work Geikie (1895) correlated research work done in Scandinavia with his own in Scotland. He classified all the deposits under separate names and showed the relationship between the late-Quaternary geographic and stratigraphic changes in Scotland and thos which had occurred in other parts of north-west Europe. Thus the Mecklenburgian stage was represented in Scotland

by Arctic plant-beds in lowlands and by the deposits of the district ice-sheets and valley glaciers in the Highlands. The Yoldia beds of Scandinavia he assigned to this stage. The Lower Forestian stage was represented in Scotland by the Lower Forest; it embraced the deposits of the Ancylus lake of Scandinavia. The Lower Turbarian stage was represented by the peat overlying the lower forest-bed of Scottish mosses, and also by the Carse-clays of Scottish estuaries; Geikie considered that the younger terminal moraines of Highland valleys were of this stage also. Corresponding deposits in Scandinavia were the calcareous tufas and the Littorina beds. The Upper Forestian stage embraced the higher woody horizon of Scottish mosses, which again had its European equivalents. The Upper Turbarian stage Geikie considered to be the upper horizon of Scottish peats; it was represented in the Highlands by the latest series of moraines, which he considered to have their equivalent in high-level valleys in Norway.

Contemporaneous with this work of Geikie were the investigations made of deposits of former lakes situated in Edinburgh; a number of sites occur within the city which contain alluvial deposits and interbedded plant remains. These were exposed at various times during the excavation of trenches for drainage, or during quarrying operations; the macroscopic plant remains have yielded information of the former vegetation and, thus of former geographic conditions.

An exposure at Hailes Quarry was described by Bennie (1894). He observed there an Arctic plant bed lying above boulder clay,

consisting of fine mud or silt with leaves, fruits and twigs of Arctic plants; silts containing seeds of aquatic plants and also hazel nuts, acorns and drift-wood lay above the Arctic bed. These strata with plant remains were covered by a bed of sand. This stratification was explained by Bennie as representing successive stages in the filling-in of a lake: the Arctic land-plants had been deposited in a small pool in which was an aquatic vegetation; the silts with hazel-nuts and drift-wood had been laid above them followed by beds of sand. Bennie described a similar sequence at Corstorphine revealed by excavation for the laying of a sewer. The Arctic plant remains were covered by a lake-marl over which was a bed of sand and gravel; below them was a fine laminated clay resting upon sand and till. Bennie regarded these Arctic plants as revealing conditions at the end of the glacial period when the climate of Corstorphine was 20 deg. F. colder than the present. The plant remains from both sites were identified by Clement Reid (1899). Reid considered that the Arctic plant beds of both Hailes and Corstorphine were late-Glacial in age and contemporaneous; the upper plant bed consisted of temperate species; included in it were marsh and aquatic plants and also weeds of cultivation.

At Slateford, Edinburgh, lacustrine deposits were exposed during operations at Redhall Quarry. As described by Henderson (1874) the exposure consisted of a bed of peat with Potamogeton fragments and seeds between two layers of boulder clay. A further section exposed at Redhall and described by Bennie and Scott (1889) consisted of a peaty layer resting upon boulders and

covered by mud or silt above which was a second peat bed containing reed and moss fragments. Clement Reid (1899) listed 77 species of plants from Redhall; he considered that the weeds of cultivation, the flax capsules and the charcoal fragments from the deposit showed that it could not be earlier than Neolithic, and thus the flora resembled that of the upper bed at Hailes Quarry.

In Holyrood Park, Edinburgh, lacustrine deposits have been revealed by cuttings made in the old lake flat that extends from the Palace to the foot of Salisbury Crags. These were described by Henderson (1883) and by Bennie & Scott (1888); a bed of peat containing remains of aquatic vegetation, and twigs of birch, hazel and other trees lay upon marl containing freshwater shells; above the peat was a clay deposit. Cadell (1913) suggested that the former lake became silted up after fluctuations in climate had occurred. The deposition of mineral matter was succeeded by the formation of peat, the wood fragments of which indicated the existence of woodland in the area that according to Cadell, 'at one time formed part of the thick forest of Drumsheugh'.

These investigations of lake deposits, like those of the peat mosses, revealed former vegetation and climatic conditions of Scotland. The plant remains discovered at Hailes, Corstorphine and Redhall indicated that a tundra type of vegetation consisting of plants Arctic in character existed in lowland Scotland during the close of the Ice Age, and that this had been succeeded by plants indicating more temperate conditions.

The work of Geikie in correlating the macrostratigraphy of

post-glacial deposits was continued and developed by F. J. Lewis. His aim was to examine peat at a large number of sites by excavating trenches and then by studying the dominant macroscopic plant remains to establish the succession of vegetation, correlating this with the climatic and glacial stages suggested by Geikie.

In the Southern Uplands, Lewis (1905) described peat at several sites; he noted at each well-defined stratigraphical features, in particular the two horizons of wood-peat already described by Geikie and named by him the Upper and Lower Forestian. Since a general similarity of strata was noted in widely separated sites, Lewis concluded that these stratigraphical features reflected changes in climate that had affected the whole of Scotland. The upland sites of Tweedsmuir and Merrick & Kells showed an upper wood horizon consisting of fragments of Betula alba or Pinus sylvestris and a lower wood horizon of stools of Betula alba; Lewis interpreted these forest beds as representing dry, warm conditions. Between them, however was peat which indicated climatic changes towards lower temperatures and increased humidity, for the forest layer gave place to a peat consisting of Sphagnum and Eriophorum vaginatum within which was a sharply defined layer of Arctic plants such as Empetrum nigrum, Loiseleuria procumbens and Salix reticulata. This layer of Arctic plants led Lewis to the conclusion that there had been a period of renewed glaciation following the warm conditions represented by the lower forest, thus confirming the hypothesis of Geikie. After the colder climatic conditions which produced the Arctic bed, a period of warmth followed

with, at first, heavy precipitation, then drier conditions during which the upper forest layer developed. Lewis postulated a subsequent period of cold which had, however, little effect in south Scotland though it gave rise to the formation of corrie moraines in the Highlands. Upland sites in the Moorfoot Hills showed no such well-marked forest layers; but a basal layer of Betula alba of shrubby size was found at some sites. Peat in the Moorfoot Hills consisted largely of layers of Eriophorum vaginatum, Scirpus caespitosus and Calluna vulgaris; an Arctic layer of Empetrum nigrum or Arctostaphylos uva-ursi occurred here as it did between the upper and lower forest layers farther west. Lewis, however, was uncertain whether to correlate the Moorfoot Arctic bed with the Highland valley-glaciation or to the later corrie-glaciation. Other peat examined by Lewis in southern Scotland were by contrast at low elevations. In Wigtownshire he recorded two forest beds but between them was a peat containing Phragmites which indicated a period of wet conditions. The absence of an Arctic layer, Lewis explained, was a consequence of the position of the sites, these being at low altitudes near the south coast; hence the period of cold which produced the Arctic bed in hill peats could have had little effect in the sheltered maritime sites of the south-west.

These conclusions were developed further by Lewis (1906) after investigations of the macrostratigraphy of mosses in the Highlands and in the Hebrides. The section he described of peat situated on the Spey-Findhorn watershed consisted of a basal layer of Arctic plants succeeded upwards by peat indicating wet conditions,

namely a layer of shrubby Betula alba and Sphagnum. Above this, Lewis noted two layers of Pinus sylvestris separated by Sphagnum peat which he considered a widespread feature of Highland peats; there was thus no lower forest bed as in Southern upland peats. Lewis thought that this striking contrast was the result of differing physiographic events in the two regions: the Highland peats began their formation at the end of the cold conditions which gave rise to the intercalated Arctic plant bed of the Southern Uplands; the Arctic bed at the base of the Highland peat was therefore synchronous with the intercalated Arctic bed of the Southern Uplands. No lower forest bed was found in the Highlands because it had been removed during the stage of valley-glaciation following the warmer period which gave rise to the development of the lower forest. A southward and downward migration of Arctic plants had resulted from the return of cold conditions in the Highlands, followed by a northward movement during climatic amelioration. As regards the upper woody horizons of the Highland sections, the lower of the two layers of Pinus sylvestris was considered representative of the upper forest bed of the Southern Uplands; the duplication of the bed and the separation of the two layers by the zone of Sphagnum Lewis attributed to the effect of the cold phase that caused the high-level corrie glaciers; this latest glaciation had produced a replacement of pinewoods by Sphagnum mosses although pine forest had developed above the Sphagnum when the climate again grew warmer and drier. In the peat-mosses of Skye and North Uist, Lewis found only one forest bed, thus correlation with other sections was difficult; he

considered that this was synchronous with the lower forest layer of the Southern Uplands. The absence of an Arctic plant bed in the Hebridean peat Lewis thought to be the result of the position of the sites which were near the sea and at low elevation.

Further investigations provided Lewis (1907) with evidence which he considered confirmed his earlier conclusions. In the upland peats of the Grampians and in the Assynt district was a layer of Arctic plants intercalated between the two layers of wood-fragments comprising the upper forest; he attributed the Arctic bed to the effect of a recent phase of corrie-glaciation, represented elsewhere in the Highlands by a Sphagnum horizon lying between the two upper forest zones. In the Shetlands, Lewis noted only one forest bed which he correlated with the lower forest; below it, however, was an Arctic plant bed representing the tundra conditions which followed the last glaciation; above it he observed a bed also containing Arctic plants he thought to be contemporaneous with the intercalated Arctic bed of the Southern Uplands.

Subsequent research has not substantiated some of the observations and findings of Lewis, in particular the occurrence of Arctic plant beds between forest layers in peat-mosses and also the glacial re-advance phases which they were thought to represent. Lewis, however, advanced considerably the study of the past vegetation of Scotland by his recognition over wide areas of a sequence of macrostratigraphical horizons and the relating of these to regional climatic changes.

A summary of the stages he recognised in peat and the corresponding terminology and climatic stages is as follows:-

TABLE I

Stages represented in peat	Terminology	Climate
1. Recent peat		Wet
2. Forest bed	Upper Forestian	Dry interglacial. Slight fall in temperature during corrie glaciation.
3. Peat bog plants with Arctic plants		
4. Forest bed		
5. Peat bog plants	Upper Peat Bog	
6. Arctic plant bed	Second Arctic Bed	(Valley glaciation in Highlands (Cold conditions in S. Uplands.
7. Peat bog plants	Lower Peat Bog	
8. Forest bed	Lower Forestian	Dry and warm. Interglacial.
9. Arctic plant bed.	First Arctic Bed	Tundra type.

The work of Lewis was followed by that of Samuelsson (1910) who investigated a number of peat mosses in the areas in which Lewis had been working. His aim was to study the features of the late-Quaternary and post-glacial geology of Scotland and to correlate the peat horizons with those of Scandinavia. His field-methods differed from those of Lewis: instead of excavation to expose the peat he made his observations from sections of the mosses revealed along erosion gullies; exact measurements were made of strata; and though macro-remains were the basis of the investigations, details were given of pollen grains found at different levels which helped him to establish the presence of plants.

Samuelsson was in general agreement with Lewis and Geikie that the stratigraphy of the mosses followed a definite and similar sequence and that the strata were contemporaneous and represented the plant response to changes in the physical geography of Scotland. He confirmed much of the stratigraphical data given by Lewis and gave a tabulated list of the occurrence of strata at many sites examined by Lewis and himself, correlating them with the terminology of Lewis and Geikie.

His views were, however, in opposition to those of Lewis in several respects. Though he confirmed the sequence of strata established by Lewis in the Southern Uplands, namely the two layers of wood fragments representing the upper and lower forest, and between them, peat containing a bed with Arctic plant remains, he did not support the observations Lewis had made of the stratigraphy of the Highland sites. He was unable to confirm the double upper forest layer; he considered that only one layer existed. Further,

the layer of shrubby Betula alba above the Arctic bed which Lewis had regarded merely as a woody facies of bog-moss development was regarded by Samuelsson as representing the lower forest layer; hence two forest layers were present there as in the Southern Uplands. Thus the mosses of the two regions had developed similarly and there could have been no removal of the lower forest bed by renewed glaciation within the phase of time represented by the Lower Turbarian of Geikie. Samuelsson contended that at that time the climate was insular but not cold, as indicated by the temperate fauna of the Carse Clays deposited during that period. In regard to the intercalated Arctic bed of the Southern Uplands, regarded by Lewis as the response to the renewed glaciation of the Highlands, Samuelsson considered that this had no counterpart in Scandinavia; nor were the plants in it exclusively Arctic, for they could also be found in regions with an insular climate or in situations close to sea-level. In the Outer Hebrides his observations differed from those of Lewis, for the latter had found only one bed which he considered to represent the Lower Forestian; Samuelsson, however, found there a lower forest bed separated from an upper wood layer by several strata including an Empetrum layer and he regarded this upper bed as Upper Forestian.

Samuelsson discussed in detail the characteristics of the periods of late-Quaternary vegetation, comparing the results of his own research with those of Geikie and Lewis. In the Arctic Tundra period he considered that Arctic vegetation had developed over the whole of Scotland after the melting of the last glaciers, although Lewis had found Arctic plant beds only at the base of his sites in the Outer Hebrides and in Shetland. The following period, the

Lower Forestian, was characterised by the spread of temperate woodland consisting of birch, oak, hazel and alder. Samuelsson believed that pine had been an early immigrant as its pollen had been identified in the wood fragments of this horizon. The peat above the forest horizon was formed in general by Sphagnum, Eriophorum vaginatum and Scirpus caespitosus associations, with an Arctic layer within it which Lewis had believed to be the result of glacial conditions. Samuelsson, though conceding that the climate of the time was insular, disagreed that it could have been cold enough to cause a renewal of glaciation, the evidence of the intercalated Arctic bed being inconclusive. The next period, the Upper Forestian, he considered to have been characterised by a continental type of climate with summerswarmer than at present. It was therefore a period of forest expansion with an upper tree limite higher than the present; thus he had discovered remains of hazel at several places in the upper forest layer at altitudes higher than the present upper tree limit of hazel. In Central Scotland, a mixed deciduous woodland dominated by oak extended upwards to 500 m. A post-glacial climatic deterioration had followed this forest phase, the Upper Turbarian of Geikie. The results were a recession of woodland and a spread of bog-moss plants; the influence of man in the destruction of the forest became very important.

Samuelsson summarised the results of research done in Scandinavia, and showed how these could be correlated with those of Geikie, Lewis and himself. In both Scotland and Scandinavia, there had been a short late-Glacial period with a tundra-type vegetation, represented by remains of such plants as Dryas octopetala and

Salix polaris found in lacustrine and peat deposits. A rapid rise in temperature had then occurred, suggested by the occurrence of the pollen of temperate vegetation in lacustrine silts above the Dryas zone, and also by the plant remains of peat-mosses; temperatures had risen to a post-glacial maximum which was higher than that of the present time. Samuelsson pointed out the important work done by Blytt and Sernander in Scandinavia, and showed how the climatic changes suggested by Blytt could be correlated with results apparent from the work in Scotland. Blytt had suggested seven divisions of late-Quaternary time in Norway, based upon the stratification of peat-mosses, namely; arctic, sub-arctic, boreal, atlantic, sub-boreal, sub-atlantic and the present. The climate of the boreal and sub-boreal was relatively dry with continental features, represented in peat-bogs by a wood-layer, consisting of oak and other deciduous trees in the boreal and pine in the sub-boreal; the atlantic and sub-atlantic were moister periods and the corresponding strata were bog-mosses. These divisions had been correlated by Sernander and by von Post with oscillations of sea-level in the Baltic and with divisions of archaeological time. The principal features of the correlationships suggested by Samuelsson are shown in the following table:

TABLE 2.

Climatic periods (Geikie)	Climatic periods (Blytt)	Vegetation (Scotland)	Vegetation (Sweden)
Upper Turbarian Moist and cold.	Sub-Atlantic Moist and cold.	Large extent of moorland.	Northern plants migrate southwards.
Upper Forestian Dry and warm.	Sub-Boreal Dry and warm.	Forest. Pine & birch above 500m. Deciduous woods below 500m.	Corylus and other southern plants migrated north. Higher tree-line.
Lower Turbarian cold and wet.	Atlantic Warm and moist.	Tree-limits lower than at present. Extension of moorland.	Wood meadows and pine forest characteristic associations on dry ground.
Lower Forestian. Warm and dry.	Boreal Warm and dry.	Forests of oak and hazel.	Deciduous forest.
Arctic Tundra.	Sub-Arctic and Arctic.	Arctic-alpine.	Dryas flora. Luxuriant aquatic vegetation.

Samuelsson, like Geikie and Lewis, based his conclusions mainly upon the stratigraphy of peat-bogs and upon the plant remains identifiable in the field or in the laboratory after a simple treatment to release fruits, seeds and fragments from the peat. Samuelsson had made some use of pollen-grains in his research to establish the probable presence of plants; the application of pollen-analysis to studies of Scottish vegetational history, however, began with the pioneer work of Erdtman (1924). Erdtman investigated certain peat-mosses situated in the north-west Highlands of Scotland, in Lewis and in the Orkney Isles and Shetland. His aim was to elucidate the development of Scottish post-glacial woodland and to compare the latter with forest development in Sweden.

His methods involved the use of a sampler with extension rods for extracting successive cores from peat-bogs, where no sections were exposed; the micro-fossils were then extracted from the peat matrix by heating the samples with caustic potash. Erdtman noted also the stratigraphical features of each site and he introduced the use of the Swedish terminology in classifying sedimentary deposits, namely, clay gyttja, plankton gyttja, lake dy, and lime-gyttja. Erdtman constructed the first pollen diagrams of Scottish vegetation in which he recorded frequencies of pollen of Pinus, Betula, Alnus, Ulmus and Corylus, counting usually 150 arboreal pollen grains, although for some samples much lower counts of 50 or even 25 were used. Salix was not recorded and no count was given of non-arboreal pollen.

The diagrams represent a very considerable advance upon the work of his predecessors in the study of Scottish vegetational

development; thus high counts of Pinus were noted at many sites and at low levels, indicating the importance of this tree early in the history of post-glacial forests; Ulmus pollen also appeared early; the previous work had shown the presence of Pinus pollen without revealing the apparent abundance of the genus. In his interpretation of the diagrams, Erdtman distinguished a horizon characterised by high frequencies of Pinus, Corylus and a lower frequency of Alnus pollen; he termed this horizon the 'A' zone and correlated it with part of the lower forest layer of earlier investigations and with the Boreal of Scandinavian peat-geologists. Above the zone, Tilia pollen appeared, but below it there were high frequencies of Betula and increased frequencies of Ulmus. Erdtman was therefore able by comparing pollen horizons or zones to obtain a relative dating of the origin and the phases of development of Quaternary deposits, synchronization of layers in mosses could thus be attempted with greater accuracy than when macrostratigraphy alone was used.

The diagrams revealed important features of the sequence of vegetational development in Scotland: at many sites, Betula was the dominant pollen, it was the earliest immigrant tree in early post-glacial times, namely the Pre-boreal, and was abundantly represented in the lower layers of a large proportion of the mosses. Betula was also dominant in the higher layers representing the Sub-boreal and Sub-atlantic. Although subsidiary to Betula, Pinus was well represented at several sites in the North-west Highlands and in Lewis, but frequencies were much lower in the Shetlands. Pollen of mixed-oak forest tree genera, Ulmus, Quercus and Tilia was relatively scarce, yet the changes in frequency which

later became the basis for zonal divisions were apparent in the diagrams; thus Ulmus appeared earlier than Quercus but gave place to the latter higher in the diagrams when Quercus reached its maximum. Relatively low counts of these genera suggest that mixed-oak forest was not abundant at any period in the area during the Post-glacial, except perhaps locally. On the other hand, Corylus showed high percentages in the A zone, and this feature became important generally in the mosses of north and middle Europe. Erdtman summarised his analyses in a generalized spectrum based upon the total pollen counted which showed the following:- B etula, 70%, Pinus, 14.6%, Alnux, 11.8%, Quercus, 2.4%, Ulmus, 1.2% Corylus, 4.25%, Salix, 11.25%. Only traces of Acer, Carpinus, Fagus, Fraxinus, Ilex and Tilia were noted. These figures, which show the character of woodland in northern Scotland and the islands were compared diagrammatically with those of other parts of north-west Europe, viz., S. W. Sweden, N.W. Germany, Russia, Denmark, Finland and Bohemia.

Further work by Erdtman (1928) upon Scottish peat and lake deposits enabled him to compare results obtained by pollen analysis with those based upon older methods. In the Southern Uplands, near Loch Skene, peat resting upon morainic material dating from the last glaciation was shown to be of Sub-boreal-Sub-Atlantic age, although according to Lewis the presence there of two forest beds and the intercalated Arctic bed showed a much earlier origin. In the Grampian Highlands, on the Moor of Rannoch, Erdtman observed pine remains in wood-peat at two horizons which he considered to be representative of the two dry periods of the Boreal and Sub-Boreal; his pollen diagrams, confirmed by the high frequencies of Corylus,

Betula and Pinus showed that the peat began its formation in the Boreal period. These findings again conflicted with those of Lewis; the latter had noted only one forest bed there and had used such evidence to support his conclusion that Atlantic glaciation had removed the lower forest bed from Highland mosses. Erdtman included in his investigations peat from above and beneath the Carse-clay of the Forth and Tay valleys enabling a dating to be obtained of the Post-glacial marine transgression. The Carse-clay itself, from samples taken from the Earn Valley, south of Perth, was considered to be Atlantic in age, and the peat below the clay to be B oreal. Pollen-analysis in this case thus supported the conclusions of Geikie and Lewis.

In a later paper, Erdtman (1929) discussing the characteristics of British climate and vegetation in Post-glacial time, showed the order in which plants had migrated into the British Isles; he showed that there had been a rapid spread of plants from the continent across the early land-bridge, assisted by favourable climatic conditions; later there had been a phase of competition between forest trees, and a climatic deterioration had destroyed forests by favouring the growth of peat-forming plants. Erdtman gave an extensive, though tentative tabular scheme of correlation for Scotland, correlating the Blytt-Sernander climatic oscillations with changes of land-level and with archaeology and stratigraphy.

Erdtman provided the pioneer pollen diagrams illustrating Scottish vegetational development; they are crude by modern standards as the interval between samples was wide and the laboratory treatment lacked refinement. Erdtman showed, however,

that pollen-analysis when combined with the observation of macro-stratigraphy could provide an accurate portrayal of vegetational change from the Late-glacial period onwards; it could also provide a time-scale against which geological events and archaeological discoveries could be measured.

In Britain, the pioneer work of Erdtman was followed by a series of pollen-analytical investigations, almost all of which, however, were done in England and Wales. Godwin (1940) using all the data available at that time upon the forest history of Britain, drew up a scheme of zonation based upon pollen analyses he had produced for Fenland sites; this scheme was applicable to all the diagrams illustrating vegetational development at other parts of England and Wales. Godwin gave a generalized form of pollen diagram of the East Anglian type and pointed out that it illustrated the successive stages of immigration and optimal development of forest trees in response to Post-glacial climatic changes. These, as recognised earlier by von Post (1929) had consisted of three phases: an initial phase of increasing warmth following the final retreat of ice-sheets; a middle phase of maximum warmth; and a third phase of diminishing warmth. The vegetational response to these changes had been characterised by an early dominance of birch and pine, followed by the entry and development of trees with greater warmth requirements, such as oak and lime; this phase was succeeded by one of partial retreat of these trees, accompanied by a phase of 'revertence' or, the return of birch and the conifers. Godwin distinguished the successive zones and sub-zones as follows:-

Post-glacial.

- VIII. Alder-oak-elm-birch-(beech) zone.
- VII. (a and b) Alder-oak-elm-lime zone.
- VI. (a, b and c) Pine-hazel zone.
- V. Pine zone.
- IV. Birch-pine zone.

An independent scheme of zonation had been applied by Jessen (1949) to diagrams from Irish sites; this was later modified so that it corresponded with the schema of Godwin.

With regard to the Late-glacial zones, I, II, III, Godwin pointed out that although investigations were being made of these in Ireland, so far only at one site in England (Hawke's Tor, Cornwall) had the three-fold stratigraphic sequence characteristic of the period been recognized.

Godwin (1940) showed a series of maps of England and Wales; upon each he gave, by means of divided circles located upon the positions of investigated sites, the pollen composition during each of the zones and sub-zones of his scheme. He pointed out that the phenomenon of regional parallelism of vegetational history was apparent from a consideration of the maps. Thus the sequence of Post-glacial climatic changes had been followed by vegetational responses which had taken a parallel course throughout England and Wales, although regional differences could be distinguished which were the result of regional differences in physical geography.

In a previous paper in which he discussed regional parallelism of forest history, Godwin (1934) had shown maps which included pollen data based upon the work of Erdtman in Scotland. Godwin gave six diagrams for Scotland, five of which were located in the north-east, and one in the Midland Valley; three were

provided for Ireland also. As Godwin pointed out, the maps demonstrated that in the British Isles as a whole, there was a general drift of pollen composition from north to south reflecting differences in climate due largely to latitude, coupled with a regional parallelism of development. In other words, natural regions existed in forest development which corresponded with the broad divisions of climate and vegetation apparent throughout Britain as recognised by Tansley (1939). Thus the map showing conditions in the Late-boreal indicated much higher proportions of Betula in Scotland than in south-east England; pollen of the mixed-oak forest however had greater values in the latter region than in Scotland. Again, Betula remained at high values also in the Early-Atlantic in Scotland, but at that time it had disappeared in south and south-east England.

The features of regional parallelism and revertence were discussed in relation to Scottish vegetational history by von Post (1945) who based his discussion upon a diagram prepared by Fraser from pollen from Strichen Moss, Aberdeenshire. He showed that the effect of the Post-glacial rise in temperature to a maximum, followed by a decline, could be traced in generalized pollen diagrams from different parts of Europe, although the actual plant response had been different in each place. The Scottish diagram displayed both revertence and parallelism clearly; revertence was indicated not only by a return of pine and birch but also by an increase in heath, grass and sedge pollen during the period of decreasing warmth; the vegetation in Scotland had thus evolved in a similar way to that of north-west Germany and Sweden.

It has thus been shown that although the development of vegetation in Scotland followed a distinctive course, the phenomenon of regional parallelism allowed the application of the zonal criteria in use in England to diagrams from Scottish sites. The schema proposed by Godwin has therefore been applied tentatively to Scottish pollen diagrams. Hence Blackburn (1946) and Harrison & Blackburn (1946) used these divisions in their diagrams of Hebridean sites; Knox (1954) also used the schema for dating peat in a Nairn site and for correlating it with archaeological artefacts. Godwin (1955) himself applied the zonal division to the diagrams of Carnwath Moss, Lanarkshire and Strichen Moss, Aberdeenshire; he observed that the diagrams showed a northern type of the pattern of Post-glacial forest history already established for England and Wales, as evidenced by the very high Betula percentages and the much lower Ulmus and Quercus counts. Donner (1957), Durno (1956), Eydt (1959) and McVean (1961) have also used these zonal divisions. Donner (1957) has noted that the usual numbers of zonal divisions could not be recognised in his own diagrams; thus it was not possible to differentiate between Zones V and VI, nor could the divisions of Zone VI into sub-zones be made.

The Late-glacial zones I, II, and III have been recognised in Scotland following the investigations of Mitchell (1948, 1952), Donner (1957), Kirk & Godwin (1963); recently, datings by radio-carbon have determined the absolute age of pollen zones.

Since the initial research of Erdtman, the elucidation of the vegetational and climatic history of Scotland has thus proceeded largely by the method of pollen-analysis. In this survey of

previous investigations it is therefore convenient to consider the pollen-analytical determinations under the zonal divisions as defined by Godwin, where these have been applied to the diagrams. In the next section, a summary is given of the vegetational character of each of the zonal divisions as revealed by the published pollen diagrams and by other work.

The pollen diagrams emphasise a considerable regional pattern in the vegetational development of Scotland; contrasting climates and soils have evidently resulted in differences in vegetational history in different parts of Scotland, although the main movements of the pollen curves in response to Post-glacial climatic changes are recognisably parallel to those of diagrams of sites in England and Wales.

