The distribution of Tilia cordata and variations in the composition of the forests in upper Swaledale and Wensleydale during the Atlantic period

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THE DISTRIBUTION OF TILIA CORDATA AND VARIATIONS IN THE COMPOSITION OF THE FORESTS IN UPPER SWALEDALE AND WENSLEYDALE DURING THE ATLANTIC PERIOD

by

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This work is wholly my own except where due reference is given.

Jean A. Hall
3 September 1979.

ABSTRACT

The thermal maximum of the Flandrian period was reached between 7500 B.P. and 5500 B.P. when the broad-leaved thermophilous forests reached the furthest northern limit of their range in Britain. Tilia cordata is regarded as the most thermophilous of the North European deciduous trees. The distribution of T.cordata at 5000 B.P. (3000 B.C.) has been documented for North England although data has not been available for parts of the Central Pennines in Yorkshire, north of Settle. Pollen analysis of peat deposits in Swaledale and Wensleydale at altitudes from 480m to 590m O.D. shows that T.cordata was present at a frequency of 1% in this area during this period.

The Atlantic period forests were composed mainly of Ulmus, Quercus and Alnus, with Betula, Pinus, Tilia and Fraxinus and the shrubs Corylus and Salix. The relative abundance of these genera varied at any one place and from place to place during the 2000 years. Pollen diagrams have been prepared for nine sites for the Atlantic period, pollen assemblage Zone VIIa in the terminology used by Godwin. The pollen diagrams include tree and shrub pollen only. Fagus was represented by scattered grains and has not been included.

Multivariate analysis of the tree and shrub pollen data has been made. The variance between the nine sites is greater than the variance within one site. The major source of the variation does not appear to be linked with the lithology of the sites.

CONTENTS

ACKNOWLEDGMENTS

I should like to thank Dr. G.A.L.Johnson and Dr. M.J.Tooley, of the University of Durham, and Dr. A.A.Wilson of the Institute of Geological Sciences, Leeds, for advice on the geology, and Dr. T.Gleaves of the University of Durham, for help with the statistics. My thanks are offered also to fellow students and friends, J.Chaudri, D.Ridgeway, M.Wilson and J.Hodgson for their cheerful assistance with fieldwork in all weathers. D.Ridgeway and M.Wilson kindly allowed the use of their data from three sites. I am indebted to Professor C.D.Pigott of the University of Lancaster, whose work on the distribution of <u>Tilia cordata</u> inspired the idea of this project, for permission to reproduce the map on page 3, and for lending me a copy of his recent paper which is in press.

I am grateful to Dr. J.Turner for stimulating teaching, patient encouragement, assistance with the multivariate analysis and especially for her compass and load-carrying capacity on field expeditions.

INTRODUCTION

The winter-linden, Tilia cordata, more usually called the small-leaved lime, is described in the Flora of the British Isles (Clapham, Tutin, Warburg, 1962) as a plant native to Britain, found in woods on a wide range of fertile soils especially over limestone rocks and commonly found on limestone cliffs. It is scattered throughout the east and west northwards to the Lake District and Yorkshire, but planted northwards to Perth. It is found on the continent of Europe from North Spain, the North Balkans and South Russia northwards to c. 63°N in Norway, Sweden and Finland, and eastwards across Russia to 75°E in Siberia, the Crimea, and the Caucasus. It is generally regarded as the most thermophilous both of native trees and of the main forest trees of the European deciduous forest belt (Pennington, 1974). The present northern continental distribution of T. cordata exceeds the northern limit of the natural distribution in Britain, which is 54° 30'N in the Lake District. The factors controlling the distribution of this tree at the northern limits of its geographical range are being investigated (C.D.Pigott and J.P.Huntley, 1978 et. seq.).

T.cordata spread into northern and western Europe during the middle of the Flandrian stage of the Pleistocene epoch (Godwin, 1975). The pollen appeared in small quantities in the late Boreal period (pollen zone VIc of Godwin's pollen-zonation) and in large quantities in the Atlantic period (pollen zone VIIa), when the frequency often exceeded 10% of the total arboreal pollen preserved in the peat in the English lowlands. This abundance of pollen of *T.cordata* lasted over 2000 years, declining after 3500 B.C. (5500 B.P.). The high values for the frequency of *Tilia* pollen suggest that it was a main constituent of the forests in England when they were at their greatest extent during the Flandrian thermal maximum (Iversen, 1960).

It has been noted that the area where high frequencies of pollen of *Tilia* occur in the pollen-record of the Atlantic period in Britain coincides almost exactly with the area of the present apparent natural distribution of the tree (Pigott and Huntley, 1978). The distribution and relative abundance of *T.cordata* in northwest and northeast England at c. 3000 B.C. is shown on the sketch map (Fig.1) which is based on a map kindly provided by Professor C.D.Pigott.

The first purpose of this investigation was to assess, by pollen analysis of peat-samples, the probable distribution and frequency of *T.cordata* growing in part of the Central Pennine Uplands during the Atlantic period, i.e. between c. 5500 B.C. to 3000 B.C. (7500 B.P. to 5000 B.P.). The region chosen was one from which no data were available, i.e. around upper Swaledale and Wensleydale and approximately 575 Km^2 in area. It is marked on the map in Fig. 1.

The evidence from pollen data of the composition of the mixed forests in the Northern Pennines during the Boreal Period (c. 8800-7000 B.P.) shows a considerable variation existing in the relative abundance of pollen taxa from one

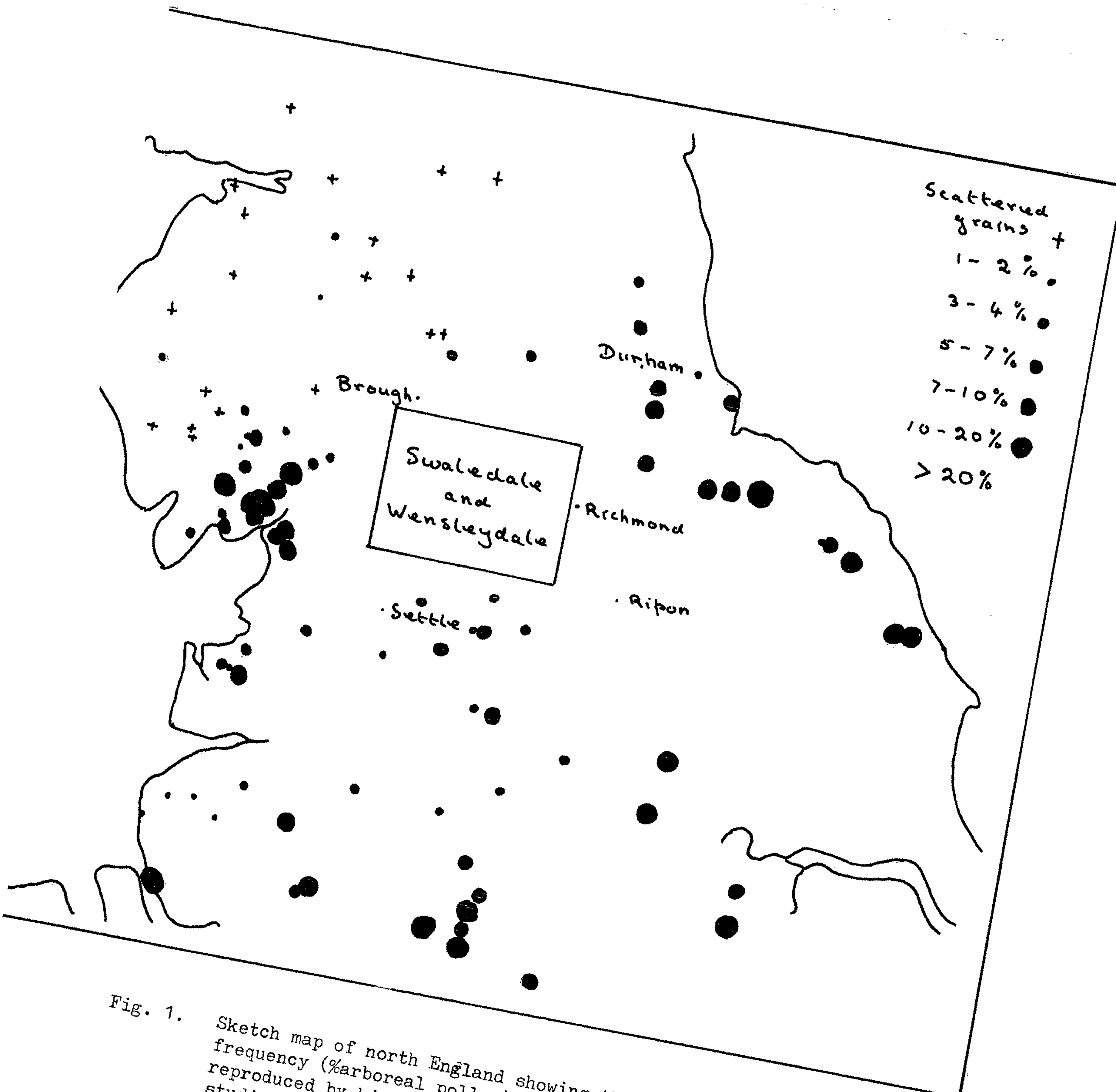


Fig. 1. Sketch map of north England showing the distribution and frequency (%arboreal pollen) of Tilia cordata at 3000 B.C., reproduced by kind permission of C.D.Pigott. The area studied is outlined by the rectangle.

site to another. This geographical variation has been the subject of recent critical study (Turner and Hodgson, 1979), and both altitude and lithology are factors associated with some of the variations.

The second purpose of the investigation was to see if there is any variation associated with lithology. The analysis by Turner and Hodgson was based on data from fifty-two sites. As only a small number of sites could be investigated in this study in the time available it was decided to keep the altitude as constant as possible and to choose sites on different rock types within the altitude range 480m to 590 m O.D. Initially, it had been planned to investigate sites at different altitudes but it proved impracticable to visit a sufficient number of sites below 300m O.D.

Swaledale and Wensleydale run from west to east in the Central Pennines and show the distinctive type of landscape of the Yorkshire Dales. The flat-topped hills rise steeply from the valley floor and prominent vertical outcrops of bare rock, known as 'scars', edge the hillside and emphasise the stepped appearance of the landform. These physical features are caused by the solid geology of the region, the step-relief being more marked as a result of glacial erosion of weathered material on the hillsides (Kendall and Wroot, 1924; King, 1960). The summits of the hills tend to reach a constant height, generally between 500m and 600m in the west although lower towards the east. This gives the impression of a plateau gradually falling in height eastwards, cut by deeply-incised valleys. Swaledale is a steep, narrow valley; Wensleydale is wider (Plates I and II).

The geological formation of the area is Carboniferous age strata resting horizontally on older rocks. At the base of the Carboniferous succession is the Great Scar Limestone and this is overlain by the Yoredale Limestone series, which in turn is capped by the Millstone Grit. The Great Scar Limestone along the floor of Wensleydale is not overlain by the later strata, other than glacial drift and moraine. The Millstone Grit is confined to the summits of the hills (Fig.2).

The Yoredale Limestone series consists of almost horizontal strata of a repeated sequence of a conspicuous limestone with an overlying sandstone which may grade into a mudstone (shale) of some kind, or coal. It is the alternation of these strata, with differing characteristics of porosity and resistance, which gives rise to the stepped nature of the sides of the Dales and to different types of vegetation cover. The resistant limestones and some of the harder sandstones stand out as scars, their upper surface forming a ledge above which rises a steeper slope of shale before the next vertical scar. Pleistocene deposits of glacial drift, boulder clay, alluvium and hillpeat cover the main strata apart from the scars. The alternation of permeable and impermeable strata makes the drainage system of the area complex. Potholes are found in the limestones and the upper edge of a limestone outcrop may be outlined by a row of shake-holes (swallow-holes) indicating where water disappears underground through porous rock (King, 1960).