The Late-glacial zones are considered first, followed by the Post-glacial zones.

The Late-glacial Period.

The rise in temperature which followed the last glaciation was halted by a temporary reversion to cold conditions and a readvance of glaciers, after which there was a general rise in temperatures to a Post-glacial maximum. The Late-glacial climatic oscillation has given rise to a characteristic stratigraphical sequence now recognised at several sites in the British Isles; a three-fold zonation system has been applied to it: Zone I represents the deposits of the last glaciation; Zone II, the warmer interstadial or Allerod warm phase; Zone III represents the return to cold conditions. Each of these zones has its characteristic content of micro-fossils, described by Jessen (1949) and Godwin (1953).

Only a few Late-glacial sites have been identified in Scotland. In south Scotland, a Late-glacial stratigraphy was described by Mitchell (1948) at Whitrig Bog, Berwickshire. Mitchell also investigated the pollen and spores at Whitrig and a diagram was produced by Godwin (unpublished). Another Late-glacial site was described by Mitchell (1952) at Garscadden Mains, Glasgow, the pollen was reinvestigated byDonner (1957), who also described two other sites, namely Garral Hill, near Keith, and Drymen, Perthshire. Donner (1957) established a Late-glaciation correlation of geological events, climate and vegetation in Scotland by investigating the stratigraphy and pollen of lake deposits at a number of sites situated near the end-moraines associated with the Highland Readvance, including Drymen and Garral Hill. He has shown that the Highland Readvance stage belongs to the Late-glacial Zone III; it succeeded the warmer phase, the Allerod interval, represented

by layers of peat or clay-mud; below the deposits of the Allerod, zone II, were the clays of the earlier period of cold represented by the Late-glacial Zone I, during which the Perth Readvance took place. Donner demonstrated that at six sites, Late-glacial climatic conditions had given rise to a characteristic stratigraphy; and at four sites a full sequence of deposits indicated the three-fold sequence of Late-glacial climatic change. Thus the Zone III deposits at sites near Oban, Garscadden Mains, Drymen and Loch Mahaick consisted of solifluxion clays and silty clays; these were laid down during the colder conditions brought about by the Late-glacial readvance. Below these, at Garscadden Mains, Drymen and Loch Mahaick, were the clay-muds and silty muds which represented the warmer period of Zone II. Conditions at Garral Hill, Keith, had produced rather different stratigraphical features owing to the character of the site, but a well-marked sequence of deposits was visible there as at the other sites. The pollen and macro-fragments of Zone II at Drymen, Garral Hill and Garscadden Mains showed a strong resemblance to the corresponding deposit at Whitrig Bog, Berwickshire. The proportion of non-arboreal pollen was very high and it consisted of high frequencies of grasses and sedges with much pollen of herbaceous plants of open habitat conditions. The Late-glacial stratigraphy and pollen thus resembled that of English and Irish sites, and the Scottish deposits could be therefore correlated with them and with those of northern Europe. The organic deposit at Garral Hill, which Donner showed to be representative of Zone II, the Allerod warmer period, has been dated by Radiocarbon. A series of samples from this horizon showed that

the duration of the Allerod was about 1,200 years, from 10,000 B.C. to 8,800 B.C. (Godwin 1959). Donner (1960) has also described results of pollen analyses carried out from samples taken from a peat at the Burn of Benholm, Kincardineshire. The stratigraphy resembled that of Garral Hill and consisted of lenses of compressed silty peat covered by brown till. Two samples were analysed and the pollen percentages suggested a vegetation in which Betula dominated the arboreal pollen and Gramineae and Cyperaceae dominated by the non-arboreal pollen. Included in the latter was that of Koenigia islandica, an Arctic plant of open habitat and indicative of late-glacial open conditions. Donner concluded that the Burn of Benholm peat was deposited during the Allerod period, Zone II, after the Strathmore glaciation of north-east Scotland; the upper till he regarded as representing the renewal of cold conditions in Zone III which gave rise at the site to the deposition of periglacial solifluxion material.

At Loch Droma, Ross-shire, organic silts within glacial melt-water deposits have been assigned to the Late-glacial (Kirk & Godwin, 1963) by pollen-analysis and by Radiocarbon dating. The pollen flora had a definite Late-glacial character resembling that of the sites investigated by Donner, particularly Garral Hill. It indicated that the conditions at the time of deposition were similar to those encountered today in the low alpine region of Lappland. Godwin concluded that although the Loch Droma deposits were Late-glacial, the Radiocarbon date of 12,814 ± 155 suggested an earlier formation than during the Allerod, and that they belonged probably to Zone I.

Several older sites in Scotland may also have deposits which are Late-glacial in age but these have not so far been dated. Thus the Arctic plant bed at Corstorphine which Bennie (1896) has described, consisting of an organic layer between mineral layers, may represent the Allerod Zone II, particularly in view of the plant identifications of Reid (1899) which recall those of similar horizons described by Mitchell and Donner and assigned to this zone. Another section described by Smith (1873) at Auchtergaven, near Perth, showed a stratigraphy which resembled the Late-glacial; remains of the contemporary animal, the Elk, were found in the deposits. The stratigraphy encountered during excavations near Holyrood Palace, Edinburgh (Henderson 1883) where organic beds were observed to be intercalated between mineral layers is also suggestive of the Late-glacial.

Zone IV, the Pre-boreal.

The amount of published material illustrating the vegetation of the period represented by this zone is not large, as most of the peat deposits of Scotland so far investigated began their formation at a later date.

Erdtman (1924) investigated several sites in northern Scotland in which early Post-glacial deposits occurred. Later, Mitchell (1952) described deposits of early Post-glacial age lying above Late-glacial material at Whitrig Bog, Berwickshire, and the pollen of these deposits has been investigated by Godwin (unpublished). More recently, Donner (1957) illustrated vegetational development in the south-west Highlands by diagrams of sites at Drymen and Oban and discussed features of the Pre-boreal; Durno (1956, 1958) has also described some of the vegetational features of Zone IV with particular reference to the diagram of a site at Braehour, Caithness.

A consideration of these diagrams shows that in the Pre-boreal, the ratio of non-arboreal pollen to arboreal pollen was high, indicating the absence of a closed tree cover. According to Erdtman (1929) the Pre-boreal forest was sparse and the open character of the woodland favoured the rapid advance of new forest trees and shrubs when the marked improvement of climate began to take effect in the Boreal period. Donner pointed out that Zone IV in Scotland was a time of very rapid vegetational and climatic transition in which the open Late-glacial vegetation gave place to closed forests and the solifluxion deposits of the Late-glacial changed to the lake-muds of Zone IV. He showed that the lowest deposits contained high frequencies of pollen of herbaceous plants. Grasses and sedges were most strongly represented and pollen of Artemisia,

Rumex, Caryophyllaceae was also present. Of the trees, Betula appeared to have been dominant, but Salix and Pinus were prominent though the latter decreased towards the end of the period. Thus Zone IV bore a strong resemblance to Zone II of the Late-glacial.

The pollen diagrams of Whitrig Bog reflect a similar type of vegetation to that described by Donner; the lowest part of the zone shows high Pinus and lower Betula, but at higher levels, Pinus falls and Betula rises. The non-arboreal pollen ratio is high at the beginning of the zone but declines at the top, indicating a closing of the vegetation cover. A varied herbaceous vegetation is represented which included Artemisia, Thalictrum and Rumex. As in the case of the more northerly sites described by Donner, grasses and sedges formed the bulk of the non-arboreal pollen.

A site at Braehour, Caithness, investigated by Durno (1958) yielded deposits which apparently began formation in Zone IV. Late-glacial characteristics are indicated by a very high Ericoid frequency and by considerable frequencies of Artemisia, Compositae and Caryophyllaceae and also by high counts of Selaginella. The arboreal vegetation was apparently dominated by Betula.

Small frequencies of Corylus pollen appear in a few diagrams which show Zone IV; Alnus is also shown in small quantities in this zone. Durno has commented upon the early appearance of Alnus in Scottish diagrams in contrast to those from English or Welsh sites where very little Alnus appears before Zone VII or late in Zone VI.

ZONES V & VI

The next pollen zones, V and VI, comprise the Boreal period, of which Zone V has been termed the Hazel-Birch-Pine period and Zone VI the Hazel-Pine period, (Godwin, 1956). Zone V is distinguished from Zone IV by the rise of Corylus to high values; the rise and development of Ulmus begins Zone VI which is subdivided into three sub-zones by the mixed-oak forest representation; thus VIa is characterised by a rise in Ulmus; in the next sub-zone, VIb, Quercus exceeds Ulmus; finally VIc shows a fall in Corylus accompanied by the appearance of Tilia and Alnus.

In Scotland, according to the published diagrams, the general pattern of change outlined above was modified considerably: thus Betula remains generally high throughout the period; in Zone VI the representation of mixed-oak forest is lower than in some other parts of the British Isles so that a zonal division of Zone VI has not so far been made. There is thus a well-marked regional character of vegetational development.

Zone V is clearly marked by the rise of Corylus. Very high values of Corylus have been shown in diagrams illustrating vegetational history of the Outer Hebrides: thus Blackburn (1946) recorded over 400% for Corylus in the diagrams for Barra, and other sites in the Outer Hebrides showed the same feature (Harrison & Blackburn, 1946, Blackburn, 1940). On the northern mainland of Scotland values are lower; a sharp fall occurs at the end of Zone VI. In Zone V, Betula retains the high values of Zone IV, but shares dominance with Pinus in Zone VI. Zone VI shows high values in general for Pinus, particularly in its later part. Durno (1958) has shown that Pinus was important in eastern Sutherland

and Caithness during the Boreal period, predominating over Betula in eastern coastal areas in the early part of the period and rising to dominance in inland and higher sites later in the period. The importance of Pinus also near the west coast of northern Scotland is shown byDurno (1959) in his diagrams illustrating the forest history of part of Wester Ross; the Zone VI frequencies exceed 50% of the arboreal pollen. The dominance of Pinus in the Boreal forest of northern Scotland is revealed also by the diagrams of Knox (1954) for Kingsteps Quarry, Nairn; and also by the diagrams Durno (1959) has used to illustrate the forest history of the eastern Grampians. That Pinus was important in south Scotland also during the Boreal is shown by the diagrams of Eydt (1960) for the Campsie Fells and by Fraser & Godwin (1955) in the diagram of Carnwath Moss, Lanarkshire. Pollen of the mixed-oak forest appears in Zone V and increases in amount in the following zone; there is, however, no well-marked succession of phases of Ulmus and Quercus; the representation is often low and therefore Scottish diagrams do not show the division of Zone VI into its sub-zones. The low counts of Ulmus and Quercus were noted by Erdtman (1924) who recorded a combined percentage of only 3.6% during the whole Post-glacial for his sites in the north-west Highlands, the Hebrides, Orkney and Shetland. Farther south, frequencies of Quercus and Ulmus are considerably higher as shown by Durno (1956) in his diagrams of Flanders East Moss, Perthshire, and also Airds Moss, Ayrshire. Tilia, the lime, appears in the Scottish diagrams only occasionally in the Boreal. Alnus, however, is present substantially in several diagrams in Zone V and shows a marked rise towards the end of Zone VI. Salix is represented by widely varying

frequencies during the Boreal.

Because of the dominance of forest vegetation, tree pollen forms high percentages of the total during Zones V & VI. Much of the non-arboreal pollen came from plants growing near the sites; thus pollen of bog and heath vegetation, namely Cyperaceae and Ericaceae with Gramineae is strongly represented.

Zone VII This zone consists of two sub-zones, of which VIIa is the Atlantic period and VIIb the Sub-boreal period. The transition from the Boreal Sub-zone VIc to the Atlantic period Sub-zone VIIa is placed in British diagrams at the sharp increase in the values of Alnus pollen. The transition marks a climatic change during which the continental climate characteristic of Boreal times gave place to a wetter Atlantic type in which temperatures rose to a Post-glacial maximum. The rise in Alnus at the Boreal/Atlantic transition is accompanied by a fall in Betula and Pinus pollen. Sub-Zone VIIa extends upwards to the level of the first substantial decline in Ulmus pollen, which marks the transition to the Sub-boreal, Sub-zone VIIb.

These pollen boundaries which mark the limits of Zone VIIa have been given absolute approximate datings by recent Radiocarbon measurements. Thus the level of the Ulmus decline established by pollen-analysis of peat at Flanders Moss, Stirlingshire, has been dated at ca.5,000 years B.P. (Godwin & Willis, 1962). No dating has yet been made by Radiocarbon of the Boreal/Atlantic transition at Scottish sites; at Scaleby Moss, Cumberland, however, the boundary has been dated at 5,500 B.C. (Godwin, 1960).

Sub-zone VIIa, the Atlantic.

Alnus, which was present in appreciable amounts before the VI/VII boundary, rises very sharply in Scottish diagrams at the transition; in several diagrams, owing to the poor definition of other pollen horizons, it is the only boundary shown (Durno, 1958; McVean, 1961). Regional differences in vegetational development are again in evidence; diagrams of sites in northern Scotland show lower frequencies of Alnus than those in the south;

thus in Wester Ross Alnus remained subsidiary to Pinus and Betula (Durno, 1959), whereas profiles from sites in Central Scotland indicate that Alnus shared dominance with Betula from the Boreal/Atlantic transition until modern times.

The Pinus dominance revealed in diagrams of sites in north-west Scotland (Durno, 1958) continued from the Boreal into the Atlantic and there is evidence in them that pine forest flourished upon high ground in that region, although after the Boreal/Atlantic transition lowland areas show the same decline in Pinus apparent elsewhere in Scotland. Durno has observed (1958) that although the higher precipitation and smaller seasonal variations in temperatures characteristic of the Atlantic dimate would appear unfavourable to pine, little adverse effect is revealed in pine pollen frequencies of that area. The Pine forest cover was however reduced periodically by forest fires, indicated by laters of charcoal from this zone in north-west Highlands (Durnon & McVean, 1959). Erdtman (1929) has also suggested the survival of large pine forests in the Grampians after the Boreal maximum when Pinus became extinct in many parts of England and Ireland. In the extreme north, Erdtman noted high Salix frequencies at sites in the Shetland Isles; there, the birch-hazel woodland of the Boreal diminished in the Atlantic partly because of peat formation, but Salix scrubs developed in some localities. In the St. Kilda island group, the Atlantic vegetation consisted of birch-hazel scrub; woodland conditions reached their maximum extent in this period, although a Plantago sward developed as a result of increased gale frequency (McVean, 1961). Mixed oak

forest in Highland areas in Zone VIIa is represented only by low frequencies of Quercus and Ulmus; Tilia occurs only as single grains and is absent altogether from some diagrams. South of the Highlands, Pinus reveals a rapid decline after the VIc/VIIa transition; the rise in Alnus is accompanied by a fall both in Pinus and Betula. Quercus and Ulmus are however strongly represented; the diagrams of Oban (Donner, 1957) show high values of Quercus and Ulmus which increase during the Atlantic, though there is no indication of higher values of Tilia. Pollen of Tilia, according to Donner, is too scarce to prove that it was present in the woodland of the time.

Zone VIIb, the Sub-boreal.

The evidence of palynology indicates that this sub-zone resembled the Atlantic in the high frequencies of arboreal pollen recorded, and that in general Scotland retained much of its cover of dense woodland. Changes, are, however, recorded during the period in the composition of the forest, and an indication of the beginnings of deforestation appears at the end of the period in the somewhat increased proportion of non-arboreal pollen revealed in some diagrams. Some regional distinctions in the composition of the forest are apparent, as in previous periods.

In the diagrams of southern Scotland, the Ulmus decline which marks the VIIa-VIIb transition is a clearly marked fall from the sustained higher values characteristic of the Atlantic period to the much lower frequencies typical of the Sub-boreal. This is a feature of the diagram of Carnwath Moss (Fraser & Godwin, 1955) and that of the Campsie Fells (Eydt, 1960). Very low counts of Pinus

are also shown in these diagrams; Eydt has, in fact, used the complete disappearance of Pinus to indicate the transition between this zone and Zone VIII. In these diagrams, like that of Flanders East Moss (Durno, 1956), Alnus and Betula are co-dominant, with Betula rising from its reduced values of Atlantic time. Quercus tends to rise in the Sub-boreal and touches its maximum values at Oban in VIIb (Donner, 1957). Flanders East Moss also records highest values of Quercus in the sub-zone. Corylus frequencies are higher in these diagrams than in the Atlantic.

In the far north of Scotland, however, regional differences are evinced by diagrams of sites in Sutherland and Caithness (Durno, 1958). Thus Quercus and Ulmus counts are very low in eastern Sutherland and Caithness (Durno, 1958); and it has not been possible to show on the diagrams the Ulmus decline. Betula and Alnus contributed most of the tree-pollen, although a considerable Pinus proportion is also shown in these diagrams. A decline in the total amount of tree-pollen which commenced at the Boreal/Atlantic transition evidently continued into the Sub-boreal. Sites near to the west coast of northern Scotland, however, reveal contrasts: thus in the Wester Ross area (Durno, 1959) high values of Pinus are evident in the Sub-boreal; a Pinus-Betula co-dominance is revealed with subsidiary Alnus, at some sites. Quercus and Ulmus values are higher than those of sites farther north-east. But total tree-pollen declines, a gradually diminishing tree cover is revealed which was in part the result of forest fires evidenced by charcoal layers in the bogs. In Aberdeenshire, pollen of Betula and Alnus preponderates during Sub-zone VIIb, as Durno (1957) has shown; Pinus, Quercus and Ulmus have low frequencies. In this

area also a fall in total arboreal pollen occurs in Sub-zone VIIb, though it is slight; and this may be attributed to the beginnings of forest clearance by Neolithic and Bronze Age agriculturists of the Sub-boreal period.

The Sub-atlantic, Zone VIII.

This period is represented at many sites in Scotland, as elsewhere in the British Isles, by an upper layer of unhumified peat, paler in colour than that below it. These two types of peat are separated by a boundary layer or Grenzhorizont, often a clearly marked feature consisting of a Calluna layer or a layer of wood peat. It is generally agreed that climatic conditions in the Sub-atlantic after the Grenzhorizont became rapidly wetter and colder, and this change has been recorded in peat-bogs at many sites in north-west Europe. The level of this climatic deterioration has been dated at c.500 B.C. by Radiocarbon which is in accordance with earlier determinations by varves and archaeological levels; at this time the transition from the Bronze Age to the Iron Age took place.

According to the English system of zoning by tree-pollen frequencies (Godwin, 1956) several characteristics distinguish Zone VIII: Tilia decreases; there is a further fall in elm; Betula however increases considerably. Scottish diagrams however do not show Tilia except as single grains; the Ulmus curve is often weakly defined; the increase in Betula is present but too gradual to be used as a zonal boundary. Blackburn (1946) used two criteria to separate Sub-zone VIIb from Zone VIII, namely, the Grenzhorizont and also the sharp increase in non-tree pollen which occurs at the base of the zone, particularly that of Ericaceae. Durno (1959) has used both of these features in his diagrams of northern Scottish sites.

In Zone VIII, the influence of man upon the vegetation of Scotland becomes an outstanding feature of the pollen diagrams.

The forested area declined rapidly during the period as a consequence of clearances by early farming communities; but there was an extension of heath and moorland. Climatic changes, however, played a part in the decline of woodland, for the wetter conditions gave rise to the spread of bogs, to soil-leaching and, as Pearsall (1950) has shown, to the formation of acid mor in place of neutral soils originally present. Such changes have been demonstrated in Aberdeenshire (Durno, 1957). The forest clearances which began there probably in the Neolithic became intensified during the Iron Age; much land was then cleared and drained by Celtic invaders using iron tools, and the effects of this activity are visible in pollen diagrams, first, from coastal sites and then farther inland as population increased. The spread of heath and moorland following forest destruction is seen in the expansion of pollen of the heathers and grasses.

During the Sub-atlantic a steady increase in Betula pollen is characteristic, the result of clearances and also of climatic revertence. Pinus is usually at very low levels but may rise rapidly at the top of the zone. Other tree pollen may also show this late increase which may be attributed to planting of trees by landowners during the 18th. century. This planting was carried out on a large scale, as Handley (1953) has shown and must have considerably affected the pollen rain in many parts of Scotland; thus in Perthshire, John, Duke of Atholl, the 'Planting Duke' covered 16,000 acres with 27,000,000 larches, Scots pine, spruce, birch and oak. Alnus shows a tendency to decrease in Zone VIII, the probable result of soil leaching or of unfavourable climate, although in some sites it maintains or even increases its frequencies. Corylus also tends to show a decrease. Some grains of Fraxinus and Fagus are shown in this zone. (Durno, 1956).

SUMMARY.

As a result of this survey of previous palynological investigations in Scotland, the following observations may be made:

1. The regional parallelism of vegetational development emphasised by von Post (1946) is demonstrated; the main shifts of pollen spectra evident in the diagrams of English sites are paralleled in most Scottish diagrams, but the character of the shift has its own distinctive features which appear to be the result of regional differences in physical geography.

2. Not all the changes that characterise English vegetational development appear clearly in Scottish diagrams; thus the representation of Quercus and Ulmus is weaker in Scotland and the result has been an absence of subdivision of the Boreal period into Zones V and VI (Donner, 1957) or of Zone VI into its sub-zones. The weakness of the pollen curves of Quercus and Ulmus is most marked in the diagrams of north-east Scotland (Durno, 1959) where in some cases no continuous curve appears. Betula and Alnus, however, are strongly represented at Scottish sites; Alnus shows an earlier development than in England and Betula appears to have been dominant over wide areas throughout the entire Post-glacial period. Pinus has its own characteristic features in Scotland and remains dominant in parts of the north even after the beginning of the Atlantic period.

3. On the basis of these previous investigations, it is possible to distinguish areal differentiation in vegetational development in Scotland. Thus there are strong contrasts in the pattern revealed by diagrams of the north-east and the north-west; in the Outer Hebrides, Quercus, Ulmus and Corylus have been more important and a

zoning of the diagrams has been possible (Harrison & Blackburn, 1946). In diagrams of eastern Sutherland and Caithness, however, Durno (1958) was able to indicate only the position of the Boreal/Atlantic transition, so poor was the representation of Quercus, Ulmus and Corylus. These differences must have been determined largely by the marked climatic contrasts between western and eastern coasts of Britain pointed out by Godwin (1934) and Kirk (1963). Thus in the north of Scotland, the more maritime west has apparently favoured the greater development of broad-leaved deciduous trees. Investigations by Durno (1959) in the eastern Grampians have also revealed a regionalism in vegetational history; he has shown that Pinus was much more important in the ancient forests of the north-east Grampians than in areas farther south, such as the Glen Clova region, where Pinus was never able to supersede Betula and where also Quercus and Ulmus were more important. In such studies as these, a number of sampling sites for pollen analysis situated within a limited area obviously gives a more accurate picture of vegetational change than one diagram in which over-representation of local vegetation may obscure the true picture of development.

Previous investigations have thus revealed a regionalism of Post-glacial vegetational history; the present-day vegetation clearly shows such regionalism, and it has been illustrated by such studies as that of Smith (1901) and Hardy (1906) and determined, as McVean (1964) has suggested, 'by climatic and geomorphological variation and in detail by differences in geology, both solid and superficial'. It is the aim of this investigation to show the distinctive character of the pattern of vegetational development in south-east Scotland.

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PART II

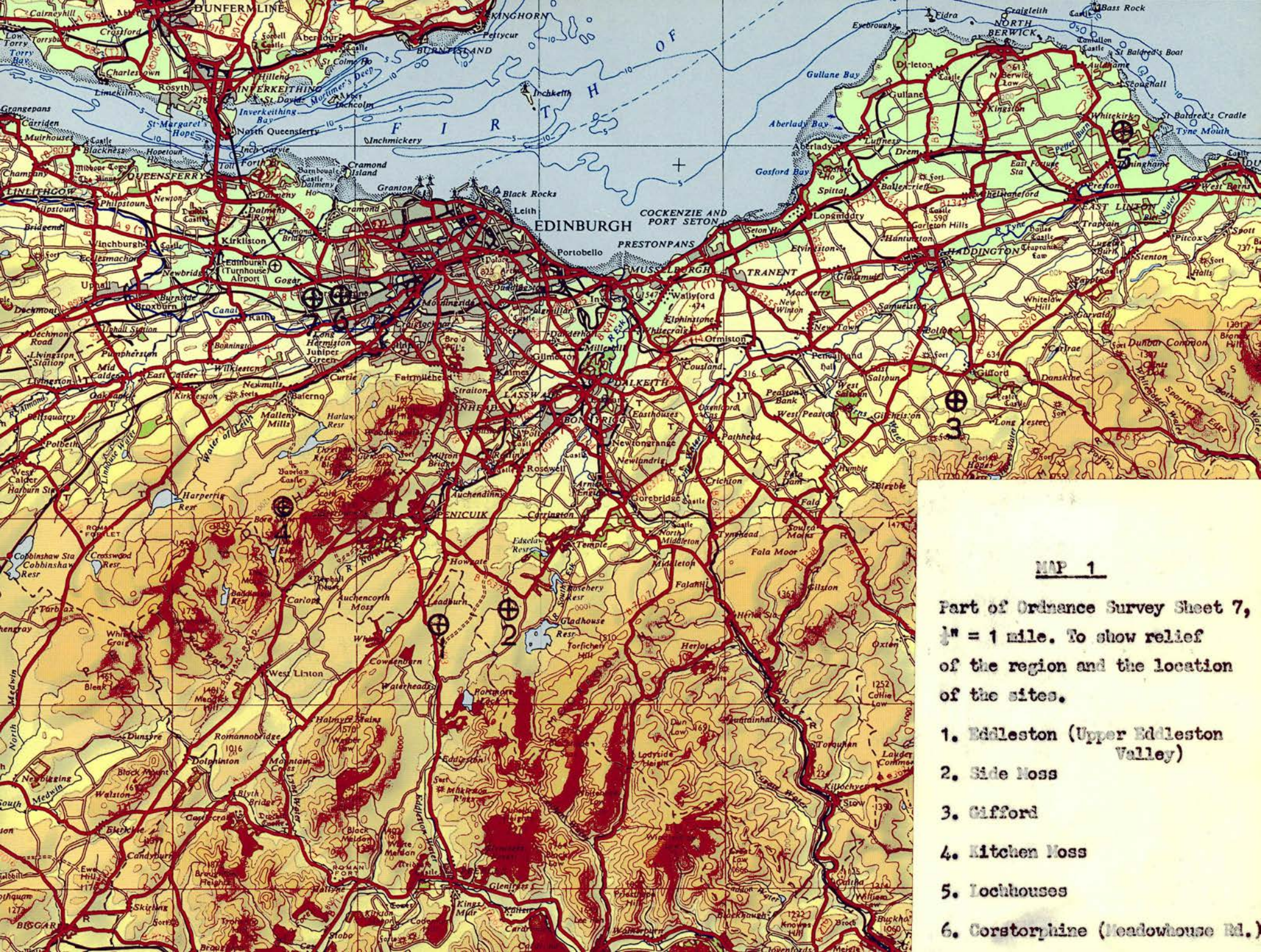
SITES FOR POLLEN ANALYSIS.

GEOGRAPHICAL FEATURES OF THE REGION OF RESEARCH.

SITES FOR POLLEN ANALYSIS.

Map 1. shows the area of the research and the positions of the sites chosen for pollen-analysis. By restricting the research to this relatively limited area, and by making use of as many sites as possible within it, two objectives are gained: firstly, as true a picture as possible of the pattern of vegetational and climatic change within the region is produced; and secondly, an accuracy of correlation of zonal data is obtained, leading to the development of a relative chronology for the whole area.

A variety of environment is presented in this region: hill, plateau, lowland and coastal conditions all occur within it; sites were therefore sought where these conditions might be represented, being at the same time suitable for illustration by pollen analysis of the vegetational development of the whole area. Three of the sites are on low ground, below 200', three are at an intermediate level, between 600' and 900'; and one is a hill site, at 1350'. The objective was to obtain at each site the longest possible series of samples illustrative of Late-Quaternary vegetational changes; a Late-glacial type of pollen and stratigraphy was, however, yielded only at one site, namely Corstorphine, and therefore the main emphasis of the investigation and discussion falls upon Post-glacial features. A full range of the Post-glacial was obtained at Eddleston and at Side Moss; sections of the Post-glacial sequence came from the sites at Gifford, Gogar, Kitchen Moss and Lochhouses; the latter site was chosen not only to illustrate vegetational conditions but to show evidence of changes of sea-level and to date such changes. Apart from hill or plateau areas where undisturbed peat still remains, suitable sites for pollen-analysis were few as this is an area of intensive agriculture and urban expansion.



MAP 1

Part of Ordnance Survey Sheet 7, 1" = 1 mile. To show relief of the region and the location of the sites.

1. Eddleston (Upper Eddleston Valley)
2. Side Moss
3. Gifford
4. Kitchen Moss
5. Lochhouses
6. Corstorphine (Meadowhouse Rd.)

The Sites are as follows: (Map 1.)

NAME	COUNTY	ALTITUDE (ft.)	MAP REF.	DEPTH OF DEPOSIT (metres)	ZONES	TYPE OF SITE
Eddleston (Upper Eddles--ton Valley	Peebles--shire.	850	242537	3.2	IV - VIII	Raised Bog
Side Moss	Midlothian	900	235555	6.8	IV - VIII	Raised Bog
Gifford	East Lothian	650	554654	6.0	V - VIII	Lake margin
Kitchen Moss	Midlothian	1,350	165608	1.8	VII - VIII	Blanket bog
Lochhouses	East Lothian	18	613821	3.2	VI - VII	Coastal basin
Corstorphine (Meadowhouse Rd.)	Edinburgh	142	201727	2.8	I - III	Alluvial flat.
Gogar	Edinburgh	150	181725	2.3	IV - V	Alluvial flat.

Outline of the Geography of the Area.

The highest land forms the Pentland Hills which rise to 1900 feet (580m.) and these hills consist of a horst of lavas and sedimentary rocks of mainly Old Red Sandstone age. They trend roughly from S.W. to N.E. and extend to within 6 miles of the coast. Between their northern face and the Firth of Forth is the lower ground which forms the site of Edinburgh; prominent in this lowland corridor are igneous crags and lake-flats of glacial origin.

East of the Pentland Hills is a tract of lower land developed upon Carboniferous rocks, most of which is drained by the rivers Esk and the Tyne Water. This lowland slopes upward from the coastal raised beaches to the escarpment of the Moorfoot and Lammermuir Hills; along the foot of these hills it forms an ill-drained plateau of height approximately 750 feet (230m.).

The southern part of the region is occupied by the Moorfoot Hills and the Lammermuir Hills; these form a plateau of Ordovician and Silurian rocks which rises abruptly from the lower land to a height of over 1,700 feet. South of the plateau is the Tweed Basin; southward-flowing streams such as the Eddleston Water drain the plateau to the river Tweed and their valleys link the Tweed to the lowlands of the Esk and Tyne rivers.

Covering the lowlands and the gentler slopes of the hills of the region are the deposits of the Pleistocene ice-sheets and glaciers. The most widespread is boulder clay which covers much of lowland Midlothian and East Lothian, but there are also extensive deposits of fluvio-glacial sands and gravels. More recent deposits such as the freshwater alluvium of river terraces and marine alluvia of raised beaches also occur.

Upon the soils of these superficial materials there developed the original cover of vegetation; very little remains of that today; forests have long since been cleared and much of the marshland and peat-moss has been drained and brought under cultivation.

Climatic conditions of the region are those characteristic of North-West Europe; it is west-maritime in type with modifications associated with its position on the east coast of Britain. In comparison with many other parts of Scotland, it is well favoured, having less rain and cloud; rainfall and winter temperature are similar to those of eastern England.

Rainfall is well-distributed throughout the year. Spring is the driest season, April recording the lowest rainfall of the spring months in Edinburgh; late-summer and autumn are the wettest months, the maximum occurring in August. Precipitation is mainly frontal rain associated with eastward-moving depressions; thus there is a decrease from west to east. The coastal margin from Edinburgh to Dunbar receives less than 25" annual average precipitation; the Pentland Hills however receive 40 to 45" but the lower part of the Esk valley in the lee of the Pentlands is much drier, Dalkeith having only 27". Rainfall increases southwards; it is 37" in the upper Esk basin and over 40" in the Moorfoot Hills. The relatively low rainfall of the lower land of the area is closely comparable with that of eastern England. Temperatures also, particularly in winter, resemble those of Eastern England. Thus Dunbar, on the coast of East Lothian, with a January mean of 38.5 deg. F. is comparable with Lowestoft, Suffolk, with 38.3 deg. F. January, and is slightly warmer than Cranwell, Lincolnshire, which has a January mean of 37.4 deg. Summer temperatures are lower, the July mean of

58.2 deg. F. at Dunbar being 3 degrees below the July mean of 61.3 deg. F. at Cranwell. A steady fall in temperatures occurs southwards from the coast towards the higher ground; thus Boghall, altitude 639 feet, has a January mean of 36.3 deg. F. and West Linton at 850 feet has in the same month 34.3 deg. F.

The vegetative season, varies according to altitude; thus Dunbar has a growing season of 8 months, but inland at Penicuik this shortens to 7 months.

PART III

FIELD EQUIPMENT & TECHNIQUES

LABORATORY TECHNIQUES.

FIELD EQUIPMENT & TECHNIQUES

Equipment for field investigation included the following: a Hiller pattern peat sampler, length of chamber 1/3rd m., with 10 light-alloy extension rods, each 1 m. in length; spade and trowel; spatulas; glass specimen tubes, 5 x 2.5 cms., corked at one end.

Trial borings were first made to determine the stratification and the actual sampling was done in the most representative spot. A surface square of peat was first removed to facilitate entry of the borer and the successive cores were extracted from within this recess, a separate boring being made for each core. When the borer was lifted each time, the outer parts of the jacket were cleaned and the samples taken from the inner part of each core at selected intervals, usually at 10 cms., though an interval of 5 cms. was used at certain sites. Each sample was placed in a clean glass tube, the stopper of which was labelled with the depth. To avoid any contamination of a sample by material from a different level, the inside of the borer was cleaned each time with fresh paper tissues. A smooth spatula was used and rubber gloves worn in these operations Where the peat or deposit profile was exposed by cuttings, the surface was cleaned or cut vertical, then samples were taken from the top of the deposit downwards at levels measured by a steel tape held vertically along the section, the tubes being filled by spatula or by pressing each into the face of the section. A record of the nature of the material and of identifiable macro-remains was kept in the field-book. The samples in the tubes were later sealed with paraffin wax and given an additional label showing the depth and the name of the site.

LABORATORY TECHNIQUES.

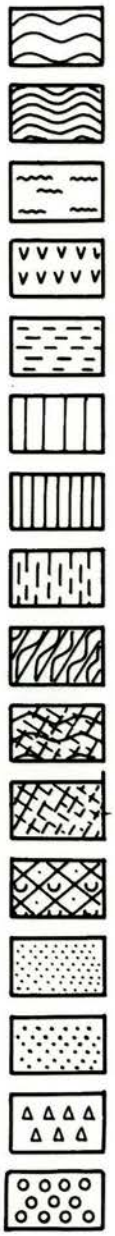
Preparation of Samples. The samples obtained in the field were chemically treated in the laboratory with the object of separating the micro and macro-fossils from their matrix and of concentrating the micro-fossils in a suitable mounting medium prior to statistical examination. The technique used depended upon the nature of the deposit. Pure peats containing abundant pollen were subjected to a method involving deflocculation by a 10% aqueous solution of caustic soda and sodium perborate at 100 deg. C. for one minute, followed by sieving, washing with distilled water and centrifuging. For samples poor in pollen, the method outlined by Godwin (1956) was used. This method consists of disintegration of the samples by digestion at 100 deg. C. for 30 minutes in 5-10% caustic soda, followed by sieving, washing and centrifuging; delignification of the centrifugate is obtained by a mixture of glacial acetic acid, (8 c.c.) sodium chlorate, (4.5 c.c) and concentrated sulphuric acid, (1 c.c.) followed by alternate centrifuging and washing. Acid hydrolysis of the celluloses then follows by the use of a mixture of 10 c.c. glacial acetic acid and 1 c.c. concentrated sulphuric acid at 100 deg. C. for 30 minutes, followed by alternate centrifuging and washing. This method gave satisfactory results. A process of chlorination-acetolysis described by Erdtman (1943) was also used but it was found to have the disadvantage of increasing the size of the pollen grains. Where mineral matter was present, as with clays or silts, the treatment with hydrofluoric acid outlined by Faegri and Iversen (1950, 1964) was followed, involving boiling of the sample in 40% hydrogen fluoride for 2 minutes in a

nickel crucible, followed by centrifuging and washing. An alternative method of eliminating mineral matter which was found to be successful was that described by Hallik (1957): the sample was suspended after acetolysis in a concentrated solution of potassium iodide and cadmium iodide and adjusted to a specific gravity of 2.5; pollen grains floated in this liquid and could then be separated off. The method outlined by Frey (1955) which also involves differential flotation, was tried but it was found to give unsatisfactory results. Microscope slides were prepared by mounting the centrifugate in about twice its bulk of safranin glycerine jelly. Macro-remains were extracted by heating the sample in dilute alkali or by soaking it in dilute nitric acid.

Identification of the micro-fossils. Pollen and spores were identified and counted with the aid of a Baker Pathalette microscope fitted with binocular tubes and a micrometer stage. The usual magnification was ca. 320 but for difficult cases a magnification of ca.1000 with oil-immersion was required. To assist identification, a set of reference slides was made from fresh pollen and these were prepared using similar methods of treatment to those used for the samples. Illustrations, keys and descriptions supplied in text-books and in other publications assisted recognition, in particular those of Wodehouse (1959), Erdtman (1943), Hyde and Adams (1958) and various numbers of Grana Palynologica (ed. Erdtman). In the determination of micro-fossil frequencies, at least 150 arboreal pollen grains (excluding hazel) were counted from the slides prepared from each sample. In very few cases was the total count of arboreal pollen much less than this number. All other pollen was counted separately and expressed as a percentage of the arboreal pollen.

All the field and laboratory work was done personally by the investigator.

KEY TO STRATIGRAPHICAL SYMBOLS.



Fresh Sphagnum Peat

Highly humified Sphagnum Peat

Eriophorum vaginatum Peat

Wood Peat

Highly humified Peat

Phragmites Peat

Carex Peat

Fen Dy

Carex-Sphagnum Peat

Sphagnum Dy

Coarse detritus Dy

Calcareous Silt

Clay

Sand

Till

Gravel

PART IV

RESULTS OF INVESTIGATIONS

EDDLESTON (Upper Eddleston Valley).

SITE

This site is situated near the Forth/Tweed watershed in Peeblesshire, in the upper portion of a valley which traverses the northern Southern Uplands in a north-to-south direction. The valley is occupied by the Eddleston Water, a stream flowing southwards to join the Tweed at Peebles. The valley is at this point broad and shallow and is between 800 and 900' above sea-level; its floor has numerous depressions or kettles most of which contain peat, separated by gravel ridges or kames, as Sissons (1958) has described. Samples were taken from a small raised bog about 4 acres in area which occupied one of the depressions. As it was clear that accumulation had been very gradual at this upland site near a watershed, a close sampling interval of 5 cms. or, in some horizons, 2 cms. was used. The surface vegetation consisted of an association of Eriophorum vaginatum, Calluna vulgaris, Sphagnum spp., Juncus spp., Galium saxatile. The site lies in an area of hill-pasture for sheep and the area is almost completely treeless at the present time.

Stratigraphy

The bog proved to be about 3.2 metres in depth, the peat resting upon a stony substratum. The lower 20 cms. consisted of very dark-brown highly humified peat mixed with mineral fragments which were coarse and sandy near the bottom of the section, but finer and siltier upwards. Above this, the next 30 cms. consisted of dark well-humified peat containing fragments of Carex spp. and seeds of Menyanthes trifoliata. Phragmites fragments also appeared in this peat. The next samples upwards, from 270 cms. to

210 cms. all contained Betula debris; the lowest parts of this woody horizon showed also more Carex remains but its upper part contained Sphagnum leaves mixed with the wood. Above this mainly woody horizon came a different kind of peat containing Eriophorum vaginatum fibres with Sphagnum fragments and twigs of Calluna vulgaris and of moderate humification (6 - 7). Fragments of Betula twigs were noted at 135 cms. but there was no definite upper ligneous horizon. Peat above 110 cms. was much lighter in colour and of low humification; it consisted of Sphagnum and Eriophorum fragments.

Bore records and laboratory identifications

Cms. from surface

020	- 110	Pale brown, unhumified Eriophorum/Sphagnum peat.
110	- 190	Eriophorum vaginatum, Sphagnum and Calluna vulgaris fragments. Twig of Betula at 135 cms.
190	- 200	Sphagnum/Calluna fragments (Humification 6 - 7).
200	- 240	Betula fragments with abundant Sphagnum remains.
240	- 260	Betula and Carex fragments.
260	- 300	Highly humified dy or limnic peat with Carex and Phragmites fragments. Several seeds of Menyanthes trifoliata.
300	- 310	Highly humified dark peat with silty fraction. Abundant Sphagnum leaves.
320		Grey sand and gravel.

The Pollen diagrams.

Although this peat was comparatively shallow, the whole Post-glacial period is represented in it, from Zone IV to Zone VIII according to the system of Godwin (1956).

Zone IV, the Pre-boreal.

The basal deposits, from 290 cms. to the bottom of the section, represent Zone IV, the Pre-boreal, or early Post-glacial. The high percentage of non-arboreal pollen (NAP) suggests an open landscape, without a closed tree cover but with a vegetation of herbaceous plants, as is apparent from the high frequencies of Gramineae, Cyperaceae, Compositae, Artemisia. Arboreal pollen is dominated by Betula, but there is a strong representation of Pinus and Salix. Corylus, Empetrum and Ericoid pollen is prominent; probably the vegetation consisted of communities of shrubs and of herbaceous plants.

Zones V & VI, the Boreal.

The beginning of the sharp upward curve in Corylus signalises the start of Zone V, the lower of the two Zones into which the Boreal is divided. The retreat of plants of open habitat is expressed by the sharp fall in the NAP component, and the development of a closed woodland dominated by Betula is expressed by the AP curves; Ulmus appears about the middle of this period and its values rise sharply towards the end. The stratigraphy indicates that at this site the Low-moor stage of peat is first represented (Fraser 1943); the moss was initially a swampy depression with a vegetation of Sphagnum mosses, grasses and sedges; later in the Pre-boreal a shallow lake was formed in which aquatic plants were present, indicated by pollen of Myriophyllum and seeds of Menyanthes trifoliata. Later in the Boreal, as the soil level was built up by the accumulation of humus, trees succeeded aquatic and marsh plants.

Zone VI indicates a replacement of some of the Betula by Ulmus,

Quercus and Alnus. This zone has been sub-divided upon the basis proposed by Godwin (1956) as the phases he has described are clearly shown. Thus in VIa, Ulmus rises to a peak value, and at the same level, Corylus pollen has a very high frequency. In the next sub-zone, VIb, Quercus pollen exceeds that of Ulmus, and Betula shows a corresponding decline. A lower Corylus count characterises Sub-zone VIc, accompanied by rising frequencies of Alnus.

Zone VII

This zone is clearly divided from the preceding zone by a sharp additional rise in Alnus. Quercus continues at high levels, but Pinus falls to a minimum at the end of the zone. There are two sub-divisions, VIIa, the Atlantic, and VIIb, the Sub-boreal. In VIIa, Alnus rises to high frequencies, attaining over 50% of the total AP by the end of the sub-zone; Betula, though recording a corresponding decrease, remains high. There is only one grain of Tilia in this sub-zone. The divisions between VIIa and VIIb is placed at the decline in Ulmus; Sub-zone VIIb shows Quercus rising, however, with a fluctuating rise in Corylus towards the top; Betula also rises, although Pinus at the same levels diminishes to a minimum. Stratigraphically, Zone VII is represented by peat composed of Sphagnum and other mosses, with Eriophorum vaginatum and Calluna fragments which overlies the wood-peat of Zone VI. Ombrogenous peat, the plant response to wetter conditions, clearly spread over the forest at this site; it is represented in the NAP diagram by the high counts of Ericaceae and the high values of Cyperaceae and of Sphagnum.

Zone VIII covers the Sub-atlantic and Historic time. A recurrence surface in the peat corresponds with the border between this zone

and Zone VII. Betula increases, and Alnus remains high, but a sharp fall occurs in Quercus. A rising NAP curve indicates a diminishing tree cover; the NAP consists of pollen of Ericoids, grasses and sedges with ruderals such as Plantago which suggests cultivation or use of the land for pasture. A rise in Pinus at the top of this zone may indicate 18th.C. plantations of pine by landowners.

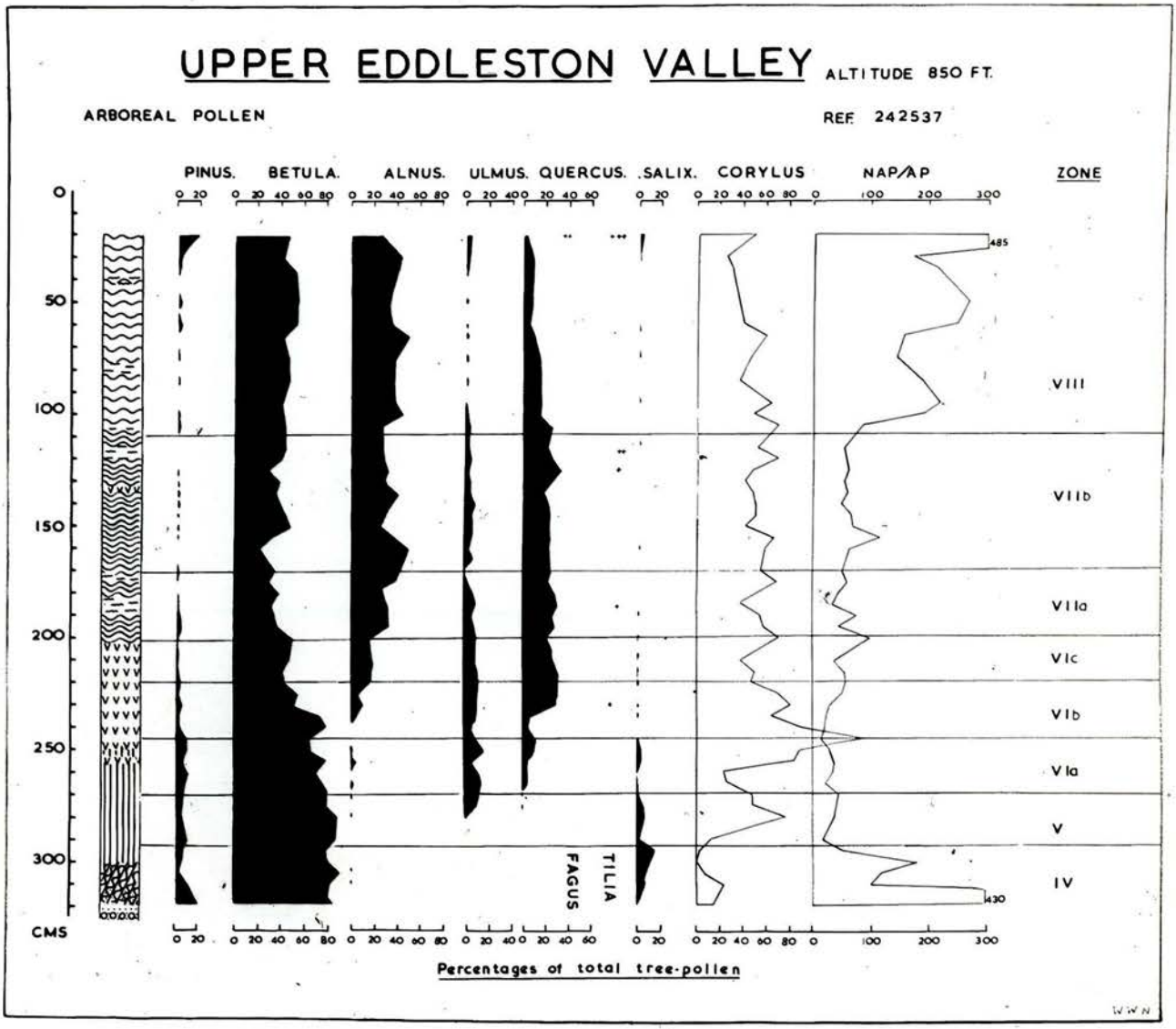


Fig.1. Upper Eddleston Valley (Eddleston); Arboreal Pollen Diagram. Although only just over 3 metres in depth, this Raised Bog contained the whole Post-glacial sequence, except for the upper part of Zone VIII.

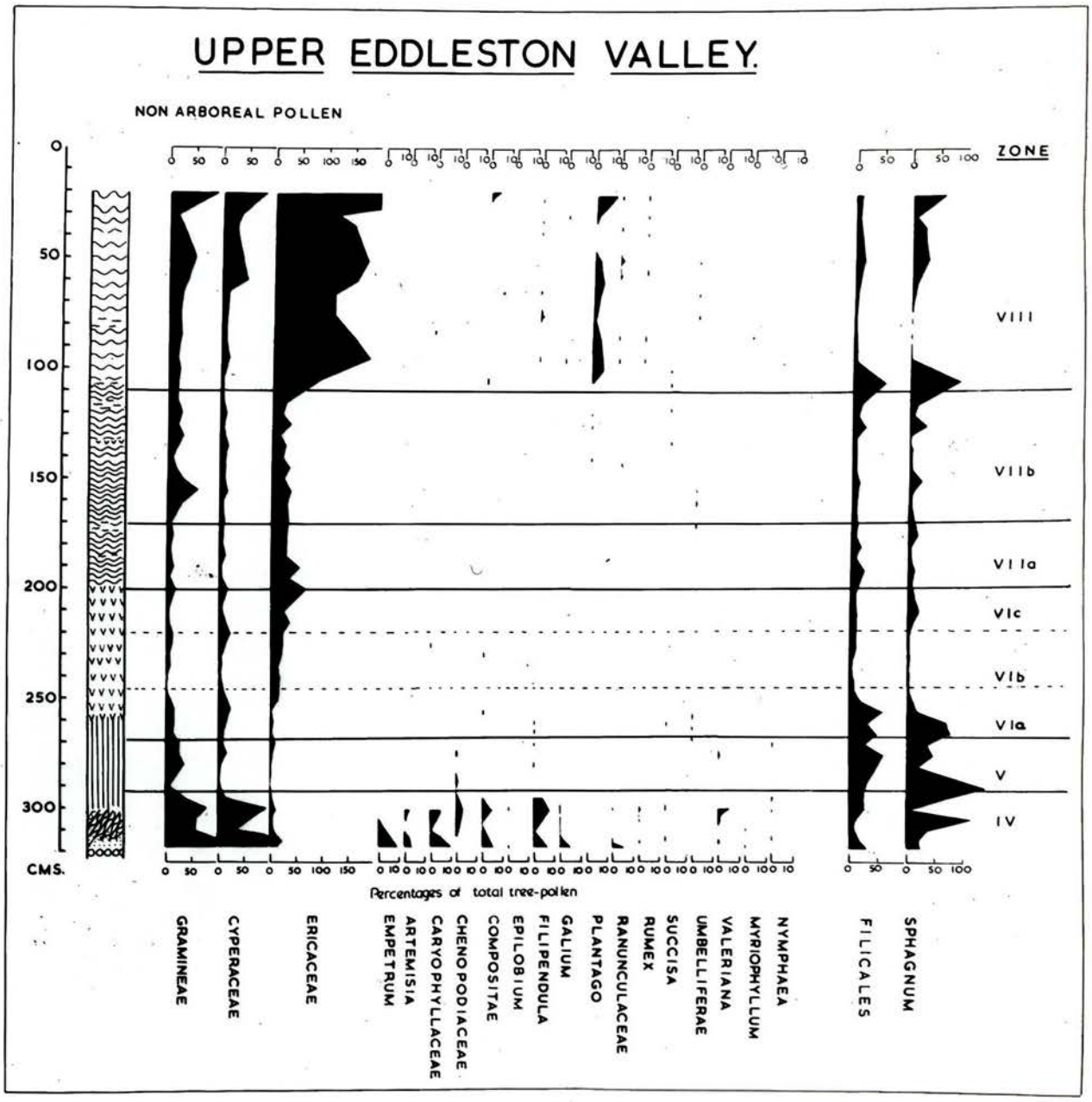


Fig 2. Non-Arboreal Pollen Diagram.

UPPER EDDLESTON VALLEY. Altitude 850 feet.

Plate 1. The site is the small Raised Bog in the foreground. Moorfoot Hills in the background. Surface vegetation - an association of Calluna vulgaris, Eriophorum vaginatum, Sphagnum spp., Juncus spp.

Plate 2. The site looking northwards.

SIDE MOSS. Reference 285555.

Side Moss is one of several raised bogs upon the broad plateau of elevation 800 - 900' which extends eastwards from the Pentland Hills and northwards of the Moorfoot Hills forming the southern portion of the basin of the Esk rivers. The plateau is developed upon Carboniferous rocks. A hummocky sheet of glacial deposits rests upon the plateau and several peat mosses have developed in hollows in the drift. Side Moss was chosen for sampling as the peat of its upper horizons was exposed for detailed study in an old quarry which has been cut along the eastern edge of the moss; samples were taken from the deeper central part with the Hiller borer, and this long range of samples was used for pollen analysis. The deposits of the central part of the moss were 6.8 m. in depth; those exposed in the quarry were 3 m. deep.

Stratigraphy

The stratigraphical features resemble those described at Eddleston which is approximately 3 miles to the south-west. The lowest deposits, which rest on sand, are limnic, consisting of dark-brown highly humified peat with fine mineral matter; they extend from the bottom, at 680 cms. up to about 500 cms. Above the lake peat is a layer consisting of wood-fragments, largely Betula pubescens and Calluna vulgaris stems, and about 70 cms. in thickness. This ligneous peat is succeeded upwards by a layer of Eriophorum/Carex peat with Sphagnum fragments. At 370 cms. the peat becomes paler in colour and is poorly humified, consisting of Sphagnum, Eriophorum vaginatum, Scirpus caespitosus and Calluna vulgaris. This type of vegetation now forms the surface of the moss. In the quarry, the upper, poorly humified peat is exposed;

nearest to the surface this consists of a layer of Sphagnum peat containing Calluna fragments, and below this is a thicker horizon of fibrous Eriophorum vaginatum peat, with Sphagnum remains. This cotton-grass-moss peat rests upon a thin layer of wood fragments in which Betula branches, Salix stems and nuts of Corylus were recognisable.

Details of Exposure of peat profile in Quarry.

Cms. from surface.	
0 - 50 . . .	Light-brown Sphagnum peat with small Ericoid twigs. Downwards from this level the peat is darker in colour and of higher humification and containing Eriophorum vaginatum fibres.
50 - 90 . . .	Regeneration complex peat with alternate bands of fresh Sphagnum peat and stem bases of Eriophorum vaginatum. Many Ericaceous rootlets.
90 - 100	Dense mat of poorly humified Eriophorum vaginatum.
100 - 110	Large Ericaceous twigs, with Sphagnum.
110 - 130	Fresh Sphagnum peat.
130 - 150	Regeneration complex peat, Sphagnum alternating with Eriophorum.
150 - 155	Abundant Ericoid twigs.
155 - 200	Thick horizon of poorly humified tussocks of Eriophorum vaginatum, with irregular bands of Sphagnum.
200 - 220	Change in colour at this level - a lighter brown Eriophorum/Sphagnum peat.
220 - 240	Darker peat, very coarse and poorly humified fibrous peat with Eriophorum vaginatum tussocks.
240 - 280	Wood peat, consisting of a layer of stems and branches of Betula lying horizontally, fresh in appearance, intermingled at the top with poorly humified light-brown Eriophorum fragments. Nut of Corylus avellana. Salix wood.
280 - 300	Twigs of Betula in a matrix of greenish peat with Carex fragments.
300 - bedrock.	Grey stony clay with large stones.