Three main zones of vegetation are recognizable along the Dales, these being determined, broadly, by altitude and

Plate I Wensleydale looking west

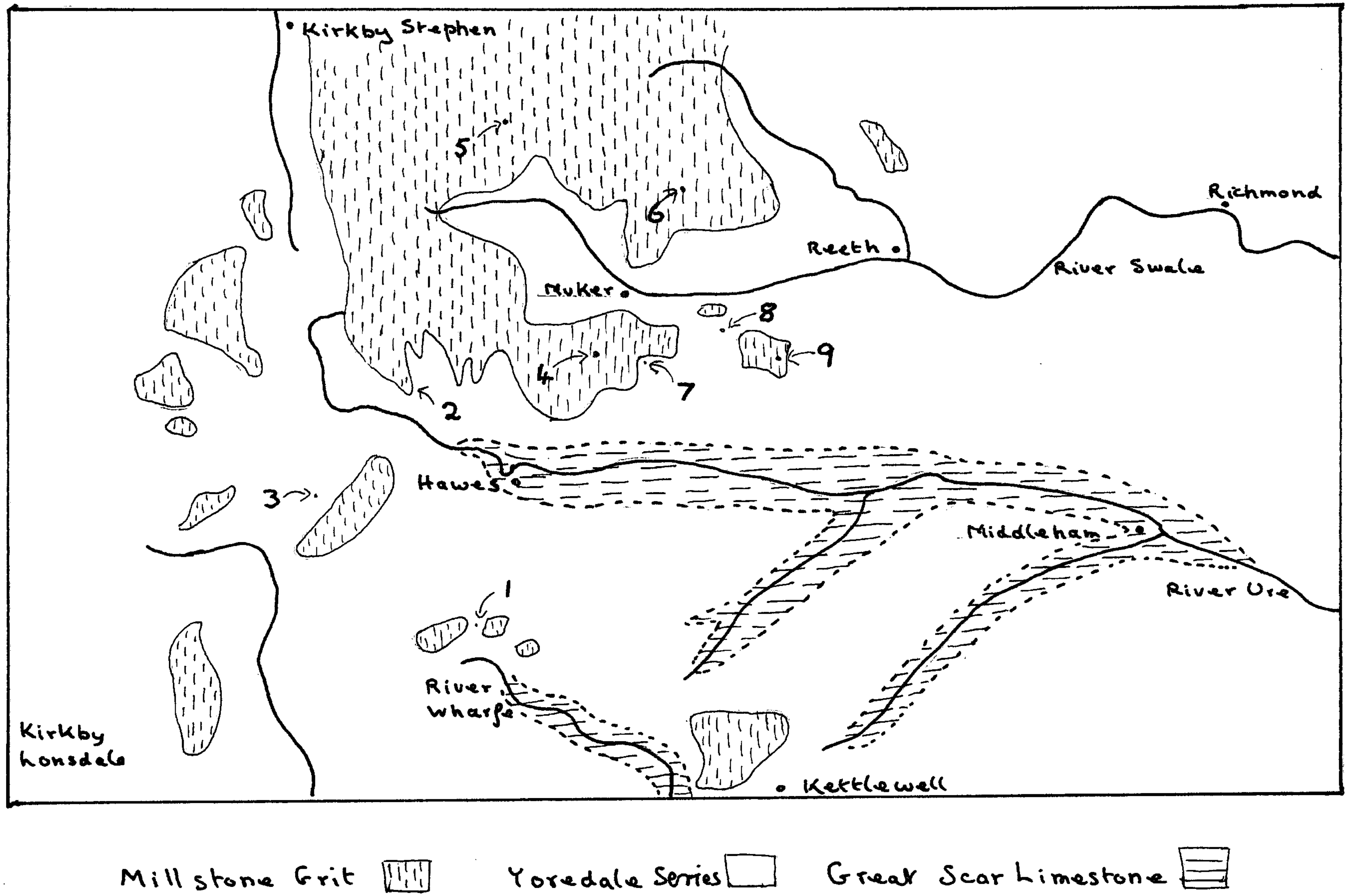


Fig. 2. Sketch map of Upper Swaledale and Wensleydale to show the geology of the area and location of sites.

solid geology.

The mean annual temperature in the valleys is higher than that of the surrounding hills whereas the annual precipitation increases with altitude. The rainfall exceeds 600mm per annum on hills above 400m O.D.

Soils derived from limestone rocks are a type of red-brown rendzina. Soil derived from millstone grit which is well-drained may be a brown earth but more usually a millstone grit soil is a podsol tending to become a peaty gley.

Meadowland and permanent pasture occupy the valleys and lower slopes. A zone of rough grassland is found on the higher and steeper slopes. The species composition of the plant communities of the rough grassland varies with the nature of the soil, whibh may be highly calcareous over limestone strata and less calcareous or podsolized over rocks of other types. The hill summits are covered by moorland. Tree growth is restricted to the lower zones, the hill-tops above 400m being too exposed. The present tree-line is generally below 300m, areas of woodland often being found at the foot of the steepest scars. Plantations of coniferous trees, as on the southeast side of Cotterdale are present to an altitude of 450m.

Extensive areas of the moorland zone are covered with peat which varies in thickness from 1.5m to 6m. The drier areas support a heath association of plants and are maintained as grouse moors both north and south of Swaledale. Where

Plate II Swaledale looking east from above Cotterdale. Swaledale is in the distance, Cotterdale in the left foreground.

small quantity. Birch was present in the north and west (Pennington, 1974).

The Atlantic period is succeeded by the Sub-Boreal and the horizon separating them is recognized by the steep fall in the frequency of Ulmus pollen. This boundary is drawn by Godwin between Zone VIIa and Zone VIIb (Godwin, 1975). When the periods were first defined by Blytt and Sernander in Sweden, the evidence from a change in peat-type and the taxa found in it suggested a climatic change in Scandinavia during which the oceanic conditions of the Atlantic period gave way to drier, more continental conditions.

In Britain there is no similar evidence to relate this horizon directly to a marked change in climate although it may have an indirect effect (Godwin, 1975). The elm-decline is generally recognized as a result of the habit of primitive man using leafy branches of elm as fodder for penned cattle (Iversen, 1949, Troels-Smith, 1960). The elm-decline horizon is more or less synchronous at 5000 B.P. $\pm$ 100 years across north Europe, on radio-carbon dating (Hibbert, Switsur and West, 1971), and is associated with an increase in pollen-types related to man's activities, e.g. Plantago lanceolata and Urtica dioica in Ireland (Mitchell, 1965) and the English Lake District (Oldfield, 1963).

METHOD

Peat for pollen analysis was collected from six sites, numbered 1 to 6. Data on the pollen assemblage for Pollen Zone VIIa, the Atlantic period, from three more sites, numbered 7 to 9, was made available from the work of M.Wilson and D.Ridgeway. The location of each site is shown in Fig. 2 and the details are listed in Table 1.

SELECTION OF SITES

The sites were selected after searching the Ordnance Survey 1:50 000 First Series map, Sheets 92, 98 and 99 for areas marked as marsh, within an altitude range of 500m to 600m, which were on level ground with little slope, where deep peat might have accumulated and secondary deposition be unlikely. The presence of hillpeat was confirmed from the Geological Survey of Great Britain Drift map (scale 1 inch = 1 mile). The solid geology of each site was checked from the Geological Survey Solid map (scale 1 inch = 1 mile), Sheets 40 and 50. Three sites were chosen where the pollen-catchment area of the peat would appear to be from vegetation growing on soil above predominantly limestone strata and three sites were chosen where the surrounding catchment area was above Millstone Grit.

All but one of the sites proved to have peat of sufficient depth, i.e. more than 2m, and to be on a level hill summit or gently sloping valley. The proposed site at Whershaw Bottom was abandoned due to insufficient depth of peat, and replaced by a site about 2Km distant, near Little Punchard Head. Although situated between Millstone Grit hilltops,

TABLE 1. DETAILS OF SITES SHOWN IN FIG. 2

SITE	NATIONAL GRID REFERENCE	GEOLOGY	ALTITUDE (m O.D.)
1. Fleet Moss	SE 862834	Limestone	560
2. Cotter End Tarn	SE 816936	Limestone	503
3. Shaking Moss	SE 794894	Limestone	549
4. White Beacon Hags	SE 893951	Millstone Grit	590
5. Fog Close	NZ 870062	Millstone Grit	540
6. Little Punchard Head	NZ 959028	Millstone Grit	520
7. Askrigg Common	SE 941935	Limestone	495
8. Summer Lodge Tarn	SE 951948	Limestone	520
9. Beldon Bottom	SE 968945	Millstone Grit	480

N.B. The geology is the solid geology immediately surrounding the site

Plate III   Cutting a peat profile at Fog Close this site is close to a large outcrop of Crow Chert and some Crow Limestone on the western edge. It is therefore somewhat similar to Sites 7 and 8, which have been classified for convenient reference as limestone sites, but the solid geology includes a considerable amount of Richmond Chert.

Sites 1 to 6 and 8 are within the altitude range of 500m to 600m, Sites 7 and 9 are a little below 500m.

COLLECTION OF SAMPLES

The peat samples at Sites 1 to 5 were collected by cutting into a peat hag with a spade to expose a vertical peat profile. Samples were taken directly from the profile by pressing glass specimen tubes into the peat and withdrawing a small quantity in the tube, working from the top of the profile downwards. The peat surface was cleaned by making a horizontal cut with a flat trowel edge before each tube was pressed in. A metal tape measure was extended vertically against the peat profile and samples taken at 10cm intervals. (Plates III and IV). Each specimen tube was closed immediately upon withdrawal with a clean plastic stopper and labelled with a waterproof ink pen. Samples were not taken from the top 0.5m of peat just below the present vegetation horizon.

At Site 3 it was necessary to cut cores of peat below the peat profile from 1.30m downwards, using a Russian-type peat-sampler. At Site 6, where no suitable broken peat was found, all samples were collected as 50cm cores. These were kept in the labelled plastic liners, carefully wrapped in plastic bags until small samples were cut from the cores

Plate IV   Collecting samples from peat profile at Shaking Moss in the laboratory. The cores were transported and stored in a horizontal position, to avoid disturbance of the stratigraphy.

The peat-sampler was pressed into alternate bore-holes about 20cm apart for each successive 50cm core, so that the peat should not be disturbed by the head of the borer whilst obtaining the previous sample. The blade and chamber of the sampler were cleaned with water or a clean cloth between taking each core.

PREPARATION OF SAMPLES

The peat was prepared for pollen analysis by treatment with 10% sodium hydroxide solution followed by acetolysis (Faegri and Iversen, 1966). Only one sample required treatment before acetolysis with hot hydrogen fluoride followed by 10% solution of hydrogen chloride, to remove silt. The pollen was mounted in glycerine jelly containing safranin stain.

Pollen counts were made from levels at 40cm intervals to locate the boundaries of pollen assemblage Zone VIIa (Atlantic period) within the peat and more levels were interpolated at 10cm and 20cm intervals. The transition from Pollen Zone VIc to Zone VIIa was recognized by an increase in the frequency of *Alnus* and a decline in that of *Pinus*. The upper limit of Pollen Zone VIIa was characterized by the marked decline in the frequency of *Ulmus*. After establishing the upper and lower limits of Zone VIIa, further samples were taken at intervening intervals between these limits to define any changes in the vegetation which had occurred during the period of Zone VIIa, from c.7500 to 5000 B.P. At each level, pollen counting stopped when at least 150 tree (arboreal) pollen grains had been recognized, excluding *Corylus* and *Salix*.

TREATMENT OF RESULTS

The pollen counts for the relevant levels at each site are listed in Appendix A. The list includes figures for the levels used to establish the lower and upper limits of Zone VIIa in the peat. These were not used in the statistical calculations. The results are presented in two ways in the text.

1. Pollen diagrams for each site have been drawn in order
   - (i) to establish the lower and upper limit of the pollen assemblage Zone VIIa;
   - (ii) to provide a graphic representation of any variation in the frequency of pollen taxa during this period.