Bore Records and Laboratory Identifications. Centre of Moss.

Cms. from surface.

20	-	50	Eriophorum peat.
50	-	80	Sphagnum/Scirpus peat.
80	-	120	Sphagnum peat with fibres of Molinia.
120	-	160	Eriophorum/Sphagnum peat of very low humification.
160	-	200	Sphagnum peat of low humification.
200	-	230	Fresh Eriophorum fibres.
230	-	280	Sphagnum peat.
280	-	370	Eriophorum vaginatum peat.
370	-	380	Eriophorum vaginatum peat of low humification, with Sphagnum.
380	-	430	Eriophorum vaginatum peat with Carex fragments at 410 cms.
430	-	520	Wood peat Betula twig and Calluna vulgaris twig at 470 cms. Betula cone scale at 460 cms. Many Sphagnum leaves.
520	-	600	Peat contains many small twigs, probably Calluna, Sphagnum leaves very abundant. Calluna fragments at 570 cms.
600	-	610	Peat of slightly lower humification (H.7.). Many small leaves of Sphagnum mosses in sample
610	-	640	Dark highly humified peat (H.8.). Seed of Menyanthes trifoliata at 630 cms.
650	-	670	Dy. A brown peaty mud with fibrous plant remains.
670	-	680	Fine grey clay, with dark organic matter.
700			Sand.

The Pollen Diagrams.

The pollen diagrams indicate that a full Post-glacial sequence is represented at this site, extending from Zone IV to Zone VIII.

Zone IV, the Pre-boreal The lowest 30 cms. of peat contains pollen of high NAP values; this includes pollen of herbaceous plants of open habitat, namely Rumex, Artemisia, Plantago and abundant Gramineae, Cyperaceae. The presence of pollen of Myriophyllum alterniflorum confirms the zonal character of this horizon for it is a typical component of Pre-boreal deposits (Godwin, 1940). Betula pollen dominates the AP, in which there are low counts of Pinus and Salix. Corylus pollen first appears in Zone IV.

Zone V is characterised by high values of Corylus, the rising curve of which marks the zonal boundary. Betula is very high and dominates the AP as in Zone IV, but Ulmus appears in this Zone, accompanied by pollen of Alnus and Quercus.

Pollen of Myriophyllum alterniflorum disappears at 650 cms, and just above this level a sharp rise in pollen of Cyperaceae occurs; this change may reflect a change from open-water conditions of the Pre-boreal lake to sedge-swamp. Ericoid pollen rises at 600 cms. which may represent a further stage in the succession, in which Calluna/Sphagnum bog replaced a sedge community. Stratigraphy and pollen both suggest the establishment of Calluna-dominated vegetation at this site, during Zones V and VI.

Zone VI. The three phases of this zone described by Godwin are distinguishable; in Sub-zone VIa, Ulmus is relatively abundant, accompanied by very high values of Corylus; in the second sub-zone, VIb, Quercus rises to higher values than Ulmus; in the third, VIc,

Corylus falls to much lower frequencies, and there is a rise in Alnus. Pinus falls to very low values.

Zone VII. The Boreal/Atlantic transition is signalized by a further rise in Alnus and the continued low values of Corylus, Quercus and Ulmus remaining fairly high. Sub-zone VIIa is divided from Sub-zone VIIb by the fall in Ulmus pollen which occurs at 400 cms. Sub-zone VIIb, the Sub-boreal, shows high frequencies of Alnus and Quercus, but Ulmus remains very low throughout this sub-zone. Stratigraphically, Zone VII is represented by Eriophorum/Carex peat with abundant Sphagnum probably indicating the initial stages of the formation of raised bog.

Zone VIII. Peat of this zone has a lower humification than that of lower horizons; very fresh Eriophorum/Sphagnum remains are conspicuous. Betula pollen shows a steady increase in this zone, but Alnus falls slowly. Quercus pollen falls sharply at the bottom of this zone, at 350 cms. and again at 320 cms. and at about 360 cms a long slow decline occurs. Deforestation during Zone VIII is indicated by pollen of Plantago spp. and by increases in Gramineae, and by fluctuations in the tree-pollen curves. Ericoid pollen increases rapidly, and it is the rise in this pollen, together with the change in peat character at about 370 cms. which has been taken to indicate the boundary between Zones VII and VIII.

Dating of the peat exposed in quarry. Pollen analyses were made of a number of samples taken from the face of the peat layers exposed in the quarry. Frequencies were as follows: (Total tree pollen percentages.)

TABLE 3.

Depth cms.	PINUS	BETULA	ALNUS	ULMUS	QUERCUS	CORYLUS	CYP.	GRA.	ERIC.	PEAT TYPE
200	0	51	36	1	10	40	15	6	128	Eriophorum/ Sphagnum
210	0	44	44	1	8	58	9	13	170	Eriophorum/ Sphagnum
220	1	41	29	½	22	51	23	34	22	Eriophorum/ Sphagnum
250	0	31	41	1	18	24	32	21	6	Wood peat
280	2	17	66	2	13	30	22	29	3	Wood peat
290	1	26	55	½	9	15	13	13	2	Wood peat

These frequencies appear to indicate that the wood horizon is of Sub-boreal age, (Sub-zone VIIb), and that the upper poorly humified peats composed of Eriophorum, Sphagnum and Calluna fragments are Sub-atlantic (Zone VIII). The Grenzhorizont is thus the junction of the wood horizon and the upper Eriophorum/Sphagnum peat. No wood horizon in this position was observed in borings in the centre of the moss.

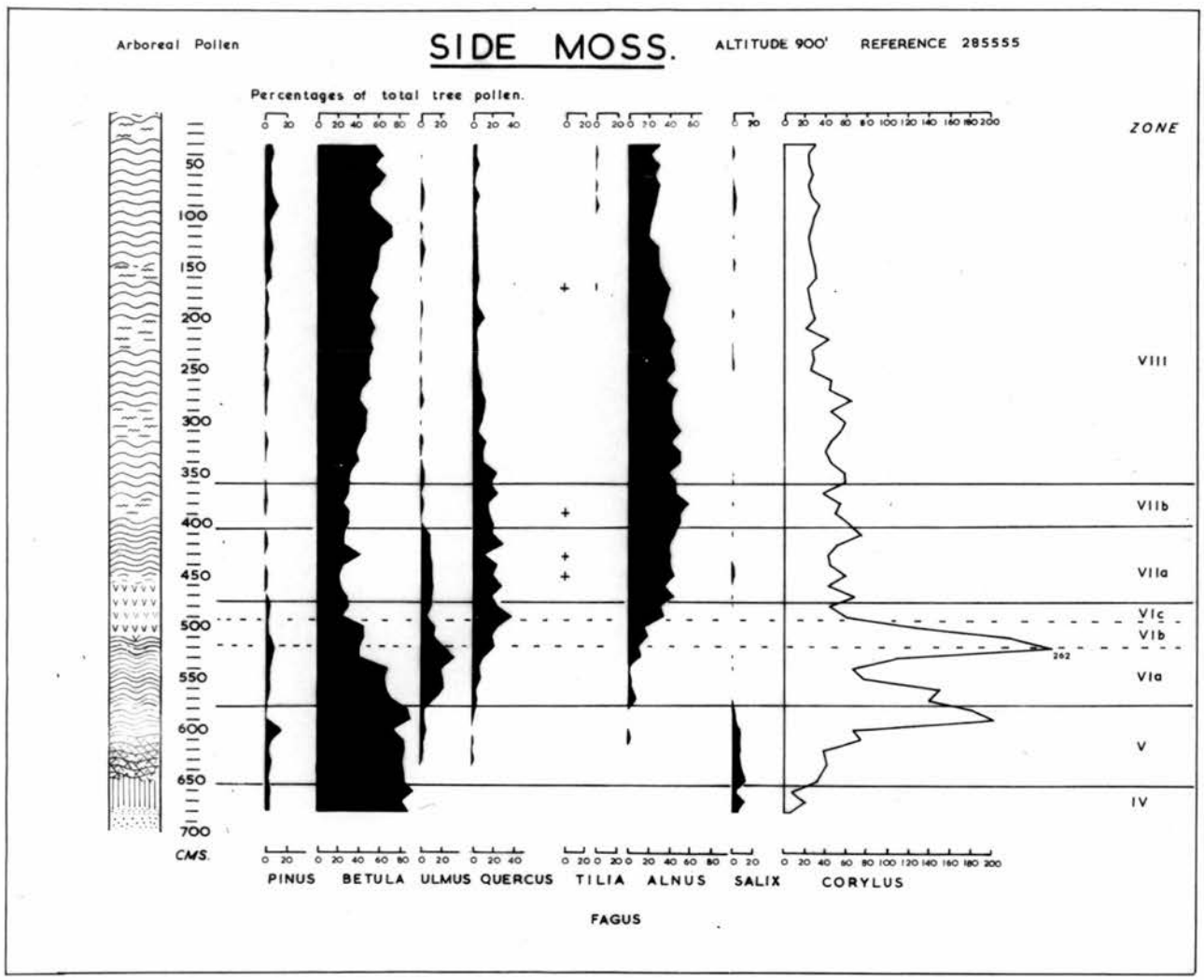


Fig.3. The whole Post-glacial sequence is represented. A strong Ulmus phase marks Sub-zone VIa; the Ulmus decline at 400 cms. is clearly shown.

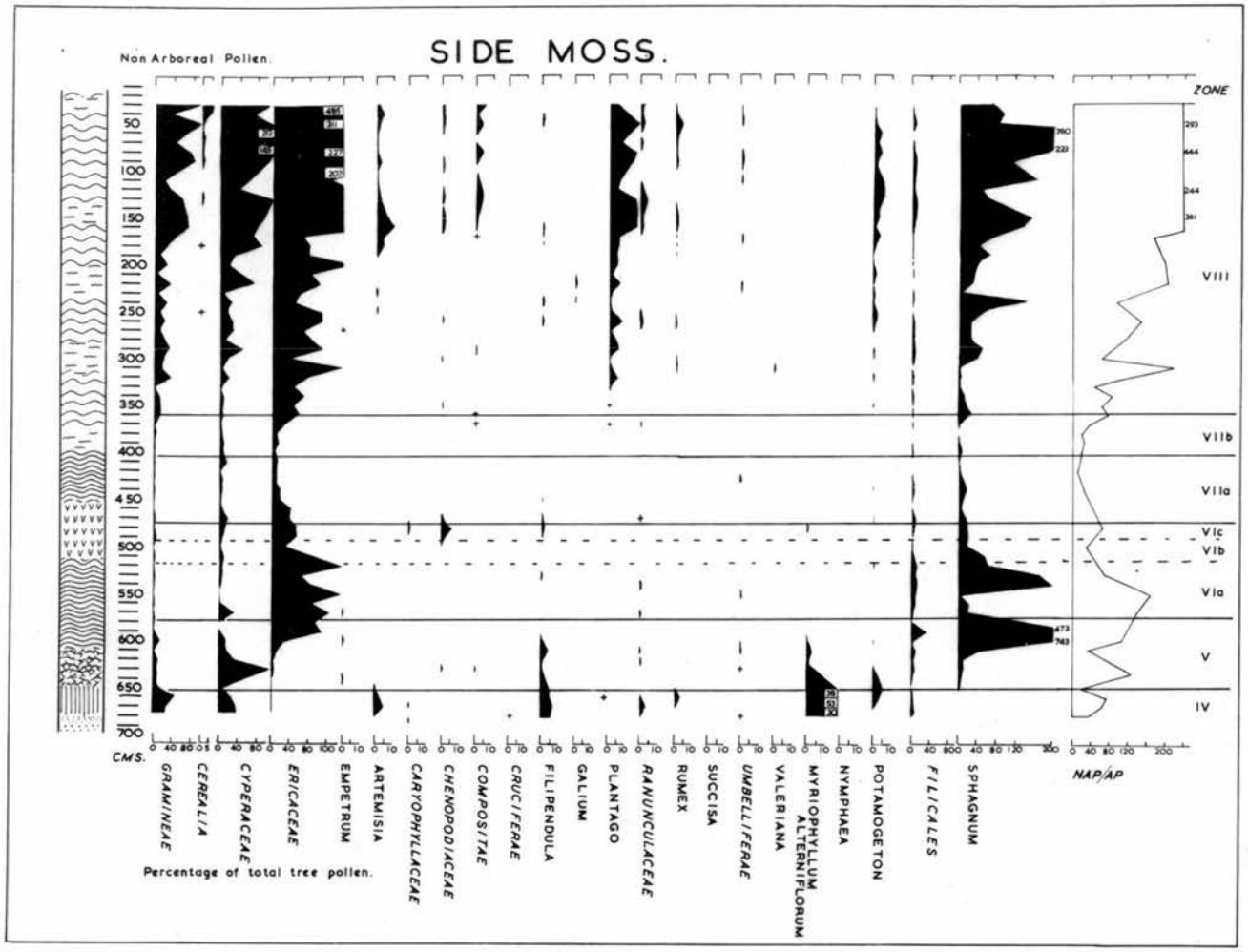


Fig.4. The Non-tree Pollen Diagram.

SIDE MOSS. Altitude 900 feet.

Plate 3. View of the moss looking westwards across the domed surface of the moss towards the Pentland Hills. Dissected Sphagnum/Eriophorum peat in the foreground.

GIFFORD. Ref. 554654.

The site is situated at Quarryford, 2 miles south-south-east of Gifford, East Lothian. The samples were taken from the margin of a lake which lies in a depression at an elevation of 650', a mile to the north of the escarpment of the Lammermuir Hills. A number of borings were made in the Carex-Juncus fen which forms the western margin of the lake; the intention was to make a complete traverse of these deposits with a succession of borings, but the presence of wood-peat some distance from the surface made penetration and extraction of the borer so difficult that samples were taken at a depth of 6.1 metres; this was the greatest depth attainable in the circumstances.

Stratigraphy

The bottom mineral matter consisted of red sands and gravels; resting upon the latter were highly humified lake muds, brown in colour and with abundant seeds of Menyanthes trifoliata. Above the lake muds came a thick horizon of greenish lacustrine peat of high humification (H.8) and with abundant fragments of Phragmites communis and Carex spp. A layer of birchwood lay upon the lake peats and above this wood horizon and extending to the surface were poorly humified peats consisting of birch stems and twigs mixed with Carex and Phragmites fragments.

Bore Record and Laboratory Identifications.

Cms. from Surface.

40 - 50 Betula fragments.

50 - 100 Phragmites communis and Carex peat.

100 - 110 Betula twigs and fragments.

110 - 130 Betula fragments.

Cms. from Surface.

130 - 150 *Phragmites* peat.

150 - 160 Fibrous peat with small *Betula* twigs. Humification low (H.4).

160 - 180 Black peat with *Betula* twigs and *Phragmites* stems.

180 - 200 *Carex* peat.

200 - 220 *Carex*-*Phragmites* peat with small *Betula* twigs. H.5.

220 - 250 Light brown fibrous peat, low humification (H.4). *Menyanthes trifoliata* seeds at 230 cms.

250 - 280 Black peat, poorly humified. *Phragmites*-*Carex* fragments.

300 - 330 Wood peat (*Betula*) with *Carex* fragments. (H.5).

330 - 350 *Carex* peat.

350 - 390 Light green peat highly humified (H.8) Seed of *Menyanthes trifoliata* at 370.

390 - 430 Light green-brown peat, highly humified. (H.8). Abundant seeds of *Menyanthes trifoliata*.

430 - 480 *Carex* peat. Wood fragment.

480 - 490 Black fibrous peat.

490 - 590 Fibrous peat, high humification.

590 - 600 Brown lake mud with seed of *Menyanthes*.

600 - 610 Coarse sand.

610 - 650 Red sands and gravels.

The Pollen Diagrams.

The base of the diagrams indicates a beginning of peat formation in early Zone VI, as *Corylus* and *Betula* are of high values and *Ulmus* is rising. The sub-zones of Zone VI are indicated, and the sharp rise in Alnus indicates the Boreal/Atlantic transition. The *Ulmus* decline has been placed at the first drop which is at 360 cms. The whole of the upper part of the diagram appears to be much influenced by local growths of birchwood, and the pollen curves are not comparable with those of the other sites in this region.

Zone VI. A clear sequence of Ulmus and Quercus values characterises this zone, which resembles in some respects that of sites in south-east England. In Sub-zone VIa from 610 cms. to 570 cms. the Ulmus frequencies rise to 17% and are accompanied by rising Quercus, though the latter has lower values. High values of Betula occur; Corylus rises to very high values in this sub-zone, reaching a maximum of 389% of the AP.

Sub-zone VIb. Quercus exceeds Ulmus at 560 cms. and this begins the next sub-zone. Quercus values rise steadily in Sub-zone VIb at the expense of Betula, and at the 500 cms. level Quercus exceeds all other pollen. Corylus values remain high, over 100% of the AP. The next sub-zone, VIc, shows reduced values of Corylus, and a rise in Alnus is indicated, Quercus remaining high; thus a very short vegetational phase is indicated, before the next Zone begins. The site appears to have been open water during the whole of the Boreal and the succeeding Atlantic periods; these zones are represented by limnic peats of high humification.

VIIa. The Boreal - Atlantic transition is placed at the sharp rise in Alnus at 430 cms; Betula and Quercus both fall considerably and Corylus diminishes to very low values. Pinus disappears altogether from the diagrams during VIIa.

VIIb. The Ulmus decline is placed at 370 cms. Above this level Betula pollen rises sharply due to over-representation by local birch-wood which begins to appear in the stratigraphy at 330 cms. The over-representation of Betula depresses the curves of Alnus and Quercus. Zone VIII is not indicated satisfactorily; there is no general rise of the NAP ratio and a rise in ericaceous pollen is also absent. The aquatic environment, however, may account

for the lack of a high ericaceous element in the pollen count. There is some indication of cultivation by pollen of Plantago in the upper part of the diagram which could be interpreted as evidence of Zone VIII or at least, post Neolithic activity.

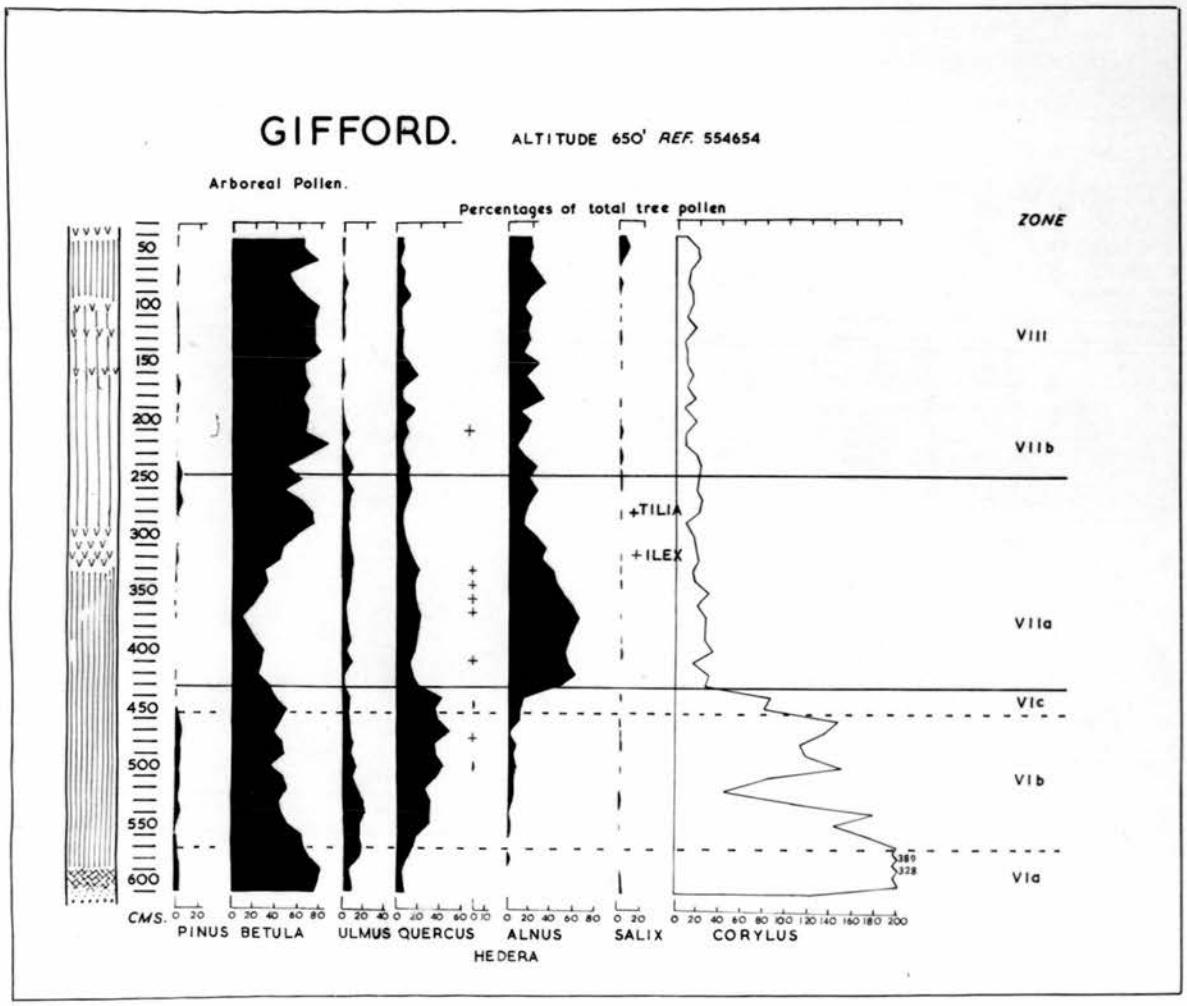


Fig 5. The Arboreal Pollen Diagram.

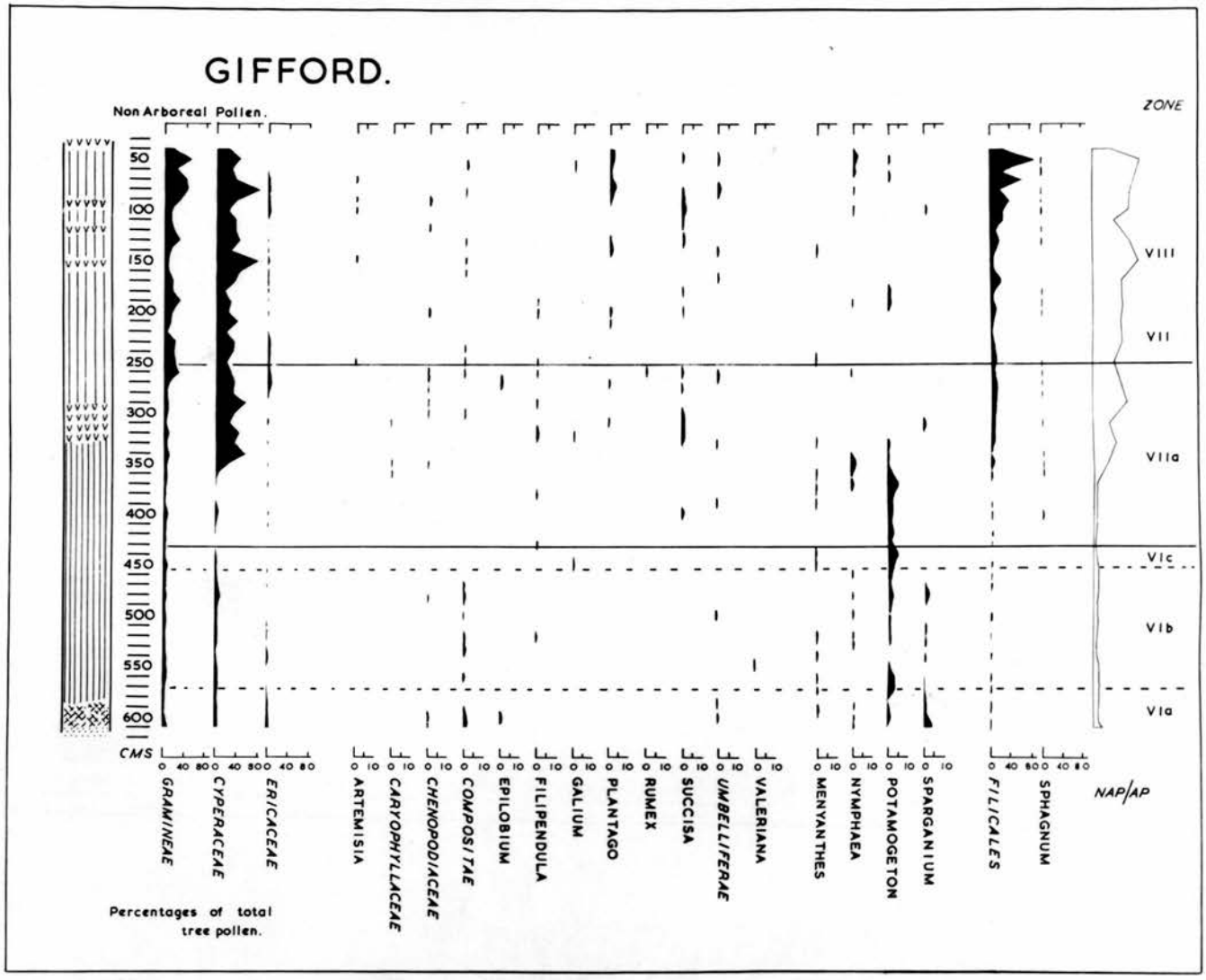


Fig. 6. The Non-Arboreal Pollen Diagram.

KITCHEN MOSS.

Kitchen Moss is an expanse of blanket bog situated on the western side of the Pentland Hills at an altitude of 1,350 ft. The site is a very gently sloping upland which forms the upper valley of the Logan Burn. The blanket-moss formation depends upon high rainfall and very high atmospheric humidity (Tansley, 1939). On the western side of the Pentland Hills the annual average precipitation is 40 - 45"; this is the lower limit for the formation of oligotrophic bog of this type. The peat is shallow; at its deepest where it is exposed along the erosion channels near to the Logan Burn it is about 2 metres in depth. The surface vegetation consists of an association of Calluna vulgaris, Juncus squarrosus, Eriophorum vaginatum and Sphagnum spp.

Stratigraphy.

The peat rests upon a sandy, stony substratum of glacial origin. The basal 10-20 cms. is a black, highly-humified peat without recognisable plant remains. Above this basal layer comes a horizon of varying depth containing twigs, roots and branches of birch, largely Betula pubescens; these fragments vary in size, and as no large stumps appear, the layer is suggestive of a birch scrub forest. The woody horizon is succeeded by a much thicker layer of fibrous, poorly humified peat without tree remains. This upper peat has a banded or stratified appearance with layers of Eriophorum vaginatum and thin bands of Sphagnum, with fragments of Calluna stems. The upper layer is much thicker than those below it; it is usually over 1 metre in thickness.

Thus a three-fold stratigraphy is displayed at Kitchen Moss; a thin basal peat, a thicker wood horizon, and an upper layer of

blanket moss formation. The junction between the upper bog and the wood-peat is an obvious horizon and it represents the 'Grenzhorizont.'

Bore records and Laboratory Identifications.

Cms from surface.

10 - 30	Sphagnum peat, low humification.
30 - 80	Eriophorum vaginatum peat.
80 - 90	Eriophorum/Scirpus peat.
90 - 100	Sphagnum peat.
100 - 110	Eriophorum vaginatum peat.
120 - 140	Fragments of Betula pubescens.
140 - 155	Black highly humified peat.
160	Trace of wood.
180	Black highly humified buttery peat.
186	Stony, sandy till.

The Pollen Diagrams.

The base of the peat represents Zone VIIa, for high Alnus frequencies are shown in the arboreal-pollen diagram, and these are combined with low Pinus and falling Corylus counts. Ulmus is considerable, but Tilia is almost absent. The transition to Sub-zone VIIb is indicated by a sharp decline in Ulmus at 160 cms. The entire horizon of wood-peat thus corresponds to the Sub-boreal. At 120 cms. the stratigraphic change to oligotrophic peat indicates the beginning of Zone VIII, the Atlantic, and a rise in non-arboreal frequencies with rising Betula tend to confirm this boundary. Thus the three upper zones of the English scheme are present here in the Pentland Hills; they correspond closely to stratigraphical changes in the peat. The non-arboreal pollen diagrams show in

general, high counts of Ericaceae, Cyperaceae and Sphagnum in Sub-zone VIIa and Zone VIII but these frequencies are reduced in Sub-zone VIIb. This pollen was apparently produced by plants growing in the vicinity of the site.

Characteristics of the Vegetation.

Sub-zone VIIa. As at Eddleston, this sub-zone, the Atlantic, indicates an abundance of Betula and Alnus; the latter does not, however, reach the frequencies it attains at Eddleston, the altitude of the site appearing to favour Betula. A lack of recognisable macro-remains, due to the high humification of the peat made it difficult to state the vegetation at this site in the Atlantic. High frequencies are, however, shown in the NAP diagram of pollen of Calluna and Cyperaceae and it seems likely that blanket bog existed at the site at this time. This type of pollen, with the Sphagnum spores which also occur indicates acid soil conditions; probably such conditions were the result of leaching on the highest hill slopes - a result of the heavy precipitation of this period.

Sub-zone VIIb. The recession of Ulmus at 160 cms. is a clearly marked feature. Below this level, Ulmus percentages average 10, but above it they fall to 4. The Sub-boreal here shows a great abundance of tree-pollen dominated as in the previous period by Betula and Alnus, though birch-pollen is very high due to local over-representation. Quercus slightly increases in this zone, though Corylus shows a slight fall. As the NAP frequencies fall in this sub-zone it appears that Sub-zone VIIb is represented in the Pentlands by forest; probably birch-scrub grew at this

elevation with possibly Alnus and Quercus in the lower land to the west, or in valley bottoms in the Pentlands.

Zone VIII. The succeeding zone, Zone VIII, shows changes in both peat stratigraphy and pollen composition. A great extension of oligotrophic bog took place, recorded in the peat stratigraphy and also in the abrupt rise in the NAP curves; the NAP is composed of pollen of Ericaceae, Cyperacea and Gramineae as in Sub-zone VIIa, with the addition of weeds of cultivation or pastoralism, such as Plantago, Artemisia and Rumex. Betula shows a steady increase during Zone VIII, but Ulmus and Quercus decline, and Corylus also falls at the end after showing high but fluctuating values in the middle part of the Zone.

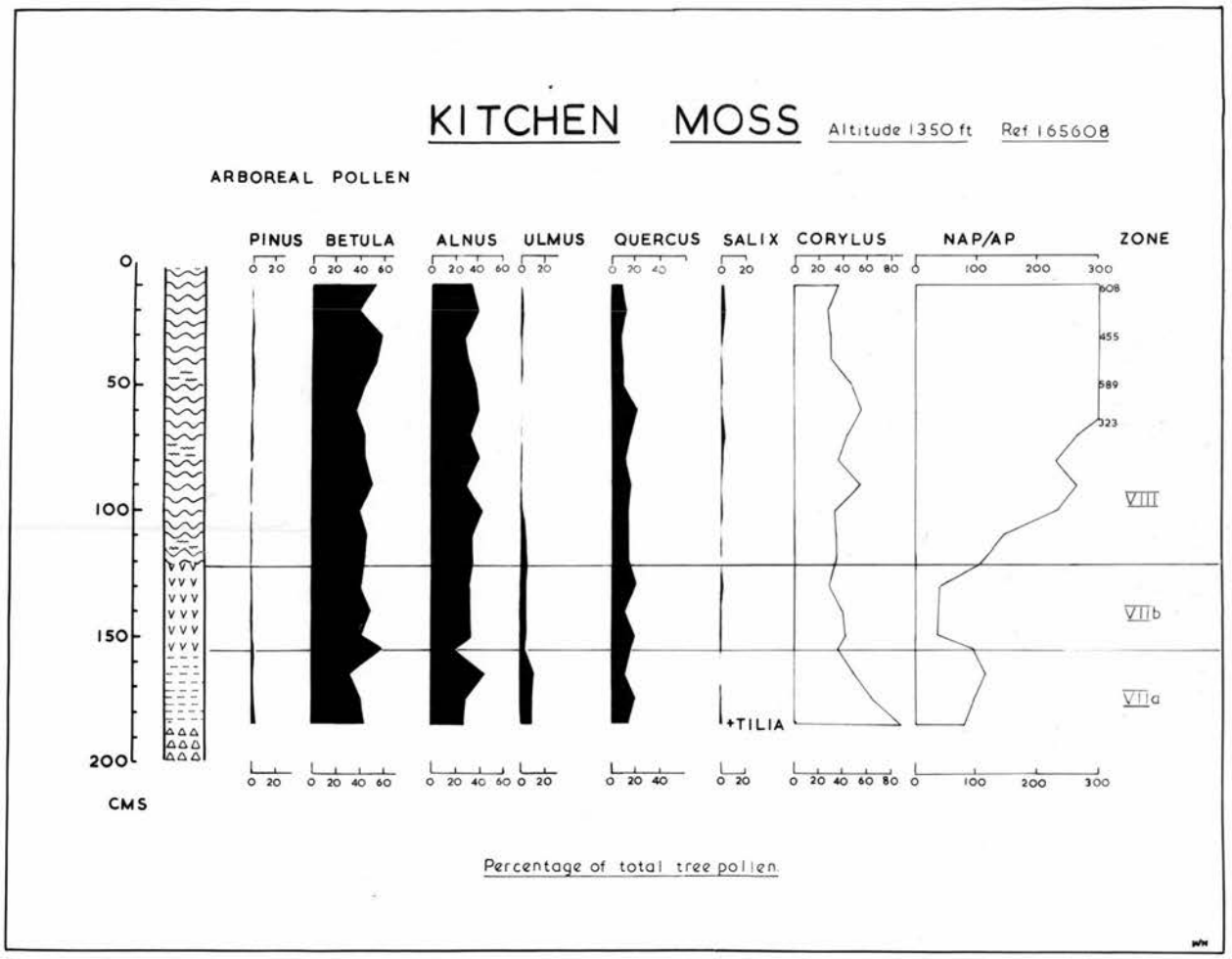


Fig.7 The Arboreal Pollen Diagram shows that the formation of peat in this part of the Pentland Hills began in the Atlantic period, Zone VIIa.
A pronounced Ulmus decline occurs at the VIIa-VIIb boundary.

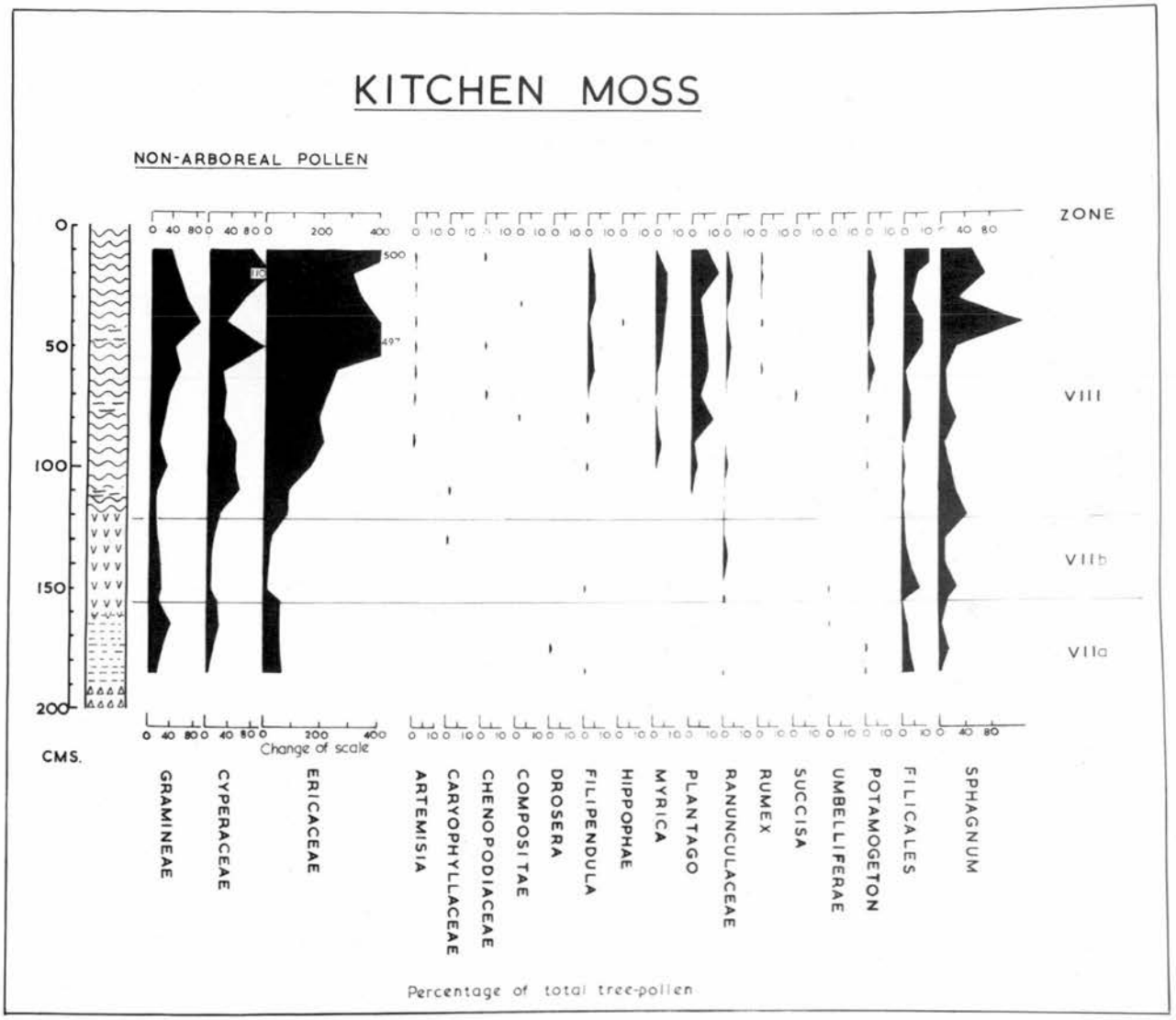


Fig. 8 Non-Arboreal Pollen. Ericaceae, Cyperaceae and Gramineae show high frequencies in Zone VIII.

KITCHEN MOSS. Altitude 1350 feet.

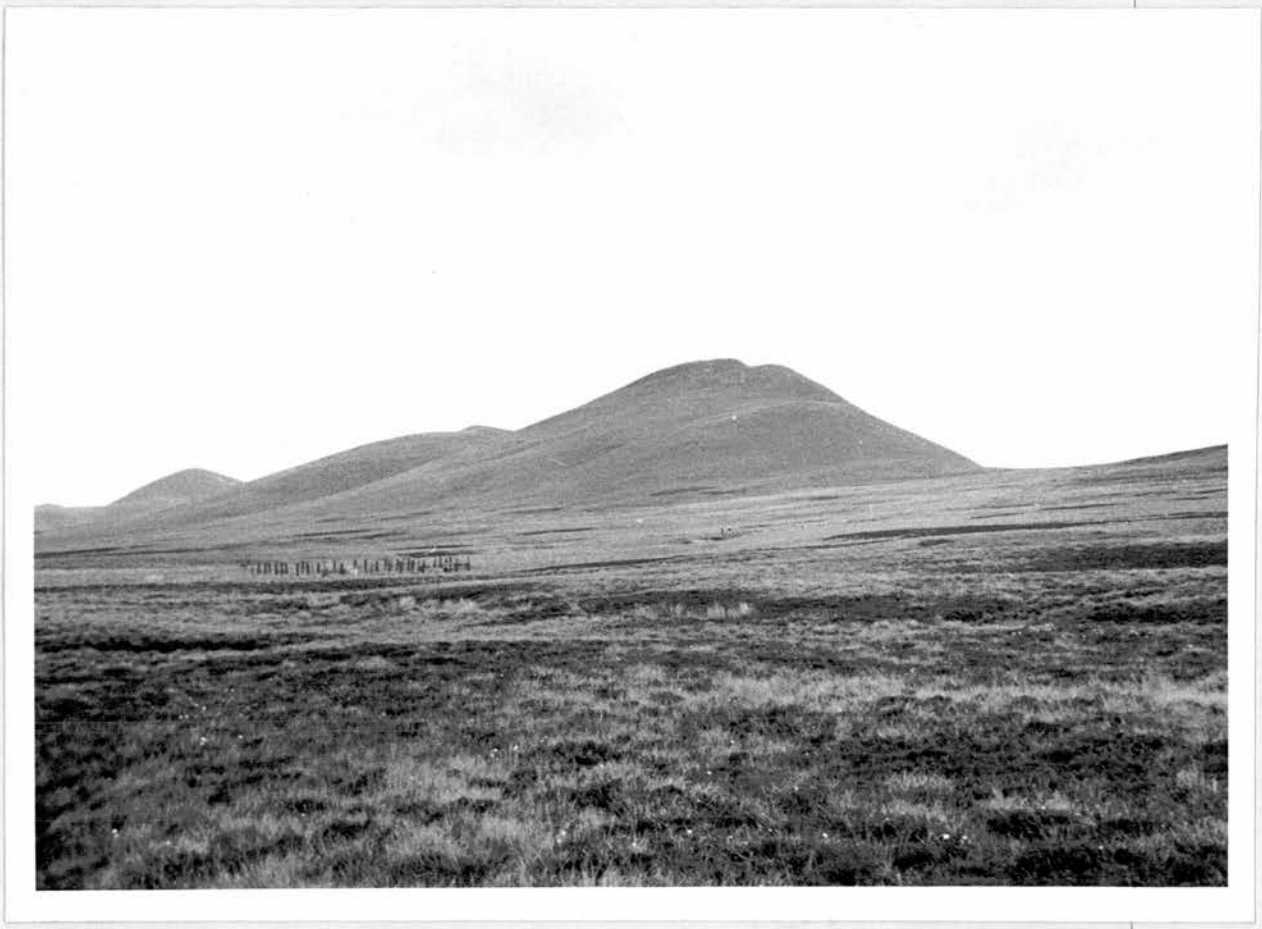


Plate 4. View from site looking westwards. Eroded Blanket Bog in foreground.

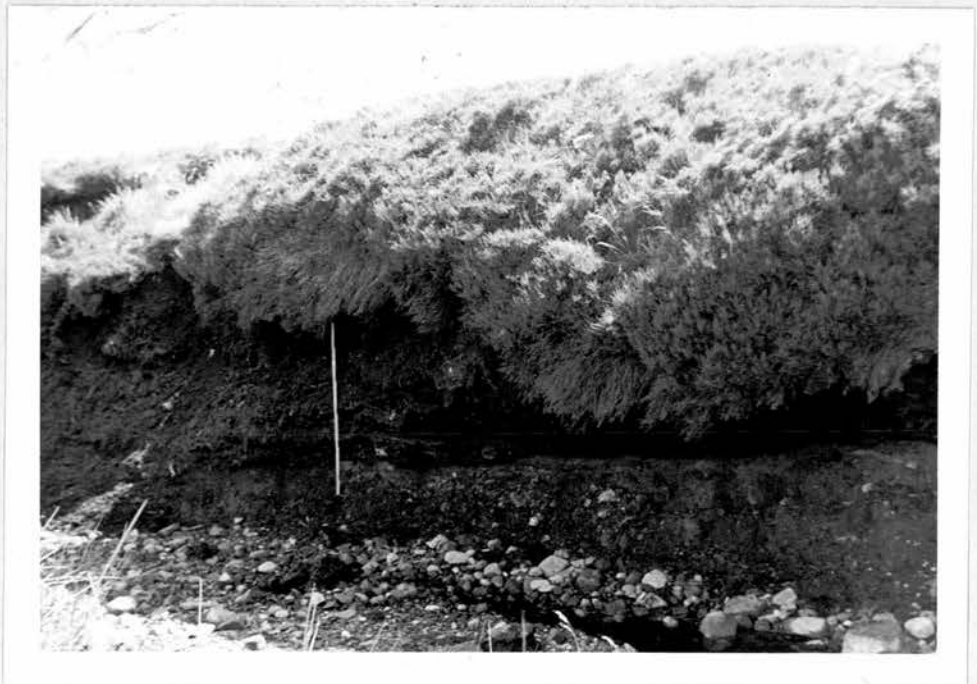


Plate 5. Sub-Atlantic Sphagnum/Eriophorum/Calluna peat overlying Betula fragments. Exposure in stream bed. Rule is 1 m.long.

LOCHHOUSES. Ref. 613821

This site was situated upon cultivated land in the valley of a small stream, the Peffer Burn, about 500 yards south-west of the outlet of the latter, and at an elevation of 18' O.D. The coastal tract of East Lothian in the neighbourhood of the site consists of low ridges of drift separated by small basins or depressions; a peat was sampled situated at the bottom of a depression linked by a shallow valley to the present course of the stream. The peat could be sampled only at this one place; no other borings could be made. Between the site and the present shoreline, a low ridge of shingle extends s.s. east - n.n. west; east of this are the coastal dunes forming Lochhouses Links.

Bore Records and Laboratory Identifications.

Cms. from Surface.

0 - 30 Soil horizon.

30 - 60 Dark-brown peat.

60 - 110 Dark green highly humified peat (H.7-8) with fine silty and sandy horizons. 2 fruits of Ruppia sp. at 90 cms.

110 - 130 Dark-brown highly humified peat-mud

120 cms.. 1 statoblast of Plumatella

130 cms.. 1 Fruit of Ruppia sp.
5 Leaves of Sphagnum sp.
Birchwood fragments.

130 - 150 Fairly well humified peat, (H.6). Sphagnum leaves and seed of Menyanthes trifoliata.

150 - 160 Silty peat with Sphagnum leaves.

160 - 170 Peat with leaf fragments (Salix?)
Birchwood fragments
Sphagnum leaves.
1 Achene of Ranunculus sceleratus.

170 - 180 Phragmites peat.

Cms. from Surface.

180 - 190 Phragmites peat with coarse sandy fraction.

190 - 240 Phragmites peat, silty; seed of Menyanthes trifoliata.
210 cms. - 1 fruitstone of Potamogeton.

240 - 250 Grey silty clay.

250 - 260 Fine brown clay with Birchwood fragments.

260 - 280 Carex and Birchwood fragments in a silty peatwith small pebbles.

3 fruits of Betula sp.
1 seed of Solanum dulcamara.
1 Cone scale and bud scale of Betula sp.

280 - 290 Peat with Carex and Birchwood fragments.

290 - 320 Grey silt.

320 - 350 Grey silty sand.

The Pollen diagrams.

The pollen frequencies appear to have been greatly influenced by the local vegetation which has produced marked fluctuations in Quercus, Alnus and Corylus. The general run of the curves does, however, permit correlation to be made with the other diagrams of the region and with pollen and radiocarbon determinations made elsewhere in central Scotland.

The samples at 230 and 240 cms. contained diatoms in which a marine and brackish-water element was present suggesting marine infringement at the time of deposition of the peat. The fruits of Ruppia sp. and also intermittent counts of pollen of Chenopodiaceae seem to confirm that the formation of the peat was in brackish-water conditions. It thus appears that when the post-glacial rise in sea-level took place, salt-water flooded the coastal basins producing small lagoons in which peat accumulated;

later conditions were such as to limit sea access so that brackish-water or fresh-water conditions prevailed in the basins. It is possible that sea access became limited or intermittent through the formation of a shingle barrier across the mouth of the Peffer Burn, of which the shingle ridge is a remnant. The growth of such shingle ridges may be accompanied by cycles of opening and closing, as Guilcher (1958) has described, thus giving rise to an alternation or interplay of brackish and fresh-water conditions within the lagoons.

It is considered therefore that the peat at Lochhouses was deposited during the post-glacial rise in sea-level, and that the pollen frequencies permit both an interpretation of the chronology of the rise and also of the vegetational conditions at this site during the time the rise took place.

As the lower part of the diagram shows dominance by Quercus and the upper part by Alnus it appears that the peat was formed over a period extending from some time before until some time subsequent to the Boreal/Atlantic transition, unless these changes in pollen frequency have been produced by purely local phenomena such as local growths of alder or oak. The lower part of the diagram, however, also indicates high frequencies of Corylus; Betula values are high at the base of the diagram and fall at higher levels; Ulmus values remain steady. These are all features of the later Boreal in this region and considering the dominance by Quercus the dating appears to be VIb and VIc, as shown. Corresponding features are to be found in the Gifford diagram at these levels, although the Betula frequencies are higher in that site as might be expected from its nearness to the hills. The

fall in Corylus at 180 cms and the rise in Alnus is thus indicative of Sub-zone VIc of the Boreal, and lower in the diagram the high values of Quercus date this period as Sub-zone VIb. At the Boreal/Atlantic transition at about 160 cms., Alnus rises above the frequencies of Quercus, and this trend continues in the part of Sub-zone VIIa that is registered in this peat. Confirming this Boreal/Atlantic dating of the deposit is the pollen of Hedera and Ilex shown by Iversen (1944) to be particularly abundant at this time. In the Atlantic period, Alnus values are high, above 60%, and Quercus values are depressed. Corylus falls to low values in the Atlantic, a feature shown in the diagrams of Gifford and Side Moss at this period, as is also the low counts of Pinus.

In the NAP diagram, the highest frequencies are of grasses and sedges which rise and fall together; there is some correspondence between these values and the occurrence of pollen of Chenopodiaceae, which may indicate periods of flooding by sea-water.

The dating of this peat, namely VIb - VIIa, is conformable with other datings of deposits associated with the Post-glacial transgression of the sea. Thus the Carse Clays of the upper Forth basin which represent the estuarine deposits of the raised beach transgression have been shown by Radiocarbon datings to have accumulated between ca. 8,400 B.P. and 5,500 B.P. (Godwin and Willis, 1961, 1962); these dates are equivalent to pollen zones VIa-VIIa. Previous investigations by pollen analysis of the peat under the Carse Clay showed that it formed during the Boreal period and that the Carse Clay itself was deposited during zone VIIa, the Atlantic period. (Erdtman, 1929). Another pollen dating of the marine transgression is that of a site on the west coast, at Soay, near

Skye, investigated by Blackburn (1940). It was shown that a marine mud, representing the maximum extent of the transgression, belonged to the early Atlantic, zone VIIa. Jessen (1949) suggested that in Ireland, the greatest part of the transgression was during Boreal time with only the later stages of it in the Atlantic, a maximum being reached about the time of the Atlantic/Sub-boreal transition. From deposits on the Lancashire coast, Oldfield (1960) has dated the period of maximum incursion as zone VIIa.

According to the results shown by the Lochhouses diagram, it appears that the sea, which had begun to rise in the upper Forth in early Zone VI, flooded low-lying parts of the coast of this region; peat-forming conditions were initiated at the site in Sub-zone VIb and these continued into zone VIIa, the Atlantic period.

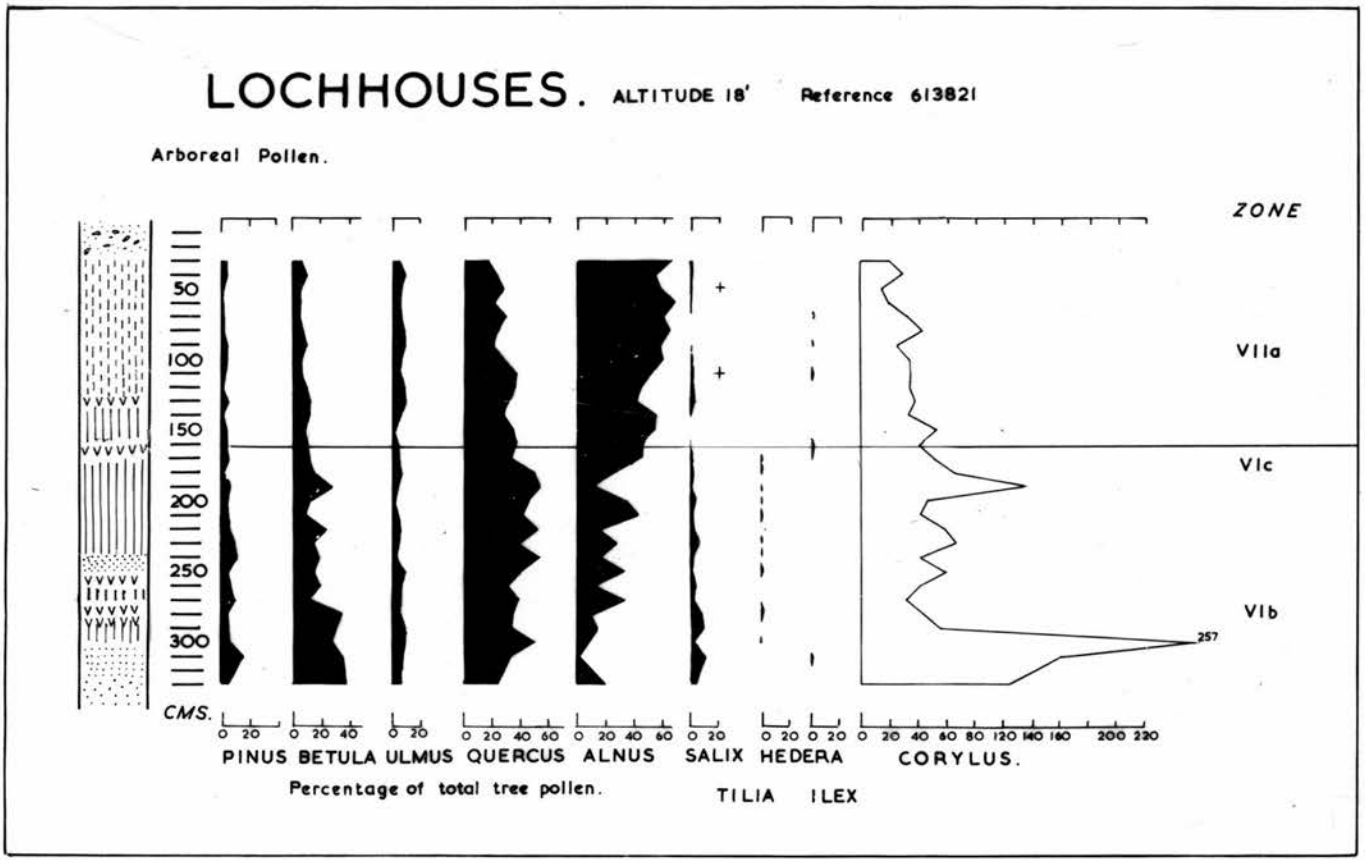


Fig. 9. The Arboreal Pollen Diagram shows the high Quercus frequencies typical of Sub-zones VIb, VIc, and the high Alnus frequencies of Zone VII. No VIb - VIc boundary is shown but this may lie at about 190 cms.