   The pollen diagrams have been drawn using the values for the percentage of total arboreal pollen excluding the shrubs, i.e. *Corylus* and *Salix*. Herbaceous pollen counts, including the Ericaceae, have been listed.
2. The results have been analysed statistically as follows:
   - (i) The application of the chi-squared test to the sample counts at each site, to test for the significance of within-site variation.
   - (ii) The application of the chi-squared test to the site totals, to test for the significance of between-site variation.

(iii) The application of the Montecarlo test to determine whether or not the between-site variation is separate from the within-site variation and not a function of it. I am grateful to Dr. T.Gleaves for the use of the program, called Montechi, and for his guidance with this test. The procedure is explained later.

(iv) A principal components analysis of the mean percentage pollen value at each site. This is a form of multivariate analysis used to summarize the observations and to describe the relationship between the many variables in terms of a simplified set of new independent variables. These are called components and are linear functions of the original observed variables (in this instance, pollen counts). The first few principal components will contain most the variance of the original data.

Principal components analysis has been used frequently in polynology; in zonation studies by Birks (1974) and Pennington (1975) and to study variation in the composition of Boreal forests by Turner and Hodgson (1979). The application of this technique is described by Birks (1974) and Webb (1973). The mathematics is described by Seal (1964) and Davis (1973).

I am very grateful to Dr. J.Turner for advice and assistance over procedure for this analysis.

Pollen counts for *Corylus* and *Salix* were included in all statistical calculations.

Plate V Fleet Moss looking south-east. About half the Moss is visible, the remainder being to the right of the picture

DESCRIPTION OF SITES

1. FLEET MOSS

Fleet Moss is south of Wensleydale at an altitude of 560m O.D., in a shallow depression between the lower slopes of Dodd Fell Hill to the west and Jeffery Pot hill to the east, on the summit of which is Fleet Moss Tarn. Drainage water from the Moss collects northwards into Bardale Beck, thence to Wensleydale and southwards into Oughtershaw Beck and Wharfedale. The Moss is approximately 0.75 x 0.95Km ($0.7Km^2$) in area and the hillpeat is deep, rising nearly 3m above the base of the erosion gullies, where bedrock is exposed. Plant remains are plentiful at the base of the peat hags, twigs and large branches of trees being exposed. The peat hags support a vegetation cover of Calluna vulgaris, Eriophorum vaginatum with Vaccinium myrtilis and occasional Erica tetralix and Empetrum nigrum. The slopes of the surrounding hills lie on Main Limestone of the Yoredale Series and the Moss has developed on Underset Limestone beneath which is a sandstone layer. A layer of light grey clay is beneath the peat. The road from Hawes to Buckden is on Main Limestone below Dodd Fell Hill and part of a Roman road is close to it. The grassland on the Main Limestone slopes is typical of a calcareous soil and provides rich pasturage for sheep (Plate V).

2. COTTER END TARN

Cotter End Tarn lies in a depression to the south of High Abbotside and Tarn Hill on a wide spur of hilltop between Cotterdale and the head of Wensleydale at an

Plate VI Cotter End Tarn from the south-west

Plate VII Shaking Moss from Widdale Fell altitude of 503m O.D.(Plate VI). The whole summit is peat-covered, the peat to the west and northwest of the Tarn being deep over an area of 0.4 x 0.3Km ($0.12Km^2$). The peat is cut by erosion channels and there is considerable secondary deposition in the water-filled channels, the bedrock being visible only occasionally. The peat hags may be 3m high, the walls sloping at an angle of 50° to 60° due to weathering and requiring a lot of digging to obtain a vertical profile. Two profiles were cut, the profile below 1.4m being displaced 0.5m laterally from the upper profile. The hags were topped by a Callunetum-Eriophoretum association. There has been considerable peat-cutting to the south of the hill summit.

Tarn Hill is formed of the base layer of the Millstone Grit Series and rests upon Crow Limestone of the Yoredale Series, which outcrops north and south of Cotter End Tarn and the deep peat. Water has accumulated due to a thin layer of sandstone lying on the Little Limestone below.

Around the Tarn are marshy plants and the tussock and pool formation bog extends over the hilltop, the tussocks formed of Calluna vulgaris and Eriophorum vaginatum with Vaccinium myrtilis, Empetrum nigrum and Rubus chamaemorus, the pools contained Sphagnum spp. In some parts, Eriophorum is dominant with frequent Juncus squarrosus and Nardus stricta.

3. SHAKING MOSS

Shaking Moss is on a small plateau at the foot of the north side of Widdale Fell above Mossdale Moor which slopes

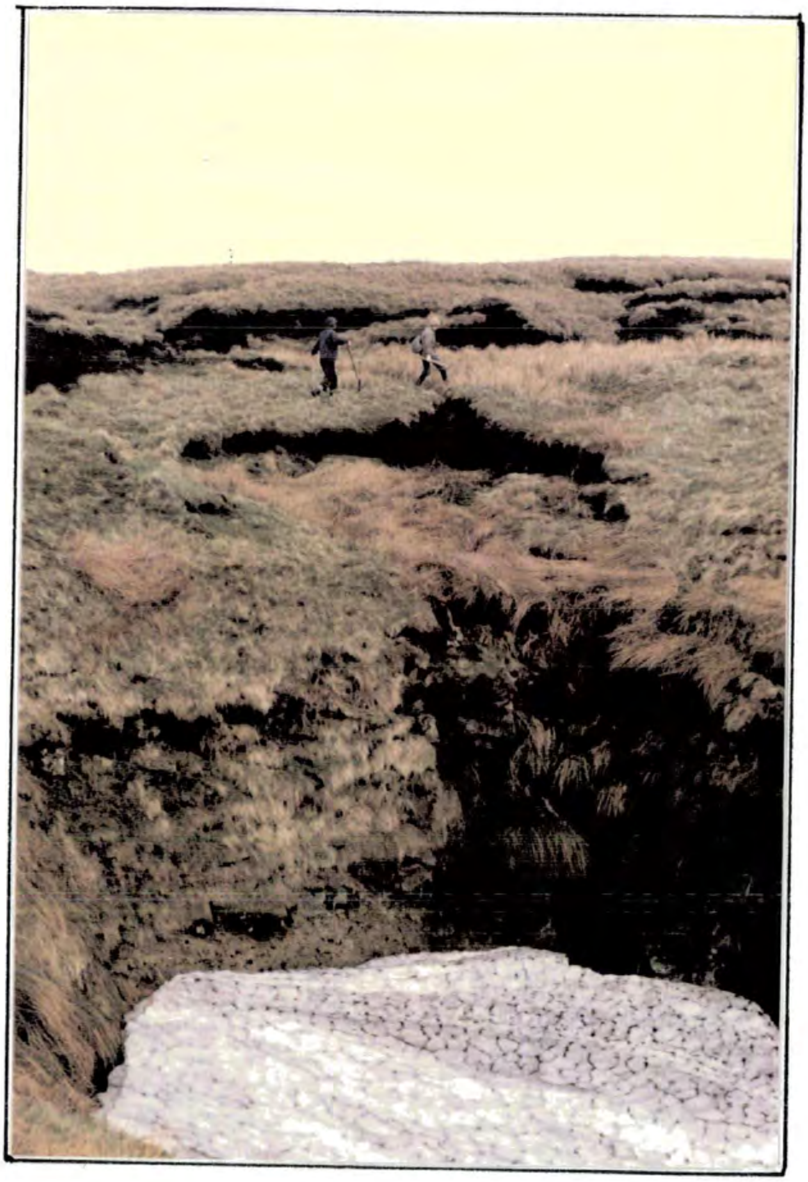


Plate VIII Shaking Moss. Snow-filled shake-hole gently northwards to Garsdale. A number of old mine pits are nearby and shake-holes (Plates VII and VIII). The edge of the Moss approximates to the 549m contour of the plateau and occupies an area of 0.3Km x 0.25Km (0.075Km^2). The peat hags are 3m above bedrock in parts of the Moss. In places the peat hags had been eroded and large level areas of peat up to 15m across were visible, some being littered with the fossilized twigs and branches of trees which had been preserved in the lowest peat-layers (Plate IX).

Shaking Moss lies on mudstone above a thin sandstone which overlays a small part of a large outcrop of Main Limestone of some 2Km^2.

The vegetation to the west of the Moss is rich grassland of the calcareous, base-rich type. The moorland slopes of Widdale Fell reflected a more acid soil bearing a Callunetum-Eriophoretum association. The deep peat was supporting _Calluna vulgaris_, _Eriophorum vaginatum_, some _Trichophorum caespitosum_ and _Empetrum nigrum_.

4. WHITE BEACON HAGS

White Beacon Hags describes a large area of hillpeat 1Km x 0.5Km (0.5Km^2) in extent about 1Km east of the hill summit called Lovely Seat at an altitude of 590m O.D. The peat is on a flat shelf of land which is the water-shed for streams running northward to Swaledale and southward to Wensleydale. In the lowest part, west of the Beacon, the peat hags are 3.5m high with almost perpendicular sides rising from bedrock above a layer of greyish silt 5cm thick. Large tree branches protrude from the base of the peat.

The vegetation on the top of the hags is mainly composed of _Calluna vulgaris_, _Eriophorum vaginatum_ and

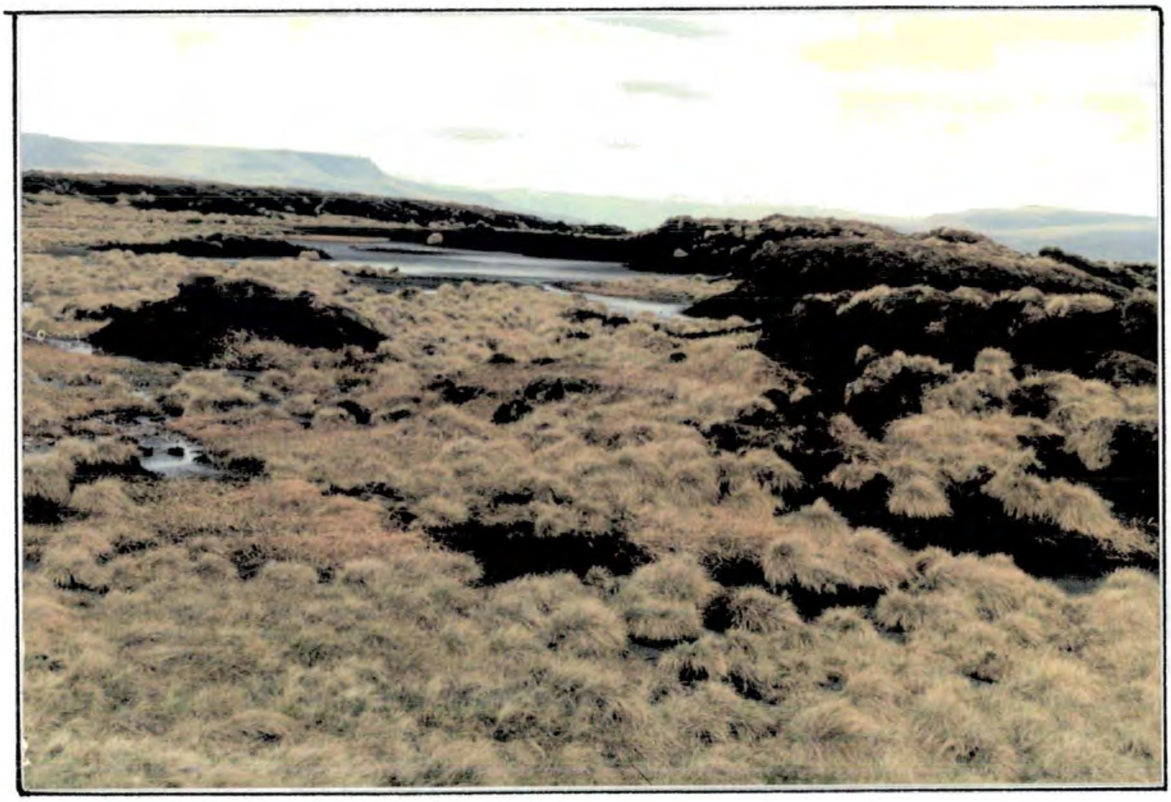


Plate IX Shaking Moss. Eriophorum vaginatum in foreground. Levelled eroded peat in middle distance.