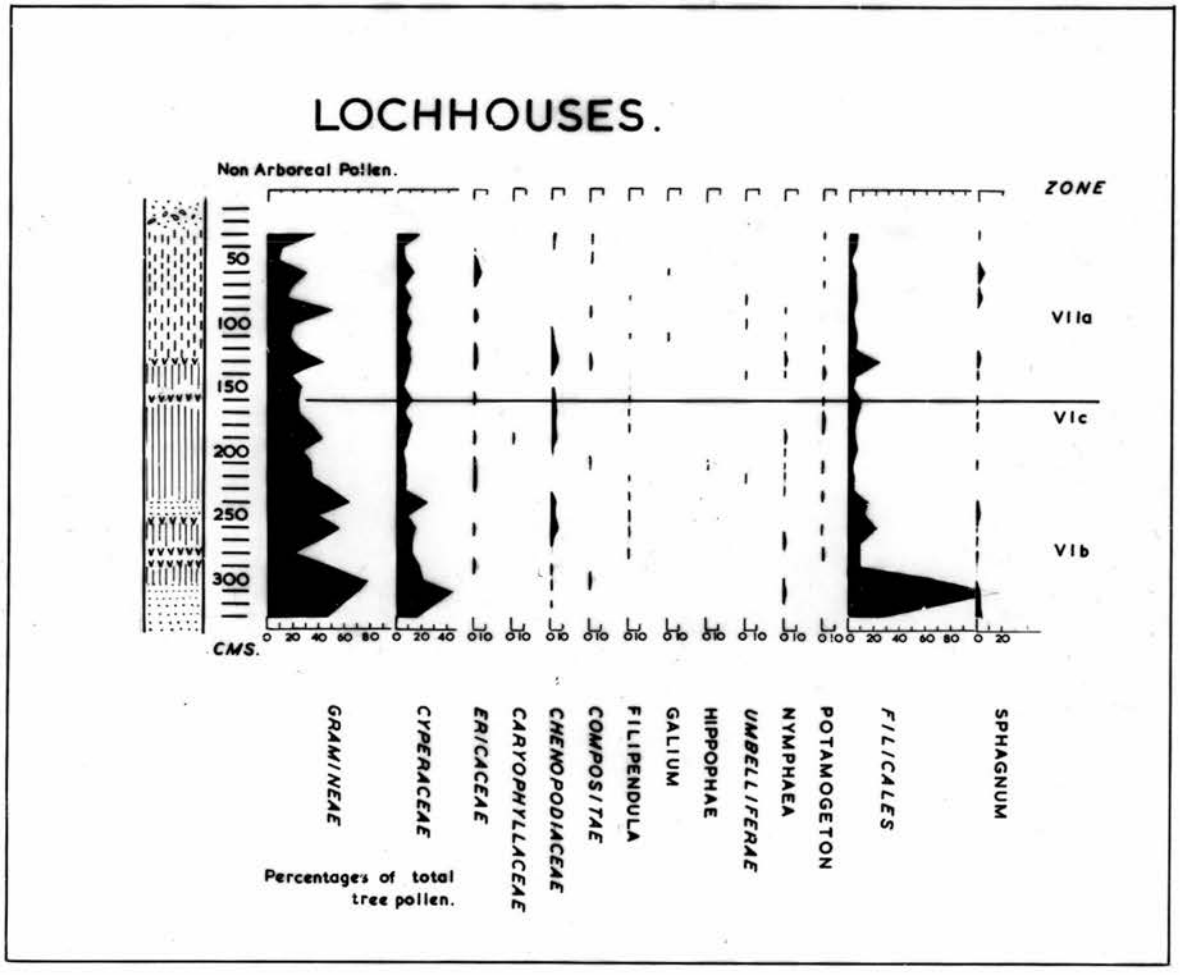


Fig.10. Non-Arboreal Pollen. Continuous marine influence is suggested by the pollen of Chenopodiaceae, in addition to macro-remains of brackish-water plants.

MAP 2. SITE AT LOCHHOUSES, near Dunbar. SCALE, 6" = 1 MILE.

CORSTORPHINE (Meadowhouse Road)

In 1962 an excavation was observed in Meadowhouse Road, Corstorphine. In a trench cut for the laying of a sewer, mud and clay deposits were exposed, and the opportunity was taken for obtaining samples from the trench for pollen-analysis. The samples were taken at the point where Meadowhouse Road joins the Saughton Road, about 350 yards south-south-west of Corstorphine Railway Station, the road surface there being 142 feet above sea-level and quite level. This spot lies near the centre of the old lake, as mapped by Cadell (1913). Northwards from the site, the land slopes gently upwards to the level of the main Glasgow Road, (167') and then a very steep rise occurs which forms the southward slope of Corstorphine Hill.

A thorough inspection of the stratigraphy was not possible, as the trench was being filled in quickly in order to minimise traffic delays along the Saughton Road. A range of samples was, however, secured from the exposed face of the trench, extending from below the upper layer of road material to the bottom of the trench which was approximately 2.1 metres in depth. It was found possible to extend the sampling downwards to 2.8 m. by using the Hiller borer, but the resistant character of the deposits below the trench level prevented a deeper penetration in the time available.

Stratigraphy and Laboratory Identifications

Cms. from surface.

0	- 90	Road material.
100	- 130	Grey silty clay.
130	- 135	Brown clay-silt.
135	- 140	Grey clay-silt.

Cms. from surface.

142 - 150 Yellow sand.

150 - 160 Yellow clay.

160 - 190 Grey-brown silty clay with abundant fibrous plant fragments.

190 - 200 Sandy clay with small stones. Fragments of mosses, grasses and sedges. Fruits of Potamogeton.

200 - 260 Calcareous silts silty clays and sandy silts with grass and sedge fragments.

260 - 280 Stiff red clay with small stones.
The base of the clay was not reached.

The Pollen diagram.

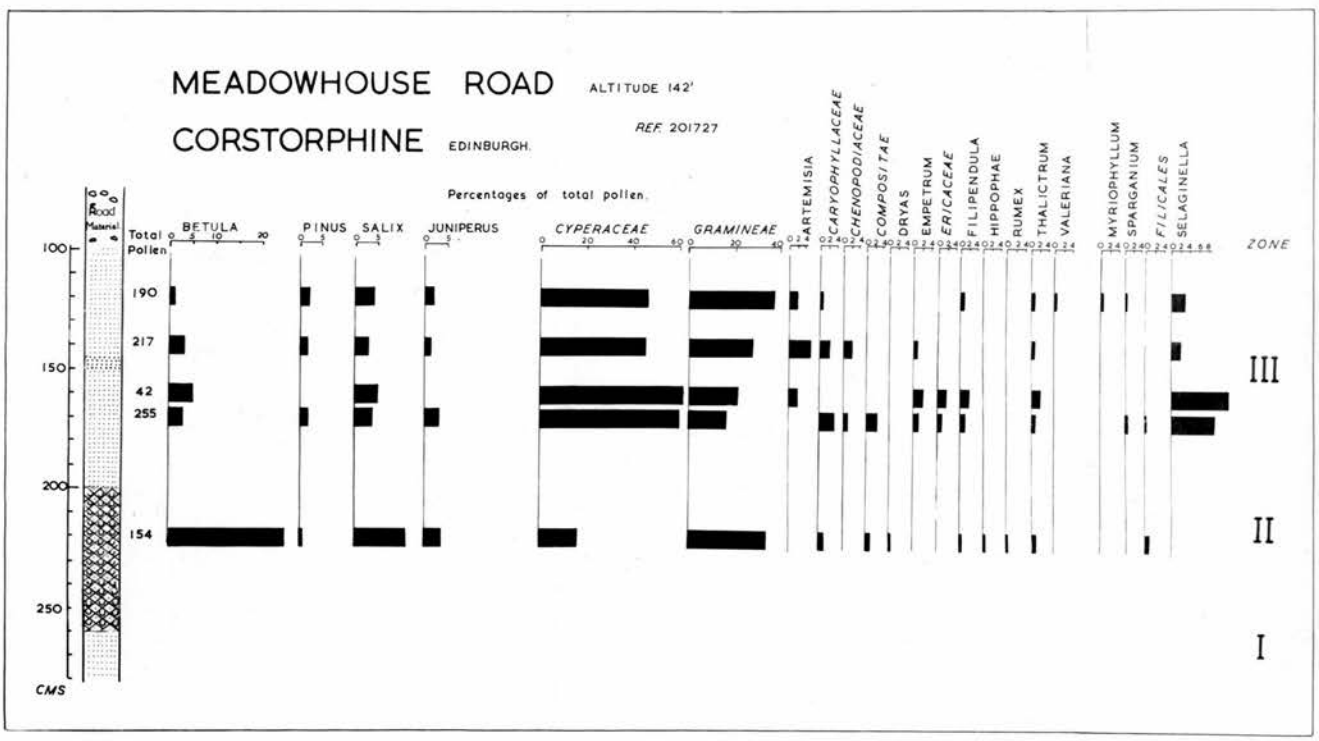
The samples were very poor in pollen. Only certain samples contained enough pollen for a reasonably satisfactory count to be made, but in no case was the number of arboreal pollen counted 150, hence the results are statistically invalid, although the required number could have been reached if a very large number of slides had been examined.

These deposits with their pollen and spore contents resemble those described at Late-glacial sites in the British Isles; enough pollen was identified and counted to indicate that Late-glacial conditions were represented at this site. The stratigraphical differentiation is three-fold and it may reflect the three-fold sequence of climatic variation of the Late-glacial period which consists of the warmer period of Zone II followed by a return of cold, Zone III, and preceded by the colder conditions of Zone I.

The lowest deposit here is a red clay, possibly a Late-glacial solifluxion deposit associated with the cold conditions of Zone I.

Above it, by contrast, beginning at 200 cms. is the horizon of calcareous muds with abundant plant fragments which may represent material deposited in the lake during warmer conditions. Finally, the uppermost horizons beginning at 190 cms. are silts and clays and silty clays which again may have been formed by solifluxion during a period of increasing cold. There was no indication of deposits above these, representative of younger and possibly Post-glacial deposits.

The pollen characteristics appear to correspond to these stratigraphic phases. The top layers of clays and silts show a high proportion of pollen of sedges, grasses and other herbaceous plants and a very low proportion of tree-pollen. Most of the arboreal pollen isthat of Salix. The herbaceous pollen includes that of Artemisia, the Chenopodiaceae, Compositae, and these may represent plants characteristic of open soil conditions. The sub-Arctic character of the landscape at the time is suggested by spores of Selaginella and by pollen of Thalictrum. Below this horizon, at 220 cms. a different vegetational picture is indicated. Although tree pollen is still scarce the frequency is greater and rises from 10 or 11% to about 30%, Betula pollen now showing the highest values, and the Gramineae and Cyperaceae falling back. These may therefore reflect somewhat warmer conditions, and may represent the Allerod warmer phase, Zone II. The lowest deposits contain only a little pollen of Cyperaceae which again suggests a different climatic and vegetational picture, that of colder conditions and a very sparse vegetation.



A Late-Glacial Deposit.

Fig.11. Only one sample from Zone II yielded pollen, but the increased arboreal frequency and the decreased frequencies of Cyperaceae, Gramineae, Ericaceae, Selaginella and plants of open habitat suggest the warmer conditions of the Allerod.

GOGAR.

Gogar is situated on the outskirts of Edinburgh, immediately to the west of Corstorphine. According to the map by Cadell (1913) the former Corstorphine Loch extended westwards as far as Gogar and this part of the loch was called by him Gogar Loch. The site of the loch, now part of Redheughs farm, is cultivated or partly built over. Housing development in the district necessitated the laying of a sewer and when a trench was excavated for this purpose across the site, a thin layer of peat was exposed, resting upon grey sandy deposits. (Plate 6.). Samples were taken from the face of the trench; difficulty was experienced at lowest levels owing to the presence of water flooding the excavation. It was found difficult to reach lower levels than the trench bottom with the Hiller sampler owing to the coarse sand which lay under the peat.

Stratigraphy.

Cms. from surface.

0	- 50	Distrubed upper soil horizon.
50	- 80	Dark brown clay.
80	- 90	Layer of *Betula* peat.
90	- 120	*Phragmites*/*Carex* peat with *Menyanthes* fragments.
120	- 130	Light-brown peat with *Phragmites* and *Carex* fragments.
135	- 165	Dark brown well-humified peat.
165	- 185	Grey-green lake muds with seeds of *Menyanthes*.
185	- 195	Dark peat with sand particles and seeds of *Menyanthes*.
195	- 230	Grey sand.

The Pollen Diagram.

It was hoped that Late-glacial material might be yielded at

this site. The lowest horizons to give a satisfactory pollen count however represent Zone IV. It is clear that a lake existed at the site during the Pre-boreal, for the pollen of aquatic and marsh plants is very abundant and macro-remains included fragments of Phragmites and seeds of Menyanthes trifoliata. Included in the pollen is that of Myriophyllum alterniflorum which commonly characterises deposits of Zone IV. Pollen of herbs indicating open conditions, such as Artemisia, is also present, although the variety and abundance of this type of vegetation which apparently existed at Eddleston does not appear to have been present at Gogar. Betula dominates the arboreal pollen but there are considerable frequencies of Salix which increases at the upper part of the zone. Corylus pollen also appears in Zone IV; Pinus is present but frequencies are low.

In Zone V, Betula remains high although its frequencies are depressed by high counts of Salix, the latter evidently due to local growths of Salix near the lake margins. As at other sites, the frequencies of Corylus rise sharply in Zone V. A decrease in the pollen of aquatic plants during the zone indicates the probable filling-in of the loch by peat which contained seeds of Menyanthes trifoliata in great numbers and this stage was succeeded by the growth of birch-wood over the lake-peat.

A sharp discontinuity in the diagrams is shown at 80 cms. Above this level the samples yield pollen of an entirely different character from those at lower levels: Betula pollen frequencies show an abrupt fall; Alnus pollen frequencies, however, increase suddenly and attain very high counts; Salix falls to very small frequencies; there are small and variable amounts of Quercus and almost no Ulmus. This pollen came from a deposit resting upon the birch-wood layer and consisting of brown clayey material, without

macro remains. Some aquatic pollen was yielded by this upper deposit, and included in the NAP was pollen of herbs such as Taraxacum.

There thus appears to be no connection between the deposits of the lower zones IV and V and the upper deposit which belongs to a very much more recent period. The high counts of Alnus in the upper deposit might indicate that deposition took place during zone VII, yet this interpretation is unacceptable as it is not confirmed by other arboreal pollen, the frequencies of Ulmus and Quercus being too low to indicate a zone VII dating when comparison is made with the pollen record of the other sites in the region. The upper deposit probably belongs to Zone VIII.

The historical records indicate that a lake existed at Gogar until comparatively recent times. Pont's map of 1610 shows a large loch at this site and this was still in existence in the 18th century as it appears upon maps by Adair (1735) and by Lawrie (1763) although another later map of 1773 shows the site to consist of marshland. By 1812, according to a later map, the marsh was drained. It is probable therefore that the upper deposit is of this recent lake; the high alder pollen frequencies are the result of local over-representation. One cereal pollen was observed, but pollen of ruderals was not as abundant as one would expect.

The pollen diagrams thus suggest that after the deposition of peat and lake muds during the Pre-boreal and early Boreal, deposition ceased at Gogar until recent times; at some time during Zone VIII, however, the site again became covered by water and a newer deposit was formed above the older peat.

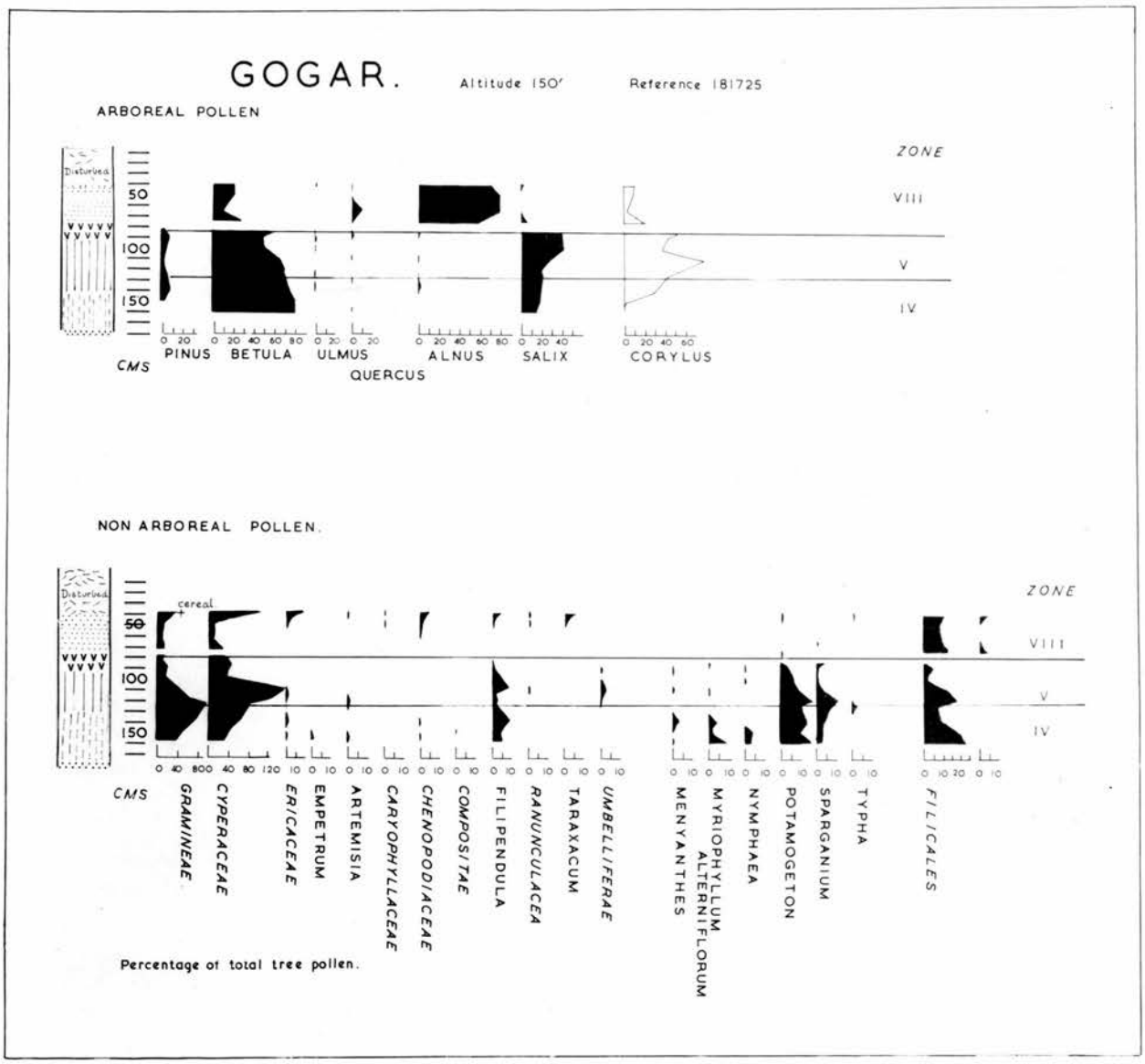


Fig. 12. Deposits of lakes of two separate periods appear to be represented.

GOGAR.

Plate 6.

The trench across the old lake flat. Corstorphine Loch extended westwards to the neighbourhood of Gogar, near this site. Altitude of site 150'
View looking north. (A Press Photograph)

PART V.

DISCUSSION OF THE RESULTS.

The Late-glacial.

The result of the investigations at Meadowhouse Rd. Corstorphine may be compared with those already obtained at Late-glacial sites in Scotland by Mitchell and Donner. A clear stratigraphical sequence was characteristic at all sites; thus at Whitrig Bog, Berwickshire (Mitchell, 1948) a lower brick clay resting upon till signified the deposit of Zone I; above it were the marls deposited in warmer conditions representing the Allerod warm sequence; succeeding the latter upwards were the clays assumed by Mitchell to have been brought down by solifluxion. At the Late-glacial sites investigated by Donner (1957) the stratigraphical changes were clearly marked; at four sites, namely, Garscadden Mains, Drymen, Loch Mahaick and Garral Hill an organic layer consisting of peat or silty muds was observed between two minerogenic layers. As the pollen content showed open vegetation conditions, it was assumed that these layers were the result of solifluxion during cold conditions. Above the Zone III deposits were lake muds representing Zone IV. The stratigraphy thus suggested a climatic sequence, with warmer Zone II deposits of the Allerod interstadial lying between the upper and lower solifluxion layers, representing Zones I and III.

The pollen diagrams at all sites appeared to substantiate this evidence. The pollen of the Zone II deposits suggested a warmer climate than that of Zones I or III. Thus at Whitrig Bog, the pollen diagrams (Godwin unpublished) indicate an increased frequency of arboreal pollen in Zone II, of which Betula contributes the greatest proportion; the other tree genera are Salix and Pinus; the shrub Juniperus shows fairly high values. Representation of trees and shrubs is however higher than at Garral Hill and the

difference in latitude probably explains this contrast; Donner suggested that during the Allerod, areas of park-tundra may have existed in south Scotland. At Garral Hill, however, the very high values of Cyperaceae and Gramineae and other herbaceous pollen compared with those of tree pollen indicate a completely treeless condition of the landscape. Donner has suggested that even in the Allerod period vegetation was completely open in northern Scotland, the evidence indicating that not even a park-tundra existed.

At Meadowhouse Rd. Corstorphine, there is some stratigraphical resemblance to the sites discussed; three horizons of contrasting character appear to be present which may reflect climatic change during the Late-glacial; and the pollen content, though poor, is unquestionably Late-glacial in character. The lower red clay is presumably a solifluxion deposit, small stones were observed in it, and it may be compared with the clay observed at Whitrig. Like the latter, its pollen content was very low and only sedge-pollen was observed. Above this horizon, the calcareous silts and sandy silts with their plant fragments provide sharp contrast. This layer contained fragments of grasses, sedges and mosses with recognisable fruit stones of Potamogeton. Warmer climatic conditions are suggested than those prevailing at the time of the formation of the red clay below these deposits. Above these again lay grey clays and silts and thin sandy layers forming an upper series. It is possible that the stratigraphical sequence here is representative of the Late-glacial climatic oscillation, the lower clay representing Zone I cold conditions, the calcareous silts the Allerod warmer phase, Zone II, and the upper clays the return to solifluxion conditions of Zone III, as at Whitrig Bog.

Some of the sections recorded by Tait (1934) during excavations

close to this site show certain similarities to the features described. The organic deposits as noted by him consisted of grey silts also, often with visible plant fragments; a thick deposit of sand lay above these, however. One of his sections in the neighbourhood of this site shows little resemblance to these stratigraphical features: thus his section No. 36, which according to his description was several hundred yards south of Meadowhouse Rd., consisted of layers of sand and stones covering a thick horizon of gravel, and below the latter, a thin bed of grey, sandy silt.

With regard to the pollen content of the deposits at Meadowhouse Road, the results are vitiated by very low tree-pollen counts, although the total count was greater than 200 at one or two levels of the upper clay; more pollen could, however, have been recorded after a much more prolonged examination of the slides. More pollen might have been expected from the calcareous silts and sandy silts than the upper clays, assuming that the latter were deposited at a time when the vegetation cover was more open; but the reverse was in fact the case.

The pollen strongly resembles that of other Late-glacial sites in Scotland; firstly in the representation of sub-Arctic or Arctic plants such as Dryas, Thalictrum, Selaginella, Empetrum, Betula nana, all of which were present; in addition, pollen of grasses and sedges shows very high frequencies - a feature of most of the other Late-glacial sites in Scotland and in northern England; in addition there is pollen of herbaceous plants such as Taraxacum, Artemisia and Rumex which indicate the prevalence of open conditions, bare soil surfaces and freedom from competition. Within the horizon of the upper layers of clay and silty clays, the frequencies of the

grasses and sedges is very high indeed; together they form more than three-quarters of the total pollen; by contrast, arboreal representation is very low and includes only Betula, Pinus and Salix, the latter frequencies being greatest. In the horizon of the calcareous silts, although only one sample yielded enough pollen to be counted, it shows that the frequency of tree-pollen increases, values of the grasses and sedges fall, and the highest frequency of tree-pollen is that of Betula. There is thus a strong suggestion that vegetational conditions in the time represented by the calcareous deposits were different, and that they reflect warmer conditions during which there was a retreat of herbaceous plants and an increased number of trees, particularly Betula. On the other hand, the pollen of the upper silty clays reflects more severe conditions of climate, for it consists of higher frequencies of herbaceous pollen, including pollen of plants of open conditions; thus the Artemisia values are higher in the upper clay horizon than in the calcareous layer. The pollen content recalls the determinations of macro-fragments carried out by Reid (1899) using the plant remains obtained by Bennie from Corstorphine; Reid's plant list includes Dryas octopetala, Betula nana, Taraxacum officinale, Empetrum nigrum, Potamogeton and others, the pollen of which may be represented at this site.

SUMMARY.

Late-glacial pollen occurred at one site. It is associated with a stratigraphic sequence which resembles that described at other Late-glacial sites in Scotland and which appears to reflect the climatic oscillation which is known to have occurred at the end of the glacial period. Pollen and stratigraphy suggest that the lowest deposits represent cold conditions, possibly Zone I, and that

the overlying deposits were laid down during warmer conditions of Zone II. An upper series of deposits is indicative of the colder conditions of Zone III. The pollen flora indicates that herbaceous plants, particularly grasses and sedges, were much more abundant than trees and shrubs.

Zone IV, the Pre-boreal.

The physical geography of Scotland underwent a rapid change between the ending of the peri-glacial conditions represented by Zone III and the development of the first forest cover in Zone V, the early Boreal. This period of transition is the Pre-boreal, Zone IV, the first Post-glacial pollen zone. Radio-Carbon dating has indicated that it began about 8,300 B.C., coinciding with the retreat of the Highland Readvance glaciers; its upward limit is the beginning of the rise in values of hazel pollen.

Zone IV is represented at three sites, namely Gogar, Eddleston and Side Moss. The stratigraphy consists of a thin layer of highly humified (H.7-8), very dark-brown limnic peat, with mineral matter which becomes coarser downwards towards the basement substratum; the most easily recognised macro-remains are seeds of Menyanthes trifoliata and fragments of Carex and Phragmites. As Jessen (1949) has shown, during Zone IV, the improvement in climate had resulted in a cessation of solifluxion and frost-weathering, so that the deposits of lakes consisted of organic muds containing fragments of the luxuriant swamp and aquatic vegetation.

Both Godwin (1956) and Jessen (1949) refer to this zone as the Post-glacial Birch Period. This is confirmed by the dominance by Betula pollen at each of the three sites investigated. Accompanying Betula is Salix and Pinus, although values of the latter are not large; Salix is particularly abundant at Gogar. Pinus begins at 17% at Eddleston at the base but falls rapidly at the top of the zone, Salix pollen showing a similar trend. Similar curves for these genera have been recorded at Drymen, near the south-western Highlands (Donner, 1957) and at Whitrig Bog, Berwickshire

(Godwin, unpublished). Betula, however, maintains or increases its very high frequencies often attaining 90% of the arboreal count.

Pollen of Alnus, Quercus and Ulmus is present but is very small in amount and cannot be shown as continuous curves. The most prominent shrub is Corylus, which is present at these sites, throughout the zone, although the frequencies fluctuate widely within it, increasing at the top, where the sudden sustained rise marks the division between Zone IV and Zone V. Corylus pollen was present at southern sites in Britain, notably in Norfolk (Godwin, 1934)and South Wales (Hyde, 1940). Matthews (1955) has observed that Corylus was already well-established in Zone IV, especially in the south and west of England; he has referred to this zone as the Hazel-Birch-Pine Zone. In Ireland, Corylus appears to have been absent at the beginning and middle of the zone, although Mitchell (1951) has shown small quantities in his diagram at Treanscrabbagh; the rise of hazel in Ireland, was, however, spectacular at the end of the zone. Durno (1958) has recorded up to 20% at sites in north-west Scotland.

A most pronounced feature of Zone IV at the three sites investigated here is the high ratio of non-arboreal pollen to arboreal pollen; this may be interpreted as indicative of a landscape in which the tree-cover was not continuous. The greater proportion of the non-arboreal pollen has come from the Cyperaceae and Gramineae; however, some of this would be contributed from the grass/sedge associations of the lake margins, the remains of which appear as macro-fragments. The grass/sedge component is very high, especially at the bottom; at Eddleston the close sampling interval revealed the following amounts:

TABLE 4.