Vaccinium myrtilis. Erica tetralix and Empetrum nigrum are also abundant. A similar plant community covers the hilltops, together with Trichophorum caespitosum, Nardus stricta, Rubus chamaemorus and Molinia caerulea.

The peat has developed on Tan Hill Grit which is a mudstone (shale) having a very thin limestone in it. The peaks around are also of the Millstone Grit series.

5. FOG CLOSE

Fog Close is the most northerly of the sites and is in a shallow depression on the plateau west of Tan Hill at an altitude of 540m O.D. The area is approximately 0.5Km x 0.25Km (0.124Km^2) situated at the water-shed of gills descending north to join the river Greta at Bowes and becks descending southwards to join the river Swale. There are disused mine workings to the north. Erosion gullies were found at the southern end where the peat walls rise 3.2m above exposed bedrock and a thin layer of yellowish-grey silt. Calluna vulgaris and Eriophorum vaginatum are the dominant plants on the peat, with Vaccinium myrtilis and occasional plants of Erica tetralix.

The peat has developed on Tan Hill Grit, the most recent of the Millstone Grit strata, and overlays a sandstone. The Tan Hill Coal seam is extensive.

The grassland around is used for sheep grazing and the species present include Festuca ovina, Molinia caerulea, Trichophorum caespitosum, Rubus chamaemorus, Galium saxatile and Potentilla spp. amongst the dominant Calluna vulgaris and Eriophorum vaginatum. Vaccinium oxycoccus occurs as well as V.myrtilis (Plates X, XI).

Plate X Moorland north of Fog Close with Calluna vulgaris and Eriophorum vaginatum

6. LITTLE PUNCHARD HEAD

The hillpeat is in a saddle, sloping southward between Little Punchard Head and Friarfold Moor on the west and Great Pinseat on the east. It is 0.5 x 0.2Km (0.01Km^2) in area, at an altitude of 520m O.D. Drainage flows south to Hard Level Gill and the river Swale. Land drains have been cut recently on the slopes of the hills and the surface of the peat was very wet, Sphagnum-filled and open pools lying between hummocks of C.vulgaris, E.vaginatum and V. myrtilis.

The peat was 5m deep in the middle of the valley, and was very soft. The cores were very wet when brought to the surface. Stratigraphic changes in the peat were clear. The peat has probably accumulated in a mere or stream bed, as pollen of Caltha, Ranunculaceae spp., Filipendula, Leguminosae spp. and Succisa were found in abundance in peat samples between 3.7m and 4.6m below the surface.

The peat is on a fine sandstone (Ten Fathom Grit) between the Millstone Grit peaks of Great Punchard Head and Great Pinseat. The lower slopes on the north side of Great Pinseat and western slopes of the Little Punchard Head are Crow Chert, a siliceous limestone, with a narrow band of Crow Limestone outcropping beneath this at the edges of the valley above the Ten Fathom Grit. The Bishop's Vein, of barytes and fluorspar runs east-west at the north end of the valley.

The vegetation of the hillslopes reflected some of the underlying geology. Acid grassland association and Callunetum-Eriophorietum associations extended from Great Pinseat to the valley. On the middle north slopes of Great Pinseat, the grassland species were those of a more basic

Plate XI Fog Close from the south. The hillpeat can be seen in the middle distance soil, and included *Thymus serpyllum*, typical of calcareous soils, and *Viola lutea*, a plant of basic soils.

7. ASKRIGG COMMON

The hill peat lies in a south facing valley at an altitude of 495m O.D. on Main Limestone, with slopes of Richmond Chert around it. The area of Askrigg and Muker has complex geological outcroppings and a number of fault lines.

8. SUMMER LODGE TARN

The hill summit, at 520m O.D. is composed of Richmond Chert, a very siliceous limestone. To the north of the Tarn and the hill peat is a concentration of mineral veins (fluorspar and barytes) and a complex layering of sandstone and limestone rocks.

9. BELDON BOTTOM

The moss fills a flat valley at an altitude of 480m O.D. and slopes down gently northwards to Swaledale beneath the steep hill of The Fleek, formed of Millstone Grit (Plate XIII).

The geology of each site was discussed with Dr. A.A.Wilson at the Institute of Geological Sciences, Leeds.

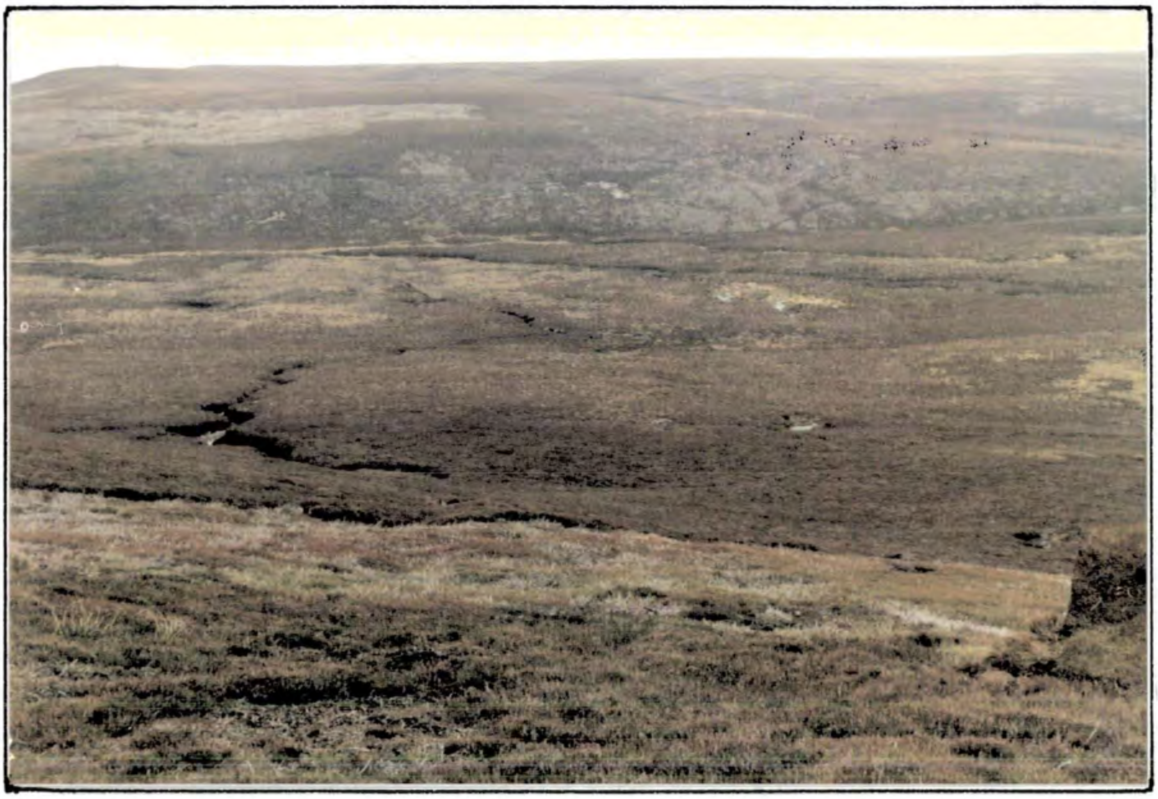


Plate XIII Beldon Bottom from the north

RESULTS AND DISCUSSION

Results

The pollen diagrams for the sites are shown in Figs. 3, 4, 5 and 6. The pollen counts are listed in Table I and Table II in Appendix A.

The lower and upper limits of Zone VIIa are shown on the left hand side of each pollen diagram. There was some difficulty in determining the elm-decline precisely at Fog Close and Little Punchard Head (Fig. 5). The decline has been drawn between the 200cm and 180cm level at Fog Close where the frequency of Ulmus drops from 8% to 5%, although there was an increase to 9% at the 160cm level and a subsequent decline to 5% again at the 150cm level.

At Little Punchard Head the Ulmus decline has been drawn between the levels 370cm and 360cm, where the frequency drops from 13% to 9%. Although this is a higher percentage than at other sites for the post-decline proportion, the levels above 360cm showed a continued small decrease of 1% or 2%. Therefore the upper limit of Zone VIIa has been drawn at the level of most marked decline of the elm frequency.

Discussion

(a) The Presence of Tilia cordata

Pollen of this species was found at all sites. At most of the sites its mean value was less than 1% of the total tree pollen. At Site 9, Beldon Bottom, however, it was higher, i.e. 1.20%. There is a slight increase in frequency at all sites towards the latter part of the Atlantic period.

Fig. 3.1. Pollen Diagram from FLEET MOSS

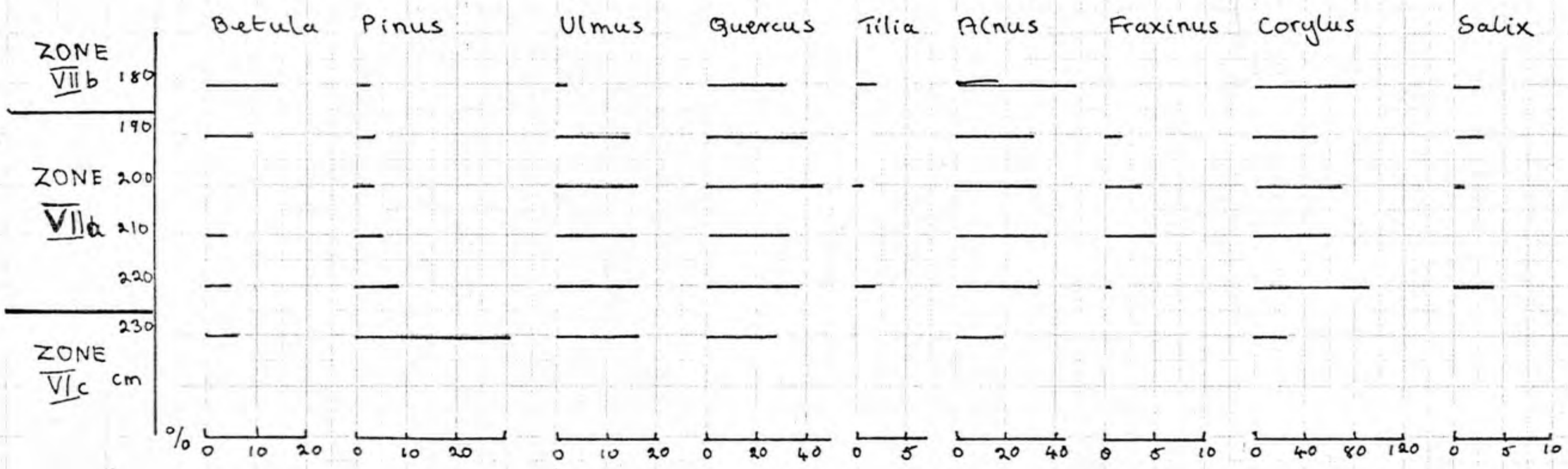
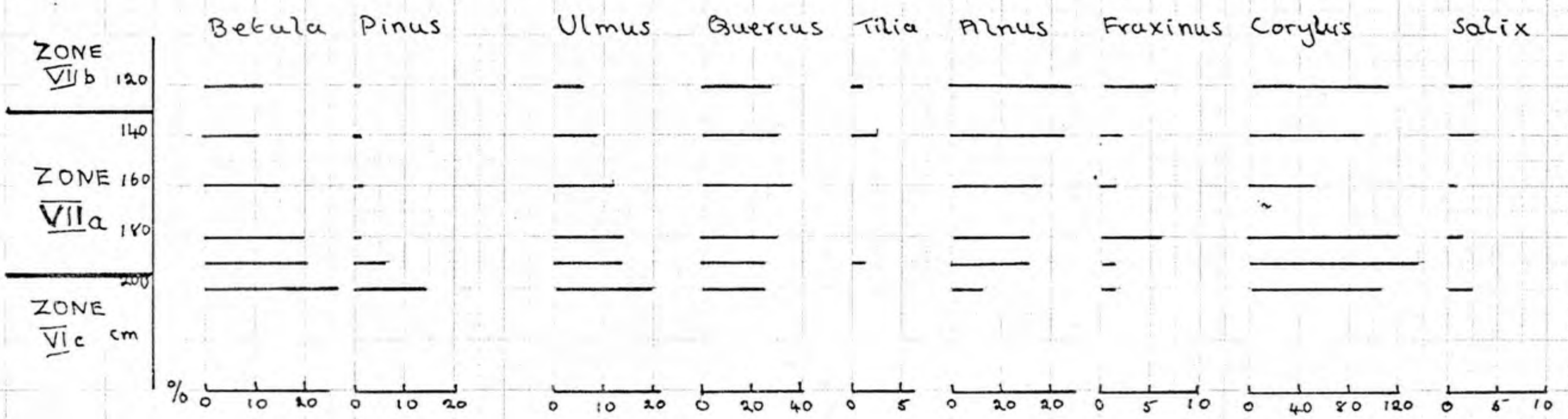


Fig. 3.2. Pollen Diagram from COTTER END TARN



% Total = Σ Arboreal (Tree) Pollen.

Fig. 4.1. Pollen Diagram from SHAKING MOSS

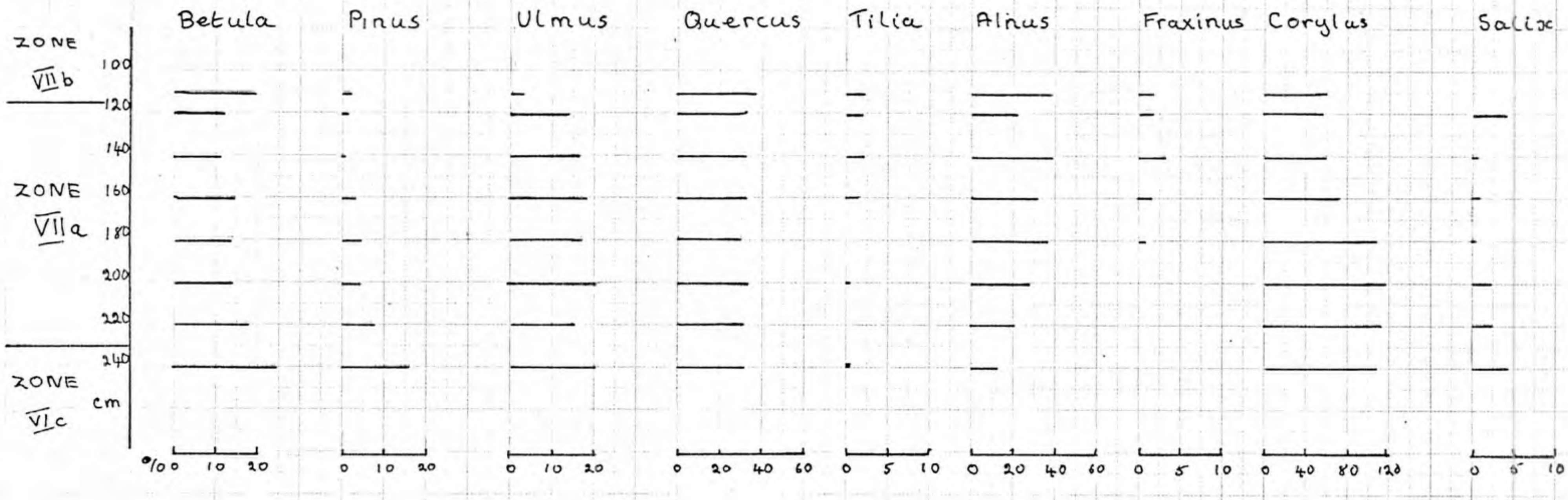
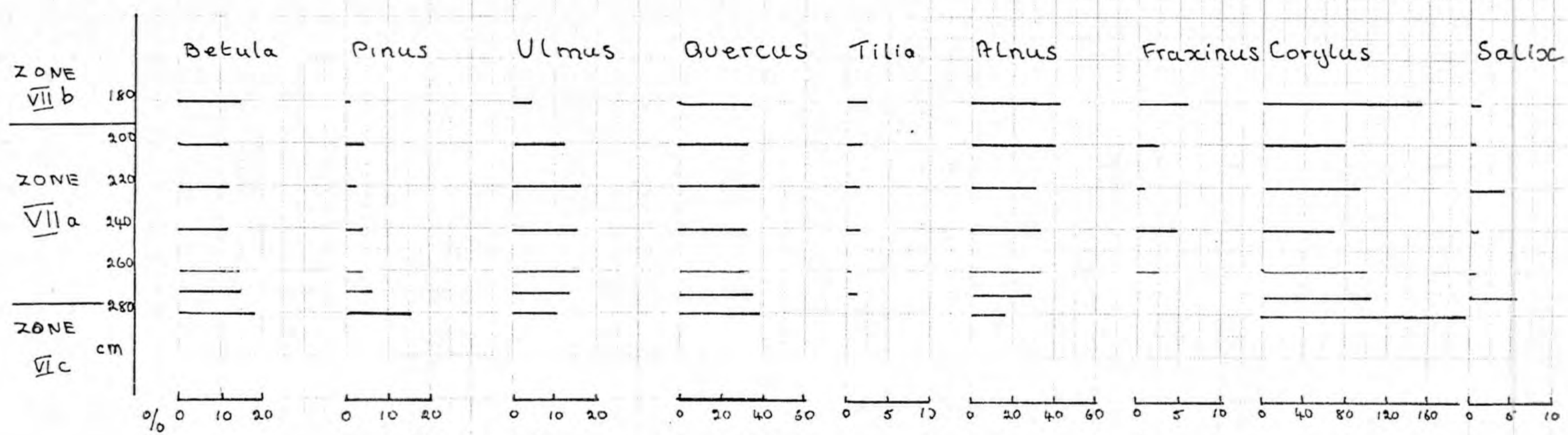


Fig. 4.2. Pollen Diagram from WHITE BEACON HAGS



% Total = Σ Arboreal (Tree) Pollen

Fig. 5.1. Pollen Diagram from FOG CLOSE

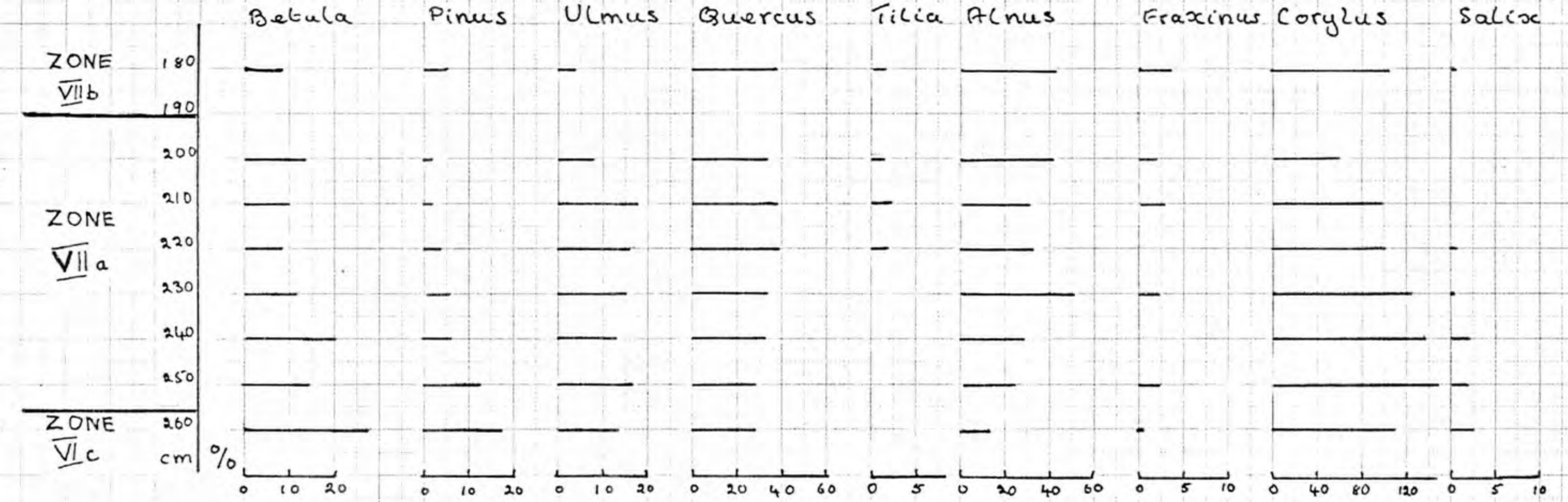
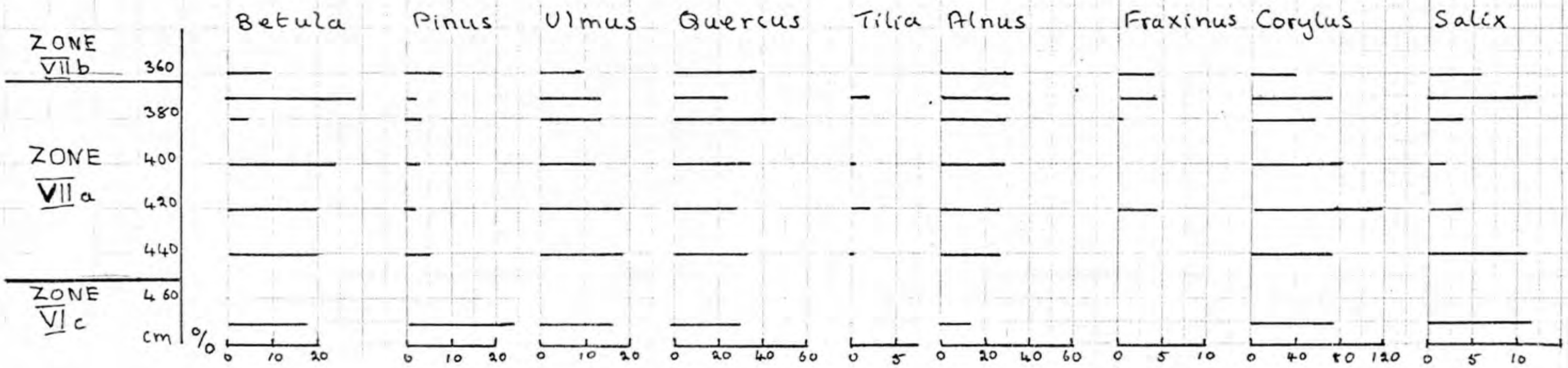
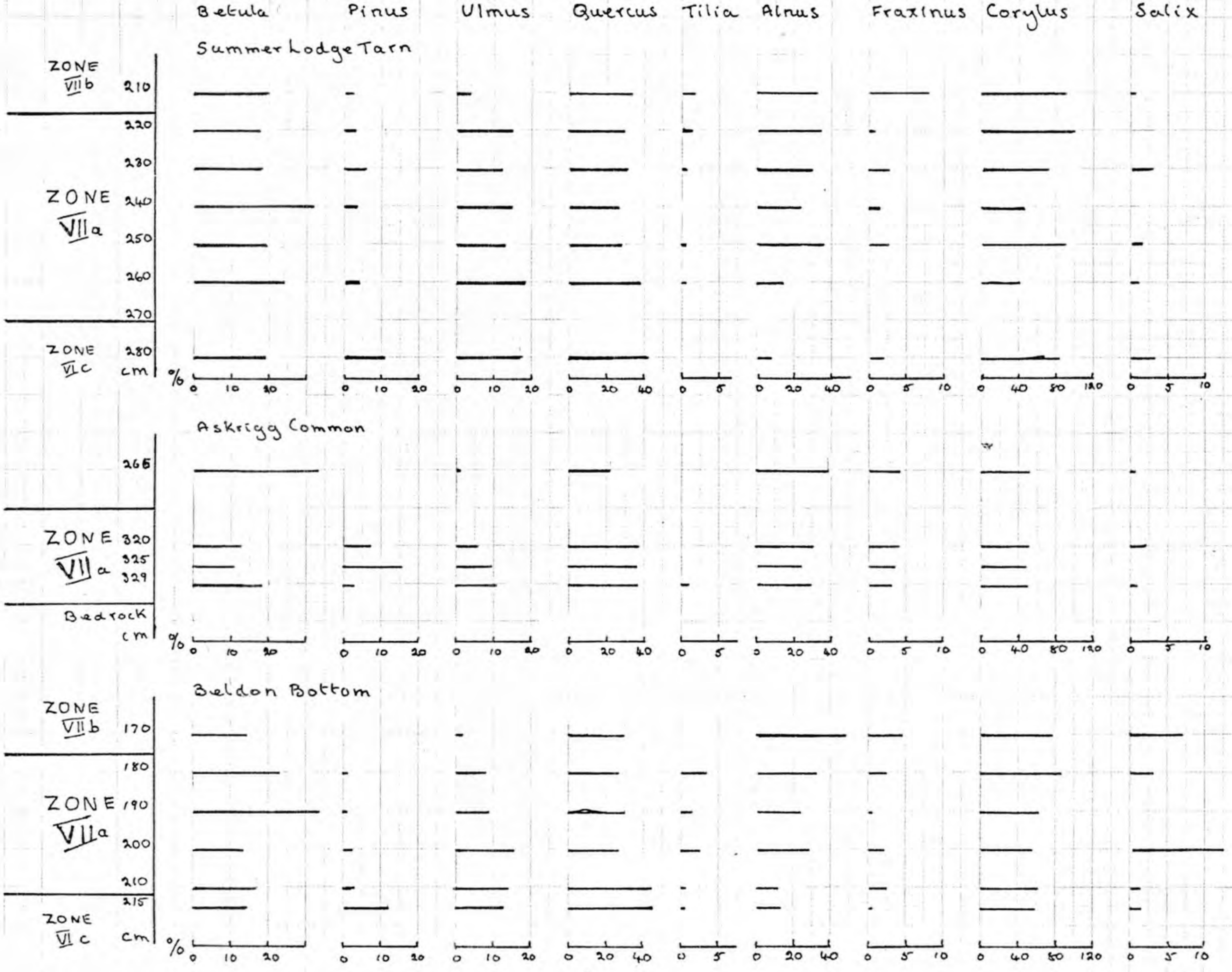