Depth of Sample. metres.	Cyperaceae.	Gramineae.	(Percentages of total tree pollen)
2.95	14	36	
3.00	95	77	
3.05	61	57	
3.10	37	57	
3.14	149	111	
3.18	296	131	

This high grass/sedge proportion recalls the open vegetation conditions of the Late-glacial; its very rapid fall, as demonstrated by the Eddleston diagram, suggests a swift closing of the tree-cover as birches advanced. The non-arboreal pollen includes that of the Ericoids which is prominent at the base of the zone but the amount falls towards the top. Pollen of Empetrum is also present at Eddleston although this disappears in Zone V. Jessen (1949) considered that Empetrum, noted in this zone in Ireland, represented the last remnant of the Arctic heath of the Late-glacial; it is possible that in the Moorfoot Hills (represented by Eddleston) a Late-glacial Empetrum heath was in retreat, as shown in the Irish sites. In later zones at Side Moss and at Eddleston abundant Calluna appears in place of Empetrum.

The suggestion of the open character of the vegetation at the beginning of Zone IV is supported by the presence of pollen of Artemisia, Armeria, Hippophae, Filipendula; all of which appeared in Zone III, and in Zone II of the Late-glacial. Donner (1957) has commented upon the similarity of the vegetation in Zones II and IV in Scotland. The pollen assemblage at these sites suggests a most varied herbaceous flora in Zone IV, it includes Compositae, Umbelliferae, Filicales, Ranunculaceae. Most of this appeared

at the higher sites, namely Eddleston and Side Moss, where the altitude is over 800 feet; much less appeared at Gogar, a much lower site (150 feet); a difference in vegetational distribution is suggested; probably the open conditions tended to persist on the higher ground in the Moorfoot region. A feature of the aquatic pollen of Zone IV of both Gogar and Side Moss was the abundance of Myriophyllum alterniflorum; Godwin (1953) has pointed out that M.alterniflorum characterises deposits older than the Boreal period.

SUMMARY. In the Pre-boreal, Zone IV, lakes at Gogar, Side Moss and Eddleston were becoming filled with limnic peat deposits; solifluxion which had been widespread in the Late-glacial had been reduced by the stabilising effect of a continuous vegetation cover. Sedges and grasses were the principal herbs but these were accompanied by frequent Compositae, Caryophyllaceae. Herbaceous plants of open habitat conditions were conspicuous but a rapid decline is shown by the pollen curves of these genera towards the end of the zone. The dominant tree was Betula; Pinus and Salix were present but reduced frequencies of pollen are recorded at the end of the zone. The principal shrub was Corylus which advanced rapidly at the close of the zone. The NAP/Ap curves fall very sharply from the bottom of the zone to the top, illustrating the swiftness of the change from open to closed vegetation. Though a rapid advance of birch forest is recorded at each site, the Eddleston diagram suggests the persistence of more open conditions in the Moorfoots, as compared with the lower site at Gogar.

Zone IV thus represents a period of very rapid transition in the physical geography of the area, in which the Late-glacial open vegetation was disappearing, as the climate improved, before the advance of the forest trees.

Zones V & VI, the Boreal Period.

The Boreal consists of two zones, V and VI, of which VI covers a longer period of time. The period isrepresented at 5 sites, two of which show both zones completely, namely Eddleston and Side Moss; the Gifford diagrams show the whole of Zone VI, and the coastal site at Lochhouses may be referred to the later Boreal extending into the Atlantic. At Gogar, only part of Zone V may be shown.

These diagrams show that in this part of Scotland during the Boreal period, the Post-glacial changes in the woodland geography took a course which was different in some respects from those of more northerly areas of Scotland and which resembled in some respects those of south-eastern England.

In Zone V, Betula increased or maintained the position it had in the preceding zone, as is demonstrated by the diagrams of Side Moss and Eddleston; the average frequency in these sites was over 75% and a reduced frequency of the non-arboreal pollen shows that woodland had spread completely over the open landscape which was characteristic of Zone IV. Diagrams of sites in other parts of Scotland confirm the early Boreal dominance of Betula accompanied by Corylus, but in the southern parts of Britain Pinus became much more important in the early Boreal. In Zone VI, Betula shows, in these diagrams of the Lothians, a steady decline as it gives place to Ulmus and Quercus, though frequencies remain high. In some areas, notably the north-east of Scotland, Betula shared dominance with Pinus in Zone VI, or was even subordinate to it, but the high Betula frequencies are a constant feature of the forest vegetation.

Pinus, on the other hand shows, according to these diagrams,

viz., Eddleston and Side Moss, a position of much less importance in the Boreal than Betula, and this is one of the features which distinguishes this region from others in Scotland and in the British Isles in general. The Pinus dominance over Betula elsewhere began in Zone V and was particularly well-marked in south-east England where it continued into Zone VI; but it then weakened towards the end of the zone giving place to the mixed-oak forest component of Quercus, Ulmus and Tilia. This Pinus phase, such a pronounced feature of the Boreal in England, is very weak in south-east Scotland as represented in these sites, although a slight reflection of it is discernible in the diagrams. Farther north, however, Pinus becomes much more important again in the middle of Zone VI and later, as shown by the diagrams of sites in east Sutherland and Caithness and in Wester Ross (Durno, 1958, 1959). In Ireland, a different position is apparent, as Jessen (1949) has shown; thus in Sub-zone VIb of the Boreal Pinus attains 75% of the arboreal pollen and especially high values are reached in western sites. This preponderance spread to the east of Ireland late in the Boreal, and at the expense of Betula. Here, however, in the Lothians Pinus apparently was not frequent in the later Boreal, as the Eddleston and Side Moss diagrams show. Farther west in central Scotland, the Pinus curve is more substantial, as Eydt (1960) has shown in his diagram of a site in the Campsie Fells; and at Carnwath (Fraser and Godwin, 1955), the Pinus curve is much more pronounced than in the eastern Lothians.

One of the distinguishing features of the Boreal everywhere in the British Isles is the abundance of Corylus. In the diagrams of Eddleston, Side Moss, Gifford and Lochhouses it shows typical

representation; a rapidly rising curve at the bottom of Zone V marks the beginning of the Boreal and at the end of the period it falls almost as abruptly. Mitchell (1951) has pointed out that the fall of Corylus should be regarded as one of the important features in the determination of the Boreal-Atlantic transition. Within these borders, the diagrams of these three sites show that in the eastern Lothians Corylus reached high levels during the Boreal as revealed by the Gifford and Side Moss diagrams which in Sub-zone VIa show frequencies of over 200%. At both these sites the initial high maximum falls in the middle of Zone VI, rising to a second maximum in Sub-zone VIb. There are many minor fluctuations in the curves, and these are probably explained by the role played by Corylus in the Boreal forests. Erdtman (1929) has suggested that as the amelioration of climate began in early Boreal time, the hazel moved into the birch forests, probably forming a pioneer scrub ahead of the mixed oak trees, the hazel front advancing and retreating in response to small variations in climatic, soil or biotic conditions. North of south-east Scotland, however, the Corylus frequencies appear to diminish; thus much lower values occur at sites in the extreme north-east, in Sutherland and Caithness (Durno, 1958) and also along the Moray Firth (Knox, 1954). In the north-west, in the Hebrides, high values are again attained, as demonstrated in the diagrams for Barra (Harrison & Blackburn, 1946). In Ireland, the Corylus values in Zone VI were enormously high; during the violent expansion of hazel in Sub-zone VIa, the curve often reaches 500% or more of the arboreal pollen (Mitchell, 1942).

Godwin (1956) has suggested that the rapid spread of the hazel was the probable response to a climatic factor associated with the

existence of a land area over what today is the North Sea. It seems clear that warmer conditions favoured the spread of hazel; in the eastern Lothians, favourable climate combined with soils of a high base status would help to account for its vigorous expansion; Godwin has pointed out that calcareous soils are favourable for hazel expansion as well as mild winters and a fairly long vegetative season. Corylus falls sharply in these diagrams at the end of the Boreal, however, and this is one of the features which distinguishes Sub-zone VIc.

The Boreal period is characterised by the rise of Ulmus and Quercus with, in English sites, the entry of Tilia at the end of Zone VI. Ulmus, as demonstrated by the diagrams of Eddleston, Gifford and Side Moss, began its rise in Zone V, rising rapidly in the lower part of Zone VI. The highest counts of Ulmus pollen were realised in the Side Moss diagram where the maximum attained 33% of the tree-pollen; it is possible that favourable soils in the neighbourhood of the site stimulated the strong development of Ulmus there; Godwin (1956) has commented upon the similar response of both Ulmus and Corylus to base-rich soil and oceanicity of climate. In all three sites which represent Zone VI, Ulmus displays a well-marked maximum and it is this feature which permits the delimitation of Sub-zone VIa, the lowest division of Zone VI, which is apparent in diagrams also of south-east England. The strength of the elm phase of Sub-zone VIa is a conspicuous feature of the regional pattern of vegetational history in this region of Scotland.

Quercus makes its first appearance in the pollen record here in Zone V, beginning at about the same time as Ulmus at Side Moss,

but slightly later at Eddleston. These two sites and also that at Gifford reveal a similar history - beginning in Zone V, a steady expansion in Sub-zone VIa where its pollen is exceeded by that of Ulmus - then a further expansion in Sub-zone VIb, the level at which it exceeds Ulmus being taken as the sub-zone boundary, as in the diagrams of sites in East Anglia. High Quercus frequencies continue into Sub-zone VIc, and then tend to diminish slightly in the next zone where Alnus rises, although oak pollen remains abundant until after the opening of Zone VIII. In these diagrams of south-east Scotland, Quercus representation is high, despite the fact that Quercus is not a prolific producer of pollen and therefore tends to be under-represented; thus at Gifford the Quercus values exceed those of all other pollen in Sub-zone VIb and reach 40%. At Side Moss again, Quercus counts are high, though the highest values there are not reached until Sub-zone VIc; at Eddleston the oak-phase is also strongly emphasised, though values are somewhat less than at Side Moss or Gifford. At the coastal site, Lochhouses, Quercus pollen exceeds that of all other trees indicating dense local oak-woods.

These pollen diagrams thus portray the existence, during the later Boreal, of a dense deciduous forest of oak, birch, elm and hazel which probably covered much of the Lothian plain and extended into the Eddleston valley and other valleys of the Southern Uplands. The highest sustained percentages of Quercus are all in the Boreal period in this region and there is a contrast in this respect with diagrams of other sites of the British Isles where higher average frequencies may be attained later, in Sub-zone VIIb or in Zone VIII. Thus in Ireland, Quercus attains its highest values in Sub-zone VIIb; Jessen has, in fact, referred to this sub-zone as the Alder-Oak

period. Oak frequencies may be much higher at English sites than are evident in south-east Scotland; thus pollen diagrams from Dartmoor sites have high oak values in the Boreal (Simmons, 1964). Scottish sites, especially those north of the Midland Valley reveal very much reduced values of Quercus; Erdtman (1924) observed that the average frequency of Quercus in the north of Scotland, the Hebrides, Orkney and Shetland was only 2.4%; Ulmus values were only 1.2%. It is the absence of clear Ulmus-Quercus phases in pollen diagrams that has prevented the application of the sub-zonal divisions to Scottish diagrams, as Godwin and others have applied them to English and Welsh sites.

Alnus appears at an early stage in the Boreal in south-east Scotland. It is first seen as early as Zone IV, and appears regularly in Zone V, though no continuous curve can be drawn; in Sub-zones VIa and VIb it shows, as indicated in the Side Moss diagram, sustained considerable values. Thus at the end of the Boreal, Alnus must have been abundant; the transition to Zone VII is marked by the final rise of Alnus.

Stratigraphic and physiographic changes also took place during the Boreal; the open-water conditions prevailing at the sites at Eddleston and Side Moss, accompanied by the deposition of lake-muds, gave place to reed-swamp and sedge-swamp as these lakes were filled in. At the Eddleston site, birch-wood invaded the reed-swamp and a thick layer of wood-peat was deposited above the limnic peat; Side Moss showsthe obliteration of the former lake by sedge-swamp and then by birch-heath peat, a dense concentration of Calluna fragments marks the upper horizons representing the later Boreal.

These indicate a phase of dryness in climatic conditions. The coastal site, Lochhouses, shows, by stratigraphy, pollen analysis and macro-fragments, the changes that took place at the coast during the Post-glacial transgression of the sea. The diagrams may be interpreted as indicating that a rise in sea-level was in progress from the later Boreal to the Atlantic period. Thus the high Quercus phase characteristic of Sub-zones VIb and VIc is apparent, followed by the rise in Alnus which is taken to signify the Boreal/Atlantic transition; the fall in Corylus which is also a feature of the transition is shown. Saltmarsh and brackish conditions are indicated by the pollen of Chenopodiaceae and also by the fruits of Ruppia and the presence of brackish-water diatoms. The dating of the rise in sea-level is conformable with other results obtained by pollen-analysis and by recent Radiocarbon determinations which show that the eustatic rise was in progress from the early Boreal and was completed in the Atlantic period. (Godwin, Suggate and Willis, 1958).

SUMMARY. Five pollen diagrams indicate the vegetational sequence during the Boreal period, Zones V and VI. They record very high frequencies of arboreal pollen compared with lower values of non-arboreal pollen, suggesting the existence in this period in south-east Scotland of a closed forest cover. An increase in Betula is recorded in Zone V, accompanied by increasing values of the scrub, Corylus, and also low frequencies of Pinus. In the next period, Corylus increased its representation and this was accompanied by the development of Ulmus and Quercus. The rise of Ulmus demarcates Sub-zone VIa and the phase of Quercus follows it

forming Sub-zone VIb. Three of the sites record these successive changes in the woodland geography of the region. This record appears to contrast, in respect of Ulmus and Quercus, with every site in Scotland so far investigated, both in the strength of the representation and in the clearly-marked character of the zonal phases. The diagrams reveal also distinctive features of the vegetation in respect of Alnus, which appears very early and which was apparently an important constituent of the woodland throughout the later Boreal, and also in the very low frequencies of Pinus; the dominance of Betula in the woodland except in the last two stages of the Boreal is indicated in the diagrams. The appearance and development of trees demanding greater warmth, namely, Ulmus and Quercus, indicates rising temperatures during this period, and signs of dryness are apparent towards its end. A coastal site shows evidence that a sea transgression occurred during the later Boreal and continued into the Atlantic.

The Atlantic Period, Sub-zone VIIa.

The Atlantic period is represented in the research area in the profiles of four sites, namely, Kitchen Moss, Side Moss, Eddleston and Gifford and part of the sub-zone appears in the diagram of Lochhouses.

The lower border of the sub-zone, the Boreal/Atlantic transition, has been placed at the sharp increase in the values of Alnus pollen apparent in four of the diagrams, and although Alnus was already present in substantial quantities in the middle and later Boreal, a further marked rise has been taken as indicative of the lower border of the sub-zone. In some diagrams of the British Isles, the concurrent fall of Pinus also defines the transition, but the Pinus curve in this region is so low that it cannot be used in the zoning. The relatively low values of Corylus, another characteristic feature of many British diagrams are, however, shown in these diagrams and they help to confirm this position of the lower border of Sub-zone VIIa. The alder attains high values in the diagrams considered here; over 40% occurs at Side Moss and over 60% at Lochhouses; it appears probable that Alnus spread rapidly in the area during the Atlantic period, and that it occupied habitats similar to those in which it flourishes today, as McVean (1953) has described, such as waterlogged soils near streams and lakes, or on higher acid soils associated with Betula, or upon wet hillslopes associated with Quercus, or in other situations where its high soil-moisture requirements were fulfilled. Some over-representation is possible, as Alnus is a prolific producer of pollen and as the sampling sites may have provided particularly favourable habitat conditions for

the development of alder communities. Elsewhere in the British Isles, Alnus reached high values in this period; over 50% is shown in diagrams of sites in southern and eastern England (Godwin, 1934), although in the extreme north of Scotland Alnus apparently remained subordinate to Pinus and Betula. In Ireland, however, the highest frequencies were not attained until the following sub-zone, at least in some localities.

Along the coast of this region, the expansion of Alnus probably resulted from a rising water-table, the consequence of the eustatic rise in sea-level which continued from the late Boreal into the Atlantic period. The Lochhouses diagram may illustrate such conditions. Farther from the coast, the rapid increase in alder may be explained by assuming that there was an increased precipitation/evaporation ratio which would give rise to wet soil conditions independently of a rising water-table.

Of the other tree genera, Betula registers a considerable decrease in Sub-zone VIIa, as shown in the Eddleston and Side Moss diagrams, although there is some recovery at the end of the period; the increase in Alnus is largely at the expense of Betula. Quercus and Ulmus tend to maintain their values, although rather wide fluctuations of Ulmus are recorded in the Gifford diagram. The decline of the latter marks the end of the zone. Single grains of Tilia are shown in three of the diagrams at this time, indicating that this warmth-loving tree may have existed in this climatically well-favoured region of Scotland in the Atlantic period. At sites in East Anglia Tilia has been recorded in considerable numbers in this period, and the possibility of long-distance transport of pollen cannot be excluded.

The existence of extensive forests in this area in Sub-zone VIIa is suggested by the low ratios of non-arboreal pollen to arboreal pollen apparent in the diagrams of Side Moss and Eddleston. Some diminution of the woodland area took place, however, as in other parts of Scotland during the Atlantic; this is shown by the Eddleston diagram, in which the period is represented by an horizon consisting of Eriophorum vaginatum and Sphagnum fragments; this ombrogenous peat rests upon the wood-peat layer which formed during the later Boreal. It is probable that the increased precipitation/evaporation ratio of the Atlantic brought about the formation of this type of peat with its characteristic oligotrophic communities in basin sites such as that at Eddleston, and this type of vegetation spread over the birchwood, forming the raised bog. In the Pentland Hills, the existence of soligenous or ombrogenous peat which began formation in the Atlantic period is suggested by the basal layer of peat at Kitchen Moss, for its pollen has high frequencies of Ericaceae, Cyperaceae and Gramineae. Conway (1954) has shown that the blanket peats of the southern Pennines originated with the climatic changes which took place at the Boreal/Atlantic transition; it seems probable that a similar peat is represented at Kitchen Moss, and that it began to form at the same time. In northern Scotland, diagrams of sites investigated by Durno (1958) show that a widespread growth of ombrogenous blanket peat commenced at the onset of Atlantic time; and at other sites in the eastern Grampians he has demonstrated (1959) the actual initiation of peat development in the Atlantic period. The Atlantic conditions in the Pentland Hills thus appear to have been similar to those in other

north-British upland areas. In Ireland, as Jessen has noted, a similar type of peat becomes common in the horizons of bogs representing the period.

Considerable changes in the physical geography are thus indicated by these pollen diagrams of this region of south-east Scotland; evidence of climatic warmth and moisture is recorded in the characteristics of the vegetation. Thus in this period, the moisture-demanding alder had become abundant in marshy and swampy areas and possibly also in better-drained tracts among oaks (Tansley, 1939); oak and elm continued to flourish, however, though they were less abundant than in parts of southern Britain. The frost-sensitive holly was certainly present in these Lothian woods, and the lime may also have been present. Betula was becoming less abundant, though it was still an important constituent of the forest, but Pinus must have been rare.

The Climatic Optimum.

Much evidence has been used by investigators to indicate the climatic optimum of Post-glacial times; attempts have also been made to work out the actual temperatures that prevailed. Andersson (1902), deduced the temperature of Scandinavia during the Post-glacial warm period from the former distribution of Corylus. His map of the fossil finds of hazel showed that the distribution during the Post-glacial warm period coincided with the present July isotherm of 9.5 deg. C. At the present time, the distribution of hazel is south of the 12 deg. C. isotherm; Andersson concluded that the July temperature had decreased 2.5 deg.C. since the Post-glacial optimum.

Iversen (1944) studied the climatic requirements of Hedera, Ilex and Viscum with a view to estimating temperatures in the Post-glacial.

He noted that Hedera pollen in Denmark increased during the later Boreal and attained highest values in the Atlantic; the favourable temperature conditions of these periods were thus indicated. Hedera and Ilex were both shown to be very sensitive to frost; Iversen considered that in addition to high summer temperatures, the Atlantic period was characterised by winter temperatures higher than at present; probably an increase in the mean temperature of the winter months by about ½ deg.C. in addition to warmer summer temperatures determined the Atlantic luxuriance of Hedera. Iversen drew thermal limit curves for Ilex, Viscum and Hedera based upon the mean temperatures of the warmest and the coldest months of sites and indicating the performance of these plants in the proximity of the station. The thermal curve for Hedera showed that where the plant was growing normally within the station area a summer temperature of about 16 deg.C. wasrequired; in winter, a lower temperature than $-1\frac{1}{2}^{o}$ in the coldest month resulted in death or incomplete development. In the case of Ilex, the plant was demonstrated to be even more intolerant of winter cold, for lower temperatures than -0.5°C. resulted in the death of the plant.

The dangers of drawing conclusions with regard to absolute climatic data from biological evidence have been emphasised. Thus Godwin (1956) has shown that such conclusions are commonly based upon the present geographical range of a species although it may not be certain that a species is fully adjusted to climatic conditions; other factors as well as climate may also influence its distribution. Faegri (1950) discussing this problem, showed that the curves constructed by Iversen in his demonstration of the climatic demands of Hedera admitted of several different interpretations of

climatic variation. He stressed the difficulties inherent in drawing conclusions from palaeoclimatological evidence "even in such simple matters as the meridional displacement of a distribution limit....Unless the opposite has been proved we must always suspect that there may be - within certain limits - a set of mutually interchangeable factors which can explain our findings"

Pollen of Hedera and Ilex, however, clearly have value as climatic indicators. The diagrams of Lochhouses and Gifford record pollen of Hedera and Ilex during zones VIb, VIc, and VIIa mainly; highest frequencies occur in the Lochhouses diagram. The Gifford diagram covers a greater range than that of Lochhouses, Hedera being recorded from VIb to VIIa in greatest frequency though pollen is also recorded in VIIb. The Gifford, Eddleston and Side Moss diagrams all show the highest frequencies of Ulmus, Quercus, Alnus, Hedera and Ilex (with occasional single occurrences of Tilia) during the period VIa to the end of VIIb, and it must be assumed that this expansion of the warmth-loving trees represents the period of greatest warmth. Temperatures at the time of the optimum have been estimated as 2 - 3 deg. C. higher in the summer than at the present day, though there was less difference in the winter from the temperatures of to-day (Lamb, 1964). Manley (1964) has suggested however that winters during the Climatic Optimum were very mild, perhaps 2 deg.C. warmer than they are to-day.

According to evidence from the Outer Hebrides (Harrison and Blackburn, 1946) the Atlantic period in Scotland was particularly warm. A nut of Trapa natans was found in the wash cast up on the shore of a brackish loch on South Uist. A fragment of peat adhering to the nut could be dated by pollen analysis, comparison being made

with diagrams of peats from the immediate neighbourhood. On this evidence, Trapa grew in Scotland during Zone VIIa; very warm conditions are indicated as the mean temperature of the warmest month along the recent northward limit of Trapa is about 18 deg. C. in Central Europe. Some doubt has, however, been cast upon the validity of this record; it has been pointed out that Trapa is a calcicole plant yet the peat adhering to it was oligotrophic, indicating acid soil conditions in which Trapa could not possibly have grown.

SUMMARY. Zone VIIa is represented in five diagrams. The period was characterised by the prominence of Alnus which spread rapidly in this area, probably displacing Betula to some extent, though the latter remained important. Quercus and Ulmus were abundant, although a decline in Ulmus took place at the end of the period. Tilia, if present at all, was rare, but its pollen is recorded at three sites. The Atlantic was thus, like the Boreal, a period of dense forest growth in the region. There was a continued rise in sea-level. Moist soils resulting from increased rainfall and a high water table gave rise to the abundance of Alnus. High frequencies of pollen of thermophilous trees, Quercus, Ulmus, Alnus and the presence of Ilex, Hedera and possibly Tilia are all suggestive of a period of warmth. There was some diminution of forest, however, owing to the development of ombrogenous bog in some situations; thus raised bogs developed in depressions and blanket bog formed upon hillslopes.

Sub-zone VIIb, the Sub-boreal.

This period is illustrated by the diagrams of Side Moss, Eddleston and Kitchen Moss.

The lower boundary of the sub-zone is at the level of the elm decline. The Ulmus recession is a clearly-marked feature in these diagrams, in contrast with those of more northerly sites as exemplified by Caithness (Durno, 1958); a sharp fall from the sustained higher values characteristic of the preceding sub-zone occurs in each. In two diagrams, namely Eddleston and Kitchen Moss, values in the Sub-boreal are approximately half those of the preceding Atlantic period, but at Side Moss, where Ulmus values reached a maximum for the region during the Boreal period, the decline is a very sharp fall from about a 10% average to one of 2%, the Ulmus values remaining low for the entire Sub-boreal. The trends of the curves of the other tree genera exhibits similar features in each of the diagrams, indicating possible correlations: Betula is higher in each than in the preceding period; Alnus is also higher, with a tendency to fall towards the end of the sub-zone. Quercus tends to maintain its frequencies of Sub-zone VIIa showing also a slight rise at the end of the sub-zone, during which Corylus also shows a similar trend. Pinus falls at some levels to zero, thus the very low representation of the Atlantic is continued.

At Eddleston and at Side Moss, the Sub-boreal is represented by highly humified ombrogenous peat consisting of macro-fragments of the oligotrophic communities of Eriophorum vaginatum, Calluna vulgaris, Sphagnum spp. At Kitchen Moss, however, the Sub-boreal period is represented stratigraphically by an horizon containing

abundant fragments of Betula pubescens, varying in size from small twigs to large stools, some of which appeared to be in the position of growth. The evidence is that at this site, a readvance of woodland occurred during Sub-zone VIIb, shrubby birches growing over the bog which formed during the Atlantic; a recession in the non-arboreal pollen curve in this diagram indicates this woodland phase in the Pentland Hills.

The Ulmus decline is represented at many sites throughout north-west Europe. It is considered by Godwin (1960) and other botanists to indicate a climatic change, probably a reduced temperature, which came at the close of the Atlantic period; this change influenced the Ulmus representation simultaneously in forests throughout Europe. A similar indication is provided by a decline in the warmth-loving lime, which occurs at the same level in some diagrams, such as that of Hockham Mere, East Anglia (Godwin, 1941); in Denmark the frost-sensitive Hedera also declines in the Sub-boreal, as Iversen (1941) has shown. Godwin (1944) pointed out that as oceanic conditions are favourable to Ulmus, as evidenced by its great abundance in Ireland during the Boreal period, a swing to more continental conditions in the Sub-boreal would result in a decline. The synchroneity of the Ulmus decline has been confirmed by Radiocarbon datings of the VIIa/VIIb horizon at many sites in Britain and Europe. The date of the decline at Flanders Moss has been placed at ca.5000 B.P. (Godwin & Willis, 1961), which corresponds with dates obtained elsewhere for the first Neolithic forest clearance in Britain. The Ulmus decline is considered by some investigators (Troels-Smith, 1953) to be of anthropogenic origin, not climatic; they emphasise the possibility of selective exploitation of elm by

primitive farmers who used the leaves and twigs of the tree for cattle fodder. Thus, work by Morrison (1959) has appeared to confirm that, in the north-east of Ireland, phases of Neolithic forest clearance have been accompanied by stages in recession in the pollen of Ulmus. In northern Lancashire, Oldfield and Statham (1963) have shown that the first elm decline at the VIIa/VIIb horizon was contemporary with high weed and grass pollen values denoting agricultural activity.