Fig. 5.2. Pollen Diagram from LITTLE PUNCHARD HEAD



% Total = Σ Arboreal (Tree) Pollen



% Total = Σ Arboreal (Tree) Pollen

In assessing the real presence of T.cordata as a constituent tree of the forests during this period, note must be taken of the constraints attendant upon the interpretation of fossil pollen data both to reconstruct the nature of the vegetation at a particular time, and to trace the history of a species. It has been stated by Moore and Webb (1978) that essential to the theory of pollen analysis is the concept that the frequency of a pollen type within an assemblage is a function of the abundance of that taxon in the surrounding area.

This relationship will be affected not only by the pollen productivity of the taxon concerned but also by the pollen dispersal capabilities of the plants themselves, and by the immediate environment.

An attempt to grapple with the variability of the relationship between pollen input and the abundance of a species in a region is the use of the R ratio, proposed by Davis (1963) where

$$R_A = \frac{\text{Percentage pollen of species A}}{\text{Percentage representation of species A in vegetation}}$$

and this ratio should be used to adjust the pollen percentage. This would then give a more accurate representation of the true proportional representation of the species in the vegetation from which the pollen assemblage was derived. It has the disadvantage however, that the R ratio itself for any particular species may vary. This could happen if the distance from the pollen source to the accumulation site or the local environment of the pollen producing species varies. These variations cannot be judged from the fossil assemblage to which the adjustment is being applied.

The pollen production of forest trees varies widely between species (Faegri and Iversen, 1964), and the production of pollen by Tilia is low compared with that of the forest trees associated with it, other than Fraxinus (Andersen, 1967). Andersen collected samples of pollen from trees within a plot of 30m radius and compared the composition of the pollen spectrum with the relative area of the canopy occupied by each species. Using Fagus (beech) as unity he calculated relative production indices. These showed that Tilia and Fraxinus were under-represented by the pollen proportion in a ratio of 0.5 : 1, whereas Quercus and Betula were over-represented in a ratio of 4 : 1. He suggested that these figures may be used as correction indices when constructing pollen diagrams from pollen deposited in a small catchment area within a forest (Andersen, 1970, 1973). If the correction factors are applied, then 1% Tilia pollen would represent 7% Tilia in the forest.

The pollen deposited in a small basin within a forest is mainly derived from within and beneath the canopy from a small area (about 1-2 ha) around the basin (Tauber 1965, 1967). Where the catchment surface is large, the pollen will have been derived from a much larger area of vegetation because pollen liberated above the tree canopy will be mixed by air-currents and may be carried a considerable distance.

Tilia is normally pollinated by insects and the pollen is not adapted to wind-dispersal. The grains are large and tend to stick together when shed, more so than do the grains of other tree species. Also the grains may cluster in groups, up to nine in number, whereas the average size of a cluster of grains of Quercus and Betula is three (Rempe, 1937). Tilia flowers in July or August, when the leaf-canopy is dense, and, therefore, when the wind-speed within the canopy is reduced and the filtration of pollen by the leaves is greater (Geiger, 1965). Both these characteristics limit the distance over which pollen may be dispersed and the pollen settles mainly within a range of a few hundred metres of its source (Andersen, 1970).

Thus it would seem that Tilia tends to be under-represented by frequency in its pollen diagram and that the pollen is likely to have been derived from trees within a few hundred metres of the deposition site.

The pollen of Tilia is remarkably resistant to decay and may be preserved in mineral soils, where other pollen types are not (Godwin, 1975). However the good state of preservation of all pollen at the sites investigated suggests that this will not have affected the relative abundance of pollen types. Godwin (1975) points out that grains of Tilia are easily recognizable, as a whole or as fragments and are unlikely to escape notice during counting.

There is evidence to suggest that the clearance of other trees, which allows more direct light to fall on the remaining trees, may induce increased flowering in Tilia and therefore increased pollen production. A marked increase in the abundance of Tilia pollen has been shown in the Lake District immediately following the elm-decline and other parts of northern England (Pigott and Huntley, 1980). This has been explained because the canopy of the woodland would be opened by the clearance or coppicing of *Ulmus*, thus promoting flowering of *Tilia*. However there is no evidence of anthropogenic forest clearance during the Atlantic period before the elm decline and it is unlikely that *Tilia* is over-represented for this reason.

Recent work by Pigott and Huntley (1980 in press) has shown the limited dispersal range of *T. cordata* growing in a mixed woodland of some 12.6 ha in Grizedale, northwest England. Pollen samples collected along radial transects from the base of a single, profusely-flowering tree showed that the amount of pollen deposited decreases along each radius and does not contribute significantly to pollen deposited on the forest floor beyond a distance of some 60-100m.

This limited dispersal of *Tilia* pollen has been demonstrated by Pigott and Huntley (1980) to provide a sensitive means of determining the former distribution of the species by pollen analysis where the pollen deposition occurs in a smaller narrow basin in a forest. From the two sites studied, they conclude that from deposition sites of small surface extent which are, or were, surrounded by forest, the presence of *Tilia* pollen, in counts of 150-400 arboreal grains from most samples in a vertical sequence, even at values as low as 1% would seem to be evidence of trees growing near the site, within distances of 100-500m.

In Swaledale and Wensleydale, no sites were nearer together than 1Km and most were much further apart. Therefore, on the basis of the considerations above, it may be inferred that the

Tilia pollen found at each site was deposited from trees growing in the vicinity of the site. At White Beacon Hags and Beldon Bottom, where the occurrence of the pollen is in continuous vertical sequence, it would appear that *Tilia* was a constituent part of the woodland within a half kilometre of each place. This would be true also for Fog Close during the latter part of the Atlantic period. These sites are on Millstone Grit. There are gaps in the vertical sequence of samples at the remaining sites. These sites are near to or on limestone or chert rocks, except Little Punchard Head.

The presence of *T.cordata* on the Millstone Grit, where the soil type may be an acid brown earth or brown podsol, accords with the present distribution of the tree in eastern England and in Europe, where it tends to occupy deep brown and grey-brown forest soils (Pigott and Huntley, 1978).

It is not certain from the evidence that it was present generally in the forest around the limestone and chert sites. This is interesting in view of its present distribution because there are large populations growing on Carboniferous Limestone in the northwest of England and many are successful on steep slopes, ravine edges, crags or scree. Pigott and Huntley (1978) suggest that the distribution is dependent not on the chemical nature of the rock but its topography; it may be the karstic morphology of the rocks which is critical.

The reason for its greater frequency or its restriction to such situations in the northwest is not certain. It could be competition, in which it has been excluded from the deeper soils by *Quercus petraea* or it could be that it has survived where growing in places inaccessible for forest clearance by man (Oldfield, 1963).

It is interesting to compare the frequency of 1% *Tilia* pollen at some sites in Swaledale, at altitudes of 500m with the frequency of 10% in the Southern Pennines at altitudes of 600m at the end of the Atlantic period (Conway, 1954), when the species had reached its maximum extent northwards in Britain (Pigott and Huntley, 1980).

(b) Variation in the species composition of the forest.

Each pollen diagram shows a variation in the proportional representation of the arboreal pollen taxa throughout Zone VIIa.

At each site, the frequency of *Quercus* fluctuates. *Quercus* reached its highest frequencies of about 45% at Fleet Moss and Little Punchard Head, the most variable frequencies being found at the latter site and ranging from 20% to 40%. The frequency was most consistent at Shaking Moss, at close to 30% throughout.

Alnus shows an increase at each site, with the highest frequency of 44% at Cotter End Tarn. It fluctuated most at Shaking Moss, however, varying from 20% to 40% in frequency.

Pinus shows a decrease throughout the period to a frequency of 1% or less but is never absent altogether from any site. It maintained higher proportions at White Beacon Hags and Fleet Moss.

The proportion of Betula fluctuates most at Little Punchard Head with corresponding changes in Quercus and Alnus. The frequency of Ulmus at Cotter End Tarn, between 10% and 13% is consistently lower than at other sites. Only three grains of Fagus were found, and these have been omitted from the results.

Pollen counts for the shrubs, Corylus and Salix, were not included in the total sum for the percentage calculations for the pollen diagrams, but the frequency is shown as a percentage of the tree pollen sums. Corylus is very variable in frequency at all sites, from between 45% to 55% at its lowest frequency to 93% to 148% at its highest frequency. Salix reached a maximum percentage frequency of 12.5% at Little Punchard Head.

The pollen diagrams suggest graphically that variations in the frequency of pollen taxa exist both at each site and between one site and another. Therefore tests for significance of this variation were applied.

The chi-squared test of the pollen count at each level on a site showed that the variation within each site was significant at all sites except Site 4, White Beacon Hags, and Site 7, Askrigg Common, where $P < 0.05$ (see Table 2).

The chi-squared value for the variation between sites, using the total pollen count for each taxon on each site is 480.3543 with 64 degrees of freedom and is significant ($P < 0.001$). However it is necessary to determine that the significance of this variation is distinct from and not

TABLE 2. THE VALUES OF CHI-SQUARED FOR: (i) WITHIN-SITE VARIATION; (ii) BETWEEN-SITE VARIATION; (iii) THE MONTECARLO DISTRIBUTION

(i) WITHIN-SITE VARIATION

SITE	CHI-SQUARED	DEGREES OF FREEDOM	VALUE OF P
1	48.119	18	0.001
2	54.758	15	0.001
3	101.831	30	0.001
4	26.737	24	0.95
5	70.164	24	0.001
6	104.64	24	0.001
7	19.055	12	0.95
8	103.915	24	0.001
9	81.42	18	0.001
Total	610.639	189	

(ii) BETWEEN-SITE VARIATION

Chi-squared = 480.35 with 64 degrees of freedom

(iii) MONTECARLO DISTRIBUTION OF PROBABILITY BASED ON 999 RANDOM SAMPLES

Class	Chi-squared	Number in class
1	0.00 - 48.03	0
2	48.03 - 96.07	0
3	96.07 - 144.11	9
4	144.11 - 192.14	98
5	192.14 - 240.18	314
6	240.18 - 288.21	361
7	288.21 - 336.24	169
8	336.24 - 384.28	39
9	384.24 - 432.32	9
10	432.32 - 480.35	0
11	480.35 - 528.39	1

Montechi, i.e. highest chi-squared value on a random number was 428.57. It falls in class 9.

The chi-squared value for the real data falls in class 11.

The probability is 1 in 1000, i.e. 0.001.

dependent upon the within-site variation, the latter having been demonstrated already as significant at seven sites. The form of the Montecarlo test used here has been designed to establish the validity of the chi-squared value for the between-site variation, notwithstanding the significant within-site variation.

The program used for the test calculated 999 times a chi-squared value, just as it did for the between-site variation, but with the forty one individual samples rearranged in a random way into nine groups which corresponded in size with those of the original sites. Then the 999 values for chi-squared were placed in size classes as shown in Fig.2 iii to show the probability distribution in histogram form, the chi-squared value for the actual data being included. It can be seen that the highest chi-squared value based on random numbers is 428.57 (Montechi) and this falls in class 9, with a probability of nine in one thousand. The chi-squared value for the actual data is 480.35 and this falls in class 11 at the tail of the distribution, and has a probability of occurring by chance of less than one in one thousand. Thus the between-site variation apparent in the data is significant being independent of the variation within any site.

Having thus established that there is a significant variation between sites, its nature can be explored by means of a principal components analysis.

The matrix for the analysis was constructed of the correlation coefficients calculated for all pairs of pollen types, using percentage mean pollen values (Hope, 1968, Pennington, 1975). The principal components were extracted from the matrix. Each eigenvector was normalized so that the sum of the squares is equal to one (standardization of data). The eigenvalues indicate the variance of each principal component. The elements of the eigenvectors or component loadings for the first three components are listed in Table 3, together with the eigenvalues and the percentage variance accounted for by each component.

The component scores are listed in Table 4. These were computed by multiplying the standardized pollen frequencies by the corresponding component loadings of the appropriate eigenvalue and summing the products (Davis,1973, Birks, 1974).

The axis of the first principal component has a high positive loading for Pinus, Alnus and Fraxinus (+ 0.272, 0.219 and 0.271 respectively), and a high negative loading for Tilia, Corylus and Ulmus (- 0.202, 0.199 and 0.136 respectively). This indicates that the major source of the variation between sites is associated with high frequency values for Pinus, Alnus and Fraxinus at sites where the frequency values for Ulmus, Tilia and Corylus are low, and vice versa. Since altitude for all sites is similar, i.e. within a range of 120m O.D. and the general climatic conditions are similar, geological factors were examined as the source of this variation. The component scores for individual sites show no consistency, other than the Millstone Grit sites having a negative score. A limestone site also has a negative score. Therefore geological factors are not the major source of the variation between sites.

The second principal component axis has high positive loadings for Betula and Salix (+ 0.403 and 0.306 respectively)

TABLE 3. PRINCIPAL COMPONENTS ANALYSIS OF THE POLLEN DATA: THE COMPONENT LOADINGS OF THE NINE ARBOREAL TAXA ON THE FIRST THREE COMPONENTS

TAXON	COMPONENT		
	1	2	3
Betula	-0.035	0.403	0.213
Pinus	0.272	-0.014	0.084
Ulmus	-0.136	-0.138	0.237
Quercus	-0.051	0.095	0.595
Tilia	-0.202	0.192	-0.274
Alnus	0.219	-0.169	-0.086
Fraxinus	0.270	0.169	-0.103
Corylus	-0.199	-0.287	-0.092
Salix	-0.077	0.306	-0.258
Variance (eigen value)	3.291	2.166	1.586
Percentage of total variance	36.6	24.1	17.6
Cumulative percentage of total variance	36.6	60.6	78.3

TABLE 4. PRINCIPAL COMPONENTS ANALYSIS OF THE POLLEN DATA

COMPONENT SCORES FOR THE FIRST THREE PRINCIPAL COMPONENTS LISTED FOR EACH SITE

SITE		COMPONENENT SCORE		
		1	2	3
Limestone	1	0.72	-1.063	-0.163
Limestone	2	0.138	-0.467	-0.603
Limestone	3	-0.584	-0.730	-0.013
Millstone Grit	4	-0.306	-0.516	-0.362
Millstone Grit	5	-0.723	-1.120	-0.025
Millstone Grit	6	-0.377	1.130	-0.531
Limestone	7	0.361	0.581	0.109
Limestone	8	-0.443	0.547	2.515
Millstone Grit	9	-0.778	1.638	-0.927

and a high negative loading for *Corylus* (- 0.287). Thus the second major source of variation is associated with a high frequency of *Betula* and *Salix* and a low frequency of *Corylus* and *vice versa*. Again, the component scores are variable and do not appear to be linked with the lithology of the sites.

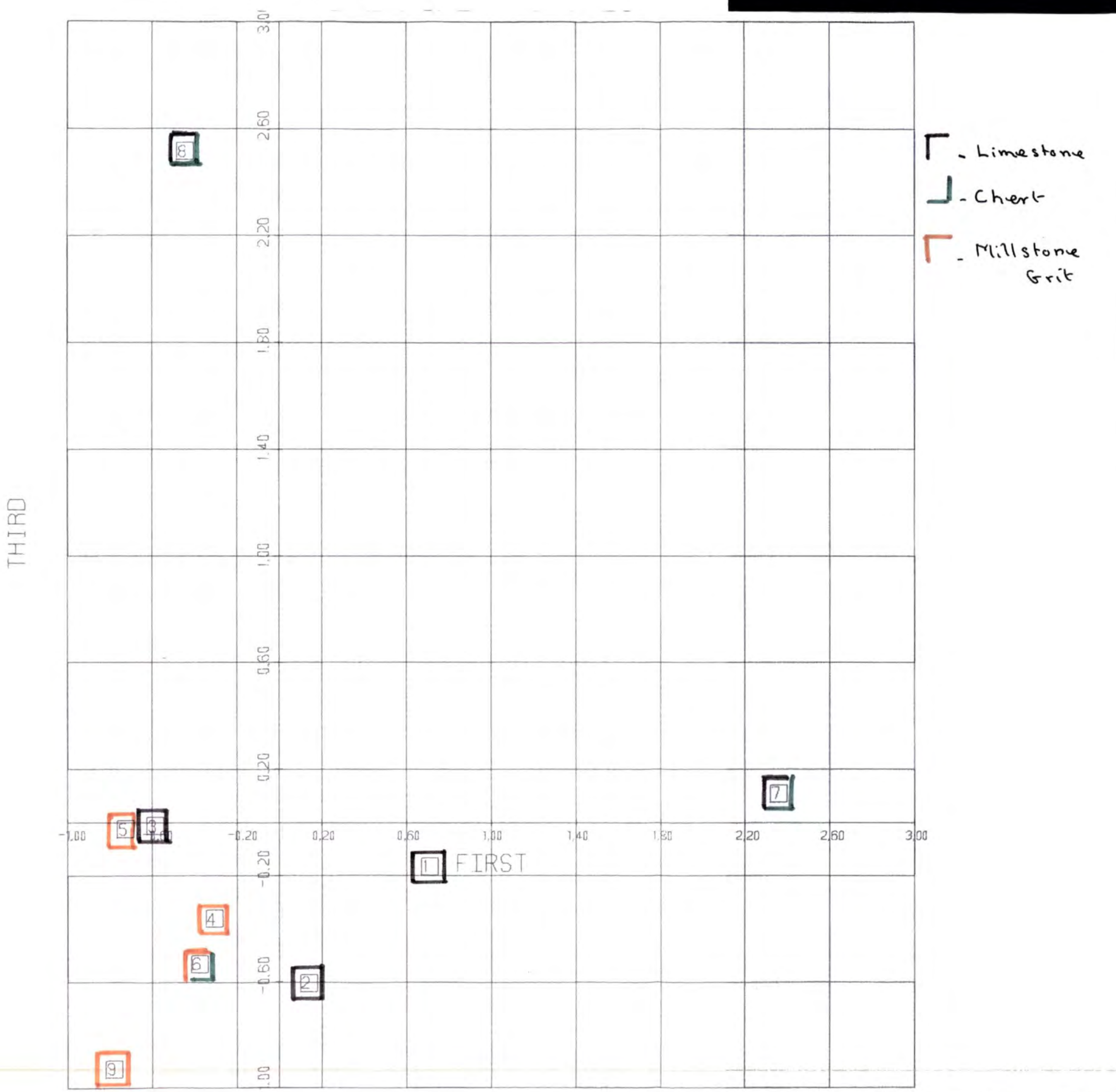
The axis of the third component carries a very high positive loading for *Quercus* (+ 0.595). The highest negative loadings are for *Tilia* and *Salix* indicating that where *Quercus* was abundant, *Tilia* and *Salix* were not and *vice versa*. The component scores show no association of this source of variation with geological factors.

The first principal component has been plotted against the second and this plot is shown in Fig. 7. Although Sites 1 to 5 are loosely grouped, Site 7 is aberrant. No clear grouping of sites based on Limestone, Millstone Grit or with Chert emerges.

When the first is plotted against the third principal component (Fig. 8) it can be seen that Sites 1 to 6 and 9 cluster together but that Sites 7 and 8 are distant but in different directions on the positive axis. It is possible that the complexity of the rock strata of these two sites, especially Site 7, Askrigg Common, might be relevant; this site is also distinct from the others in the plot of first against second principal component. Both Askrigg Common and Site 8, Summer Lodge Tarn, are situated near Richmond Chert outcrops and important mineral veins. However, this does not take account of the similarity of lithology with that of Site 6, Little Punchard Head, which is clearly grouped