In the three diagrams of south-eastern Scotland under consideration here, it is clear that the Ulmus decline is older than the first indications of anthropogenic influence upon the vegetation, namely, the appearance of pollen of the plantains (Plantago) and that of other weeds of cultivation, an increase in the pollen of Gramineae, or marked changes in the curves of trees and hazel. Thus, in the diagram of Eddleston, the first pollen of Plantago appears at 140 cms. which is a considerably higher and younger level than that of the Ulmus decline which takes place at 170 cms. The case of the Pentland Hills site, Kitchen Moss, is even clearer, for the first Plantago pollen is not recorded until the lower part of Zone VIII. The phases of forest clearance indicated by these diagrams will be discussed when the next zone is considered. On the evidence of the Side Moss and Eddleston diagrams, the beginnings of cultivation were made in the latter part of Sub-zone VIIb which corresponds to the late Bronze Age; there is no indication that early farming began in this area at an earlier time represented by the Ulmus decline. Neolithic and Bronze Age settlement in this region appears to have been very scanty; a predominantly coastal distribution of population with extensions along major river valleys

is implied by the positions of burials during the period 2000 - 1000 B.C. (Piggott, 1951), and the sites for pollen analysis are situated relatively far from the coast in positions where it seems unlikely that early forest clearances for agriculture would be initiated. It thus appears improbable that in this region the Ulmus decline was the result of primitive agricultural activity.

The precise character of the climatic shift implied by the sudden weakening of the elm curve is uncertain. It had no immediate effect upon the Quercus representation, for the frequencies of the latter rise slightly at the end of the period, as is shown in the Eddleston diagram. Assuming that the Upper Forestian horizon of Lewis and Geikie represents the Sub-boreal, a drier climate is suggested by the spread of Pinus on to the bogs at this time in parts of Scotland. Thus the ligneous horizon in this area shown at Kitchen Moss may have been the response to a drier climate. Manley (1962) has suggested that in Northern Britain the climate of this period was drier than at present. Godwin (1956) considers, however, that there is little evidence for dryness during the Sub-boreal. Jessen (1949) thought that in Ireland the maxima of Quercus pollen so often shown in diagrams during Sub-zone VIIb indicated that the Post-glacial climatic optimum occurred there not during the Atlantic but in the Sub-boreal. It has been pointed out that a slight Quercus maximum is also apparent in these diagrams of south-east Scotland at the end of the period; some grains of Tilia are also present, particularly at Eddleston; sites at other places in the Midland Valley also show high Quercus values in this period, and this evidence may perhaps indicate a continuation of Atlantic warmth into the Sub-boreal, a conclusion that has been reached

by Steven (1951) and also Durno (1959).

SUMMARY. The Sub-boreal is represented in three diagrams, each of which shows the Ulmus decline marking the transition level from VIIa to VIIb. The principal forest trees were Betula and Alnus with abundant Quercus. Ulmus values were much reduced. Corylus was the most prominent shrub. The period was thus one of apparently dense forest, but the appearance in its later stages of pollen of weeds of cultivation indicate the beginnings of clearance for farming. There was no change in the vegetation of raised bogs but in the Pentland Hills an advance of birch woodland occurred. Apart from reduced values of Ulmus, there is little evidence of climatic deterioration in the period.

The Sub-atlantic, Zone VIII

The period isrepresented in the diagrams of Side Moss, Kitchen Moss and Eddleston. The boundary between the Sub-boreal and the Sub-atlantic has been placed at the level of the Grenhorizont, a stratigraphical feature usually accepted as evidence for determining the horizon in the pollen series (Godwin, 1945). At about the same level, the NAP curve begins an upward trend due to an increase in the frequencies of Ericaceae, Gramineae and Cyperaceae, this being a common feature in Scottish and Irish diagrams and used as an additional boundary indication (Blackburn, 1946). Pinus is here at a very low level, another characteristic of this level (Eydt, 1960) though Betula shows a steady rise. The upper peat at these sites is thus shown to be of Sub-atlantic age; it consists of poorly humified remains of Sphagnum, Eriophorum vaginatum and Calluna vulgaris.

A sharp increase in climatic humidity occurred at this level (Brooks, 1949) dated by Radiocarbon elsewhere in the British Isles at 500 B.C. (Godwin, 1960). Manley (1964) has estimated that the Sub-atlantic recession resulted in a fall of about 2 deg. C. in the summer temperature accompanied by a considerable increase in cloud and precipitation and a decrease in evaporation. The climatic change is indicated by a rapid increase in the rate of growth of the peat which occurred at each site, resulting in an increase in the depth of this horizon which is much greater than that of the preceding layers. As Durno (1961) has shown, the cool, wet climate of the Sub-atlantic gave rise to a fast rate of accumulation of peat, although the greater depth may be attributed partially to the fact that this upper horizon has not undergone the compression that reduced

the thickness of lower horizons. The swing towards wetter conditions gave rise to a renewal of the formation of ombrogenous blanket bog in the Pentland Hills, which has been shown here to be Sub-atlantic in age. The tree remains in Kitchen Moss which are of Sub-boreal age represent woodland which has been destroyed and covered by the extension of Sub-atlantic blanket bog. Thus in that part of the Pentland Hills, a picture is conveyed of thickening blanket bog creeping downhill from higher levels and enveloping the birch-scrub woodland of the Sub-boreal period. At Side Moss and at Eddleston, the upper peat built up the convex surface of the raised bogs in this period.

The pollen diagrams show that the natural vegetation of this region underwent drastic changes during the Sub-atlantic, a period which embraces the Iron Age and the historic periods. These changes were brought about both by man and by climatic change and their effects upon the vegetation cannot be distinguished separately with certainty, although deductions can be made from the pollen curves. Man brought about disforestation and the replacement of woodland by grassland and other semi-natural communities; the wetter climate also had an adverse effect upon the woodland by promoting soil leaching and the formation of acid mor soils.

Phases of pre-historic forest clearance by early man have been demonstrated by pollen frequencies by Iversen in Denmark (1941). A series of occupation stages could be distinguished; forest was first cleared by the use of fire, then the cleared land was used for grazing or for cropping; later, the land was abandoned but birches and hazel and then oak and elm readvanced upon the clearance.

The entire episode was recorded by the pollen curves and in particular the occurrence of pollen of the plantains which are associated with grassland and with grazing by cattle. It is possible to distinguish in these diagrams, by using the curves of Plantago, Gramineae, Ericaceae, Corylus and variations in the arboreal pollen, comparable phases of disforestation which took place in south-east Scotland during the Sub-boreal, Sub-atlantic and historic periods; some correlations may be suggested by reference to the archaeology and history of the region. Similar studies have recently been made in Britain by Simmons (1964) and by Turnder (1964).

Clearance of woodland in this region is indicated by the curves of pollen of Plantago spp. Thus in the Pentland diagram, plantain pollen is first recorded at 110 cms., several centimetres above the boundary of Zone VIII; this upward Plantago curve is accompanied by a similar trend in Gramineae and at the same level the proportion of AP lessens, Betula showing a decrease. Ericoid pollen is seen to rise at this level. These features of the pollen record appear to indicate that grazing commenced in the Pentlands in the neighbourhood of the site in the early Sub-atlantic and that an extension of grasses and heath plants occurred at the expense of trees, notably of birch.

According to similar evidence in the Eddleston diagram, pastoral activities began rather earlier, in the late Sub-boreal, but the main destruction of forest, as in the Pentland Hills, occurred in the Sub-atlantic. At 100 cms. there is a marked rise in NAP values, contributed by Ericoid pollen and by Plantago, at the same level as a sudden fall in Quercus which may be interpreted as extension of heath and a phase of clearance of oak forest during the Iron Age,

although there is an indication in the Betula curve that birches were also involved in the clearance.

It is in the diagram of Side Moss, however, where these anthropogenic effects are most clearly marked. At this site, peat formation during the Sub-atlantic was more rapid than at the others; the period is represented by 360 cms. of peat compared with slightly over 1 metre at Eddleston and Kitchen Moss. The sampling interval of 10 cms. thus provides a more detailed record of vegetational responses to disforestation than at the other two sites. The first evidence of forest clearance at Side Moss appears about the VIIb/VIII transition and it is shown by a rise in Gramineae which corresponds to the occurrence of single grains of Plantago, and above this level, a fall in Quercus indicates clearance of oakwood. A second, more extensive phase of disforestation is suggested at 320 cms. where a continuous curve of Plantago is established, initiated by a marked rise in this pollen and accompanied by a peak in Gramineae frequency and also in an advance of Ericoid pollen values. Above this level, Quercus again records a marked decrease and a further permanent effect upon the oak forest is indicated. Just above this level, at 300 cms., a rise in both Corylus and Betula occurs showing that some readvance of scrub probably took place, and a fall in Plantago and Gramineae represents this minor reversion to woodland; confirmation of this may be shown by the Ericaceae curve which falls. There may have been an advance of Alnus into some of the cleared land, as there are peaks in this curve at these levels. It is clear, however, that there was no general readvance of forest; the grazing area was gradually extended, checking a renewal of the woods, and this is recorded by higher and higher counts of Plantago

and Gramineae, at the expense of Quercus, and of Alnus at higher levels. Once the land was cleared, browsing animals prevented regeneration, which would have been slow as a result of the climatic and soil conditions, as Kirk (1957) has suggested.

Extensive clearances of apparently Iron-Age origin are thus indicated which had a lasting effect upon the woodland by the destruction of mixed woodland species and by the extension of pasture. Some confirmation of these changes is afforded by the archaeological evidence relating to the Iron-Age economy in south-east Scotland, although the evidence is of a general character. According to Piggott (1951), hill-forts and settlements were widely distributed in the Lothians and in the Tweed valley in the Iron-Age. He considers that the range of hill-forts may extend back into the 3rd century B.C. This period may be represented by the lowest metre or so of the Sub-atlantic peat at Side Moss. The Iron-Age economy in this region was based probably upon pastoralism (Piggott, 1961). Farmers carried on a form of ranching which involved herds of cattle and a limited nomadism; the extent of pasture constantly increased, as the pollen records at these sites suggest. Moreover, the construction of the numerous hill-forts and villages required much use of timber; this was used in building both defence fortifications and houses, as excavation at hill-fort sites has shown; these structures involved the destruction of woodland. As an example, Braidwood fort in the Pentland Hills had a massive enclosing palisade of timber, probably built during the early Iron-Age, as Piggott (1957) has suggested, and the buildings within it were also of timber. An additional need of timber would also

arise from use of charcoal for iron-smelting, an industry carried on in the Pentland Hills in the Iron-Age, as indicated by excavations at Castlelaw Fort (Childe, 1933). Forest clearances are likely to have proceeded from centres such as these, in both an upward and downward direction; upward clearances would have involved the birch-scrub woodland of the Sub-boreal; downward clearances would have been at the expense of the mixed deciduous forest of the lower valleys. The decline in Betula between 90 and 60 cms. in the Pentland diagram may reflect this disforestation.

Later phases of clearance are perhaps discernible: in the diagram of Side Moss, a long period of decline in Quercus, Alnus and Corylus commences at 250 cms. which may represent a steady encroachment upon the remaining woodland by Anglo-Saxon farmers. Radford (1962) has suggested that the Anglian advance into Scotland took place at about 600 A.D. The invaders brought with them techniques of dealing with heavier soilsand removing trees to form permanent agricultural communities, and this phase may be represented in the diagram. The decline in Quercus which begins at about 60 cms. in the Kitchen Moss diagram may also relate to this period; a peak in Plantago occurs in it at the same level. The first occurrence of pollen of cereals which is indicated in the Side Moss diagram is presumably contemporary with this period, although the continued increase in Gramineae suggests the continued importance of use of the land for grazing.

There is a small representation of Fagus in the late Sub-atlantic, which is however apparently greater than at any site so far recorded in Scotland, and this is analogous to the distribution in England, which shows higher values in the south and east (Godwin, 1956).

T he curve of Betula shows a steady increase in the Sub-atlantic in these diagrams, in accordance with the principle of revertence, and the consistency of the increase, as indicated in the Side Moss diagram, indicates a probable climatic causation.

SUMMARY. Three diagrams show vegetation changes in the Sub-atlantic. A widespread recession of the forest cover of the Sub-boreal is indicated in this zone resulting from a deterioration in climate which became cooler and wetter, and from clearance activities which began to take effect at about the time represented by the VIIb/VIII transition. During Zone VIII, clearance became intensified as indicated by rising frequencies of pollen of Plantago. Rising values of Gramineae suggest the use of the cleared land for grazing, and rising values of the Ericoids shows the extension of heath. Oak, alder and hazel retreat during this period as the encroachment proceeded, but part of the decline may be the result of climatic deterioration. Correlations are suggested between the retreating forest and Iron-Age and Anglo-Saxon settlement. Fagus appears in this zone; cereal pollen also appears and increases at the top of the zone.

PART VI

SUMMARY OF CONCLUSIONS.

Summary - the Regional Features of the Development of Vegetation.

A regional character in vegetational development during Post-glacial time is evident in the pollen diagrams of the sites of this region: the climatic sequence of the Post-glacial gave rise to changes in the vegetation which were parallel to those of other parts of the British Isles but which followed in this region a distinctive pattern. In order to emphasise the regional contrasts between the past vegetation of this part of Scotland and other parts, the results of this research may be compared in tabular form (see below) with those obtained by Erdtman (1924) and Durno (1958). Erdtman calculated values for the individual tree species based upon a total count of 14,843 arboreal pollen grains from the deposits sampled over a large area which included north-west Scotland, the Northern Isles and the Hebrides; thus he obtained a general pollen spectrum which conveyed a picture of the forest-character of the region in Post-glacial times. Durno made a similar calculation, based upon a total tree-pollen count from samples at sites in Sutherland and Caithness. The corresponding figures for this area of south-east Scotland have been based upon a total pollen count of 26,792 arboreal grains from samples of deposits of four sites, namely Kitchen Moss, Side Moss, Eddleston and Gifford:

TABLE 5.

	North-West Scotland and Isles.	Sutherland and Caithness.	South-East Central Lowlands
Birch	70 per cent	60 per cent	52.1 per cent
Pine	14.6 "	24 "	2.5 "
Alder	11.8 "	14 "	24.8 "
Oak	2.4 "	1 "	13.3 "
Elm	1.2 "	1 "	5.1 "
Lime	-	.08 "	.06 "
Beech	-	.02 "	.05 "

The following regional characteristics of this region of south-east Scotland are apparent from the table:

There has been a general dominance of birch in the Post-glacial, but the preponderance is much less than that of the northern areas; contrasts in soil and climate explain the difference.

Pine has been much less important than in north Scotland; as the pollen diagrams have shown, the strong pine phases of the Boreal were not in evidence in thisregion, though slight movements of the curves are discernible.

The representation of the trees that respond to conditions of greater warmth and richer soils is very much stronger in this region of south-east Scotland than in the more northerly districts. This is evident from the higher percentages of Oak, elm and alder. Alder, as the diagrams have indicated, has been important in the vegetation of this region from the middle Boreal and was already abundant before the final expansion took place at the beginning of the Atlantic period. From that point onwards it became co-dominant with Betula

or exceeded the latter until the revertent phase of the Sub-atlantic resulted in higher frequencies of Betula.

Oak and elm were apparently much more abundant in the woodlan ds of south-east Scotland than in the more northerly areas. The Boreal was the period of their greatest abundance, and as the diagrams have shown, the phases of their successive entrance and development in this region were similar to those of the forests of south-east England. Though elm declined at the end of the Atlantic, oak continued to be abundant until the Sub-atlantic.

Lime and beech were rare in this region, as in the north.

Summary of Conclusions.

Changes in vegetation which took place in south-east Scotland during the Late-Quaternary have been studied by pollen-analysis and stratigraphy of peat and lake deposits.

During the Late-glacial, severe climatic conditions are indicated by the vegetation and stratigraphy. There was much soil movement by solifluxion and no continuous cover of vegetation existed; pollen examination suggests an open landscape with herbaceous plants some of which were Arctic or sub-Arctic. Some amelioration of climate during this period may be shown by a contrasting stratigraphy and by higher frequencies of tree-pollen, but this phase was succeeded by a return to colder conditions with lowered tree representation and unstable soil surfaces. This phase may be correlated with the re-advance of glaciers in the Highlands which took place in Zone III; the earlier, warmer phase may represent Zone II.

At the commencement of the Post-glacial at ca. 8,300 B.C., the Late-glacial herbaceous plants were much in evidence, but the land was rapidly colonised by trees, of which birch was most abundant; Pinus and Salix were frequent in this Pre-boreal period. During the Boreal, climate grew warmer and woodland cover became complete except where there were lakes and marshes; birch was the dominant tree but a rapid expansion of hazel took place. In Zone VI, the later Boreal, this primeval forest changed its composition owing to the entrance and development of elm and oak. An elm phase was succeeded by that of oak and together these species, favoured by climate, caused birch to lose dominance. There was an increasing amount of alder in the later Boreal, but pine was unimportant and

lime, if present at all, was rare. Woodland trees, aided perhaps by climatic dryness, spread over bogs and marshes in this period.

In the Atlantic period, Zone VIIa, there was a further expansion of alder, as a result of a high water-table and increased rainfall; it became dominant in favourable localities and invaded mixed-oak woods, but abundant moisture gave rise to ombrogenous bog development. The abundance of the mixed-oak trees and the presence of ivy and holly indicate the warmth of this period. A rise in sea-level which had commenced in this area during the later Boreal, continued in the Atlantic. At about 3,000 B.C. a change of climate resulted in a decrease in elm; elm and pine were both infrequent during the Sub-boreal, Zone VIIb, but birch began to reassert its dominance, though oak remained abundant. In some localities an advance in woodland took place, as in the Pentland Hills, where birchwood spread over the former bog surface. In the Sub-atlantic period, however, Zone VIII, which began ca.500 B.C., there was a readvance of ombrogenous bog vegetation owing to a climatic change towards cooler and wetter conditions; a degeneration of soils owing to increased leaching took place which favoured the return to dominance of birch. There were extensive alterations in the character of the vegetation in this period which were the result of the activities of man. Signs of cultivation had appeared in the Sub-boreal, but during the Sub-atlantic these increased and were accompanied by a reduction in forest cover and an extension of grassland and heath. Clearance phases occurred in this period which resulted in a permanent reduction of woodland, oak, hazel and alder all being affected. There was also a spread of heath and the plants of open conditions again became common. The

appearance of cereals in the Sub-atlantic is characteristic of the period. Towards the end of the period the beech appeared. Plantations increased the amount of woodland in the later Sub-atlantic.

Several features distinguished the vegetational development of this region of Scotland from that of other regions. During the Boreal period, Corylus, Ulmus and Quercus were abundant in the forests, probably responding to favourable climate and soil in this region. The successive development of Ulmus and Quercus during Zone VI have allowed the division of this zone into sub-zones as in pollen diagrams of East Anglian sites. Pinus, however, was apparently much less important than in other parts of Scotland. During the Post-glacial, Betula and Alnus were very abundant; the latter showed strong development during the later Boreal before its expansion in the Atlantic period.

TABLE 6.

TABLE SUMMARISING GEOGRAPHICAL CHANGES IN SOUTH-EAST SCOTLAND

POLLEN ZONE RADIOCARBON DATE.	VEGETATION CHARACTERISTICS.	GEOLOGY.	CLIMATE.	CULTURAL EVENTS.
	Fagus.			18th.C. planting
VIII	Betula rising. Alnus Corylus, Quercus. Quercus at low values. Ruderals abundant. Ericaceous heath development.	Formation of blanket peat and upper peat of raised bogs.	Cool wet.	Cereal pollen. Clearances intensified. Extension of grassland.
500 B.C.	Rapid rise in NAP.	Grenzhorizont		Clearance of Quercus, Corylus.
VIIb	Alnus-Betula-Quercus Corylus woodland.	Formation of wood peat. & ombrogenous peat.	Some evidence of drier condits.	First signs of Clearances.
3000B.C.	ULMUS DECLINE		HIGHEST TEMPERATURES	
VIIa	Alnus-Betula-Quercus Corylus woodland. Ilex present.	Formation of ombrogen. peat. High water table. Sea-level rising.		
5,500 B.C.	BOREAL ATLANTIC TRANSITION			
VIc.	Corylus falling. Alnus rising.	Sea-level rising.		
VIb.	Quercus-Betula-Ulmus woodland with abundant Corylus.	Wood peat or Calluna peat.		
VIa.	Betula-Ulmus woodland.	Lakes become filled in.	Warmth increases	
V.	Betula-Corylus woodland.			
IV.	Colonization of open heath by Betula. Abund. Herbaceous plants	Deposition of lake muds.		
8,300 B.C.	POST GLACIAL BEGINS			
III	Herbaceous plants.	Intense solifluxion.	Cold	
8,800 B.C. II	Slight rise in		Amelioration	
10,000 B.C.	AP. Betula maximum.	Organic lake deposits		
I	Herbaceous plants.	Solifluxion.	Cold.	

A SUMMARY OF THE PRINCIPAL RESULTS OF THE RESEARCH.

Knowledge of the Post-glacial physical geography of Scotland appears to have been advanced by this research in the following respects:

1. The Pre-boreal, Zone IV, is shown to have been a short period of rapid climatic and vegetational transition, confirming the results of previous research in other parts of Scotland. Herbaceous plants followed by trees advanced over bare soil surfaces of the Late-glacial so that the open landscape gave place to one with a tree cover dominated by Betula. A rich aquatic vegetation existed but diminished during the rapid filling-up of lakes with peat.

2. In the Boreal, Zones V and VI, the research shows the characteristic high Corylus frequencies of Zone V and the rise of Betula to early dominance. There was soon, however, a decline in Betula and a steady advance of trees responding to higher temperatures, namely Ulmus and Quercus. The sequence of entrance and development of these trees was clearly defined and they appear to have attained greater abundance in this region than anywhere else in Scotland so far investigated, and presumably this was a result of favourable soil and climate. The Quercus dominance in Zone VI is unusual in Scottish diagrams though typical of sites in England. On the other hand, there was remarkably little Pinus compared with other Scottish sites; every diagram shows this feature and only a faint trend is visible of the Pinus development in Zone VI characteristic of other areas.

3. The Atlantic, Zone VIIa, shows little that is regionally distinctive, except for the relative abundance of Hedera and Ilex which points to the warmth of the climate of this period. The high

Alnus frequencies are a reflection of theabundant soil moisture of the period. In the Pentland Hills, according to evidence from the one site, there was a development of ombrogenous peat in the Atlantic, as in other upland areas of the British Isles.

4. The coastal site confirms the dating of the Post-glacial marine transgression; it shows a rise in sea-level in the late Boreal and its continuation into the Atlantic.

5. In the Sub-boreal, Sub-zone VIIb, Ulmus falls very sharply. Trends in other arboreal pollen evidenced in other parts of Scotland are shown in these diagrams, notably the rise in Betula after its retreat in the Atlantic. The wood-layer noted in the Pentland Hills is of Sub-boreal age; it presumably corresponds to the Upper Forestian of Geikie and may indicate a possible drier climatic phase.

6. In the Sub-atlantic, Zone VIII, the research shows the changes in the natural vegetation which were brought about largely by human agency. At the end of Sub-zone VIIb and during the Sub-atlantic, the diagrams reveal phases of forest clearance and the extensions of pasture and cultivation. It was possible to relate variations in the frequencies of Plantago with those of trees and grasses and thus to interpret the apparent replacement of woodland by pasture. So far this has not been done in Scotland. The research dates these changes as late Bronze-Age extending into Iron-Age/historic time and shows that they post-dated the Ulmus decline. The effects of the colder, wetter climate of the Sub-atlantic are shown in the extension of ombrogenous bog and in the decline of Quercus, Corylus and Alnus.

7. The Late-glacial site, though the pollen counts are not high enough for validity, exhibits what may be interpreted as the three-fold sequence of stratigraphy characteristic of the period;

the pollen indicates a sub-Arctic type of vegetation in Zone III, though warmer conditions with a higher arboreal frequency are shown to have prevailed during Zone II.

APPENDIX.

Peat and other deposits at Carrick Knowe, Edinburgh.

Investigated 19.9.1962.

In addition to the two sites in the Corstorphine district of Edinburgh already described, viz. Meadowhouse Rd. and Gogar, a third site was investigated there, but as the results cannot be regarded as entirely satisfactory they have not been included in the main part of the thesis.

Particulars of the research are as follows:

A peat was located on the edge of the Carrick Vale Golf Course, Edinburgh, which now occupies part of the former bed of the ancient Corstorphine Loch, according to the map drawn by Cadell (1913). The Hiller sampler was used to extract samples of this peat and of the overlying and underlying deposits. The exact spot chosen for sampling had to be off the course and a convenient site eventually selected was on the north-east edge of the course, 400 yards south-east of Pinkhill Railway Station, at a height of 150 feet O.D. approx.

The peat was very thin, only about 30 cms. in thickness, and was covered by just over 1 metre of yellow-brown clayey soil. Below it was a grey sandy deposit; some penetration of the sand was possible and it appeared to become coarser downwards.

Tait (1934) had described deposits revealed in this area during the excavations for a sewer; he had noted near Pinkhill Railway Station a sequence consisting of red-brown sands covering grey shelly marls with plant remains; an antler of Cervus giganteus had also been found during the excavations. Earlier investigations in the

same area by Bennie (already described on page 13) had shown that Arctic plant beds lay beneath sands and gravels. The interest of this site thus lay in the possibility of locating Late-glacial deposits which the records suggested are present here, and of applying pollen-analysis to them.

The peat, a limnic deposit with abundant seeds of Menyanthes trifoliata, yielded satisfactory pollen frequencies at two depths as follows:

	Percentages of total tree pollen:	
	150 cms. from surface.	160 cms. from surface.
Pinus	6	3
Betula	41	33
Alnus	41	50
Ulmus	½	3
Quercus	3	5
Salix	9	6
Corylus	15	13
Cyperaceae ..	27	7
Gramineae ..	21	3
Potamogeton ..	½	-
Nymphaceae ..	½	-
Filicales ..	16	5
Sphagnum ..	3	1
Ilex ..	½	-
Artemisia ..	½	-
Filipendula ..	-	½

The peat may be dated as Zone VIII. It clearly belongs to a late stage of deposition and resembles the deposit of the Gogar Loch which was formed in a lake during a recent period. Old maps show

the existence of Corstorphine Loch until recent times and the pollen counts indicate a recently formed peat; thus Betula and Alnus frequencies are rather high and those of Quercus and Ulmus are low. Grass, sedge and aquatic pollen are present. The picture conveyed is that of a relatively modern lake probably bordered by birch and alder woodland and fringed with sedges and reeds.

As these deposits are not Late-glacial, the latter must lie at greater depth. It was decided therefore to dig a trench through the sandy horizon which lay beneath the peat. This was not possible on the Golf Course and a site was found near the northern edge of the Course on the bank of the drainage ditch known as the Stank, and immediately opposite the platform of Pinkhill Railway Station. At about this spot Tait observedthe Late-glacial deposits he recorded.

The deposits exposed in the trench were as follows:

Cms. from Surface.	
0 - 50	Clay soil.
50 - 150	Yellow Clays.
150 - 250	False-bedded red and yellow sands.
250 - 260	Grey Silts.
260 - 300	Clays, silts and sandy layers.

At 300 cms. this work had to be abandoned as water seeped into the trench from the Stank. The samples of the silts and clays taken from the lowest parts of the trench were given the usual laboratory treatment for pollen analysis, but they yielded no recognisable pollen. No macro remains were observed in these deposits.

Raised Bog at Balerno Common, Midlothian.

Ref. 164638

Samples were taken for pollen-analysis from a raised bog situated about 2 miles south of Balerno, Midlothian, on the north-west slope of the Pentland Hills, the aim being to supplement the data yielded by Kitchen Moss.

The peat was about 5.5 metres in depth. The lowest horizon, 2 metres in depth, consisted of limnic peat with Phragmites or Carex fragments mixed with Betula twigs. Above this lay poorly humified Eriophorum/Sphagnum/Calluna peat.

The pollen frequencies followed no recognisable pattern owing to over-representation of vegetation that had existed close to the site; the tree-pollen curves thus showed no consistent features enabling a dating or zoning of the deposits to be attempted. This work had therefore to be given up.

Peat at Bush House, near Bilston, Midlothian.

Ref. 251637

This site also proved to be useless. Samples were extracted of a thin peat, 1.5 metres deep, consisting of highly humified peat with Betula fragments, resting upon boulder clay.

In this case, pollen extracted by the usual laboratory methods was almost unidentifiable; grains were either distorted or badly broken up, and the work was abandoned.

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