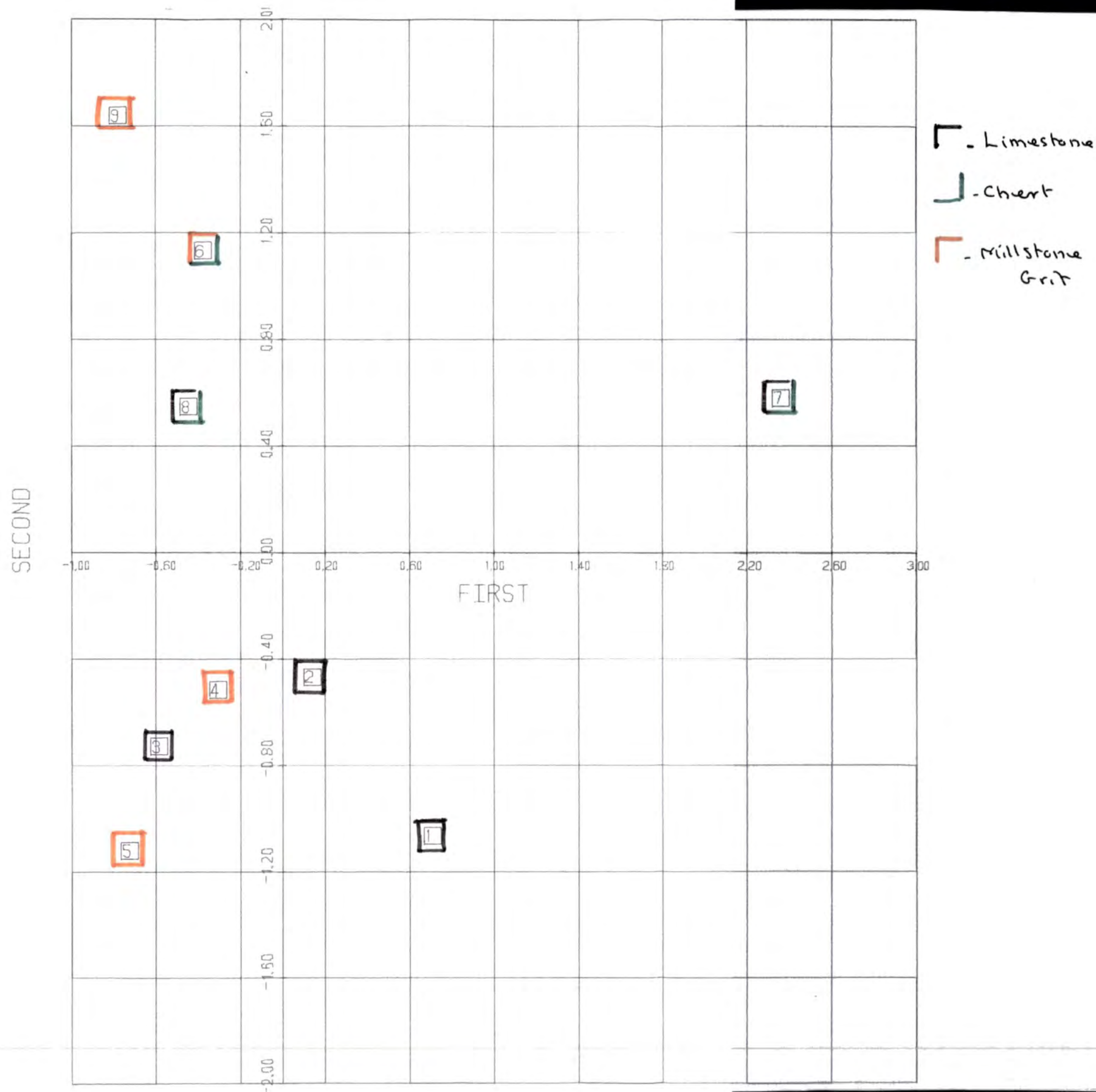
Fig. 8 Component Scores

[redacted]



[redacted]

Fig. 7 Component Scores



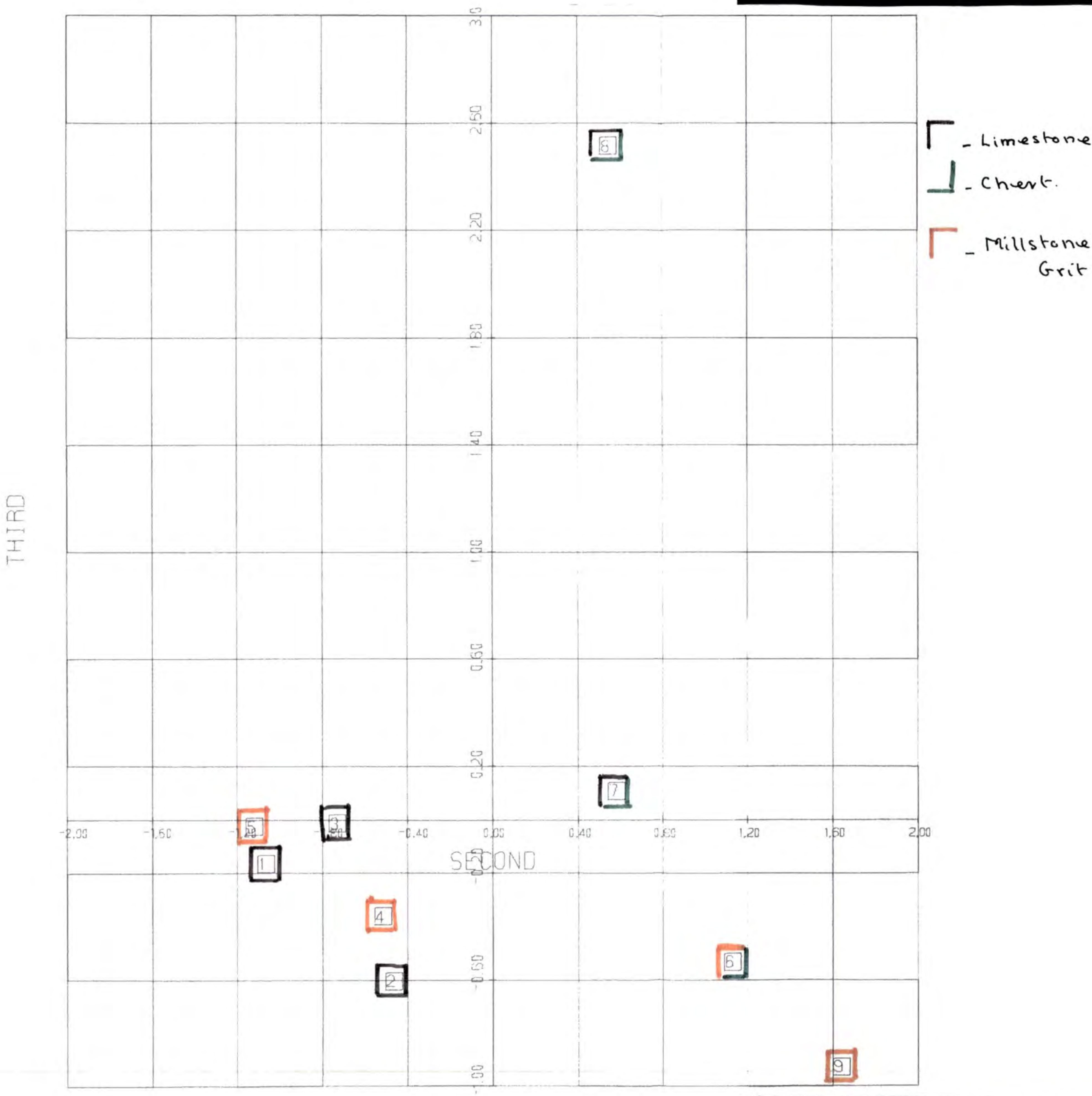
here with the remaining sites, and not Sites 7 or 8. There appears little link between these latter sites on this graph.

When the second principal component is plotted against the third, Sites 1 to 5 cluster together, and include three limestone sites and two Millstone Grit sites. Of the remainder, the proximity of Sites 6 and 7 might suggest a link between those on Chert rocks, but Site 8 does not cluster with them. Beldon Bottom, Site 9, is on Millstone Grit and is closer to Site 6, Little Punchard Head, than to the other Millstone Grit sites, Sites 4 and 5. The nature of the rock strata therefore does not appear to be the source of the observed variation (Fig. 9).

It has been pointed out that glacial drift influences the soil type (Dr.I. Johnson, pers. comm.). In the Dales, the boulder clay on the hills contains a substantial amount of calcareous rock fragments irrespective of the bedrock type. Thus soil over a predominantly Millstone Grit stratum may be more calcareous in nature than if it had been derived only from the grit-stones beneath it. At the sites concerned, however, this would be applicable to less than 40% of the total area estimating this from the Geological Survey Drift map.

In selecting sites for study, the altitude range was limited, the lowest site being Beldon Bottom, at 480m O.D. and the highest White Beacon Hags at 590m O.D. Nevertheless it is possible that microclimate variations of significance could occur within this altitude range of 110m. Given that geology was not the source of the variation, the results of the principal components analysis were scrutinized for a connection between altitude and the major sources of variation.

Fig. 9   Component Scores



No connection was established.

(c) Pollen of Ericales and Herbs

The abundance and type of each local pollen taxon varied greatly from site to site which suggested changes in the local vegetation at the deposition surface (Janssen, 1973).

It is noteworthy that a pollen grain of Polemonium caeruleum was found at Fleet Moss. This is a species used as an indicator for a limestone substratum (Pennington, 1974, Moore and Webb, 1978).

CONCLUSION

The results of this investigation indicate that Tilia cordata was distributed throughout the hill forests of Swaledale and Wensleydale from 5500 B.C. to 3000 B.C. It appears that the tree increased in abundance slightly during this period when the climate became more oceanic and the thermal maximum obtained. It was growing on soils derived from limestone and millstone grit rocks and seems to have been more frequent on the latter.

The evidence from pollen analysis shows that the vegetation of the present moorland areas of Swaledale and Wensleydale during the Atlantic period was mixed deciduous forest and that the species composition of the forest changed in relative abundance during this period. Pinus continued to grow in the area during the 2000 years but in small quantity.

The composition of the woodland varied from one place to another even within distances of 1.5Km to 10.5Km with regard to the relative abundance of the species present. There is no evidence from the sites investigated that these variations were associated directly with geological factors.

REFERENCES

Andersen, S.Th. (1967).

Tree pollen rain in a mixed deciduous forest in South Jutland (Denmark). Rev. Paleobotan. Palynol. 3,267-75

Andersen, S.Th. (1973).

The differential pollen productivity of trees and its significance in the interpretation of a pollen diagram from a forested region. In: Quaternary Plant Ecology (ed. by Birks, H.J.B. and West, R.G.), 14th Sym. of Br.Ecol. Soc., Blackwell Scientific Publications, Oxford.

Andersen, S.Th. (1970).

The relative pollen productivity and pollen representation of north European trees, and correction factors for tree pollen spectra. Danm. geol. Unders. Ser. II, 96.

Birks, H.J.B. (1974).

Numerical zonation of Flandrian pollen data. New Phytol., 73, 351-358.

Clapham, A.R., Tutin, T.G., and Warburg, E.F. (1962).

Flora of the British Isles. Cambridge University Press, London.

Conway, V.M. (1954).

Stratigraphy and Pollen Analysis of Southern Pennine blanket peats. Journal of Ecology, 42.

Davis, J.C. (1973).

Statistics and Data Analysis in Geology. Kansas Geological Survey, Wiley, U.S.A.

Davis, M.B. (1963). See* below.

Faegri, K. and Iversen, J. (1975).(1964, reprinted 1966).

A Textbook of Pollen Analysis. Blackwell Scientific Publications, Oxford.

Geiger, A. (1965).

The Climate near the Ground. University of Harvard Press, Cambridge, Mass.

Geological Survey (1954).

British Regional Geology - The Pennines H.M.S.O. London

Godwin, Sir H. (1975)

History of the British Flora. Cambridge University Press, London.

Hibbert, F.A., et al,(1971). See* below.

Hope, K. (1968).

Methods of Multivariate Analysis. University of London Press, London.

Iversen, J. (1960).

Problems of the early post-glacial forest development in Denmark. Danm. geol. Unders., ser. 4 4(3)1.

Janssen, C.R. (1966).

Recent pollen spectra from the deciduous and coniferous-deciduous forests of northeastern Minnesota: a study in pollen dispersal. Ecology 47, No. 5, 804-825.

Janssen, C.R. (1973).

Local and regional pollen deposition. In: Quaternary Plant Ecology (ed. Birks, H.J.B. and West, R.G.), Blackwell Scientific Publications, Oxford.

Kendall, P.F. and Wroot, H.E. (1924).

Geology of Yorkshire. Printed by Hollinek, Vienna.

King, Cuchlaine A.M. (1960).

British Landscapes through Maps. 2. The Yorkshire Dales. The Geographical Association, London.

Mitchell, G.F. (1965).

'Littleton Bog, Tipperary: an Irish Agricultural Record.' Journ. Roy. Soc. Antiquaries of Ireland, 15, pp. 121-132.

Moore, P.D. and Webb, J.A. (1978).

An Illustrated Guide to Pollen Analysis. Biological Science Texts, Hodder and Stoughton, London.

Oldfield, F. (1963).

Pollen analysis and man's role in the ecological history of the south-east Lake District. Geografiska Annaler., XLV.

Pennington, W. (1974).

The History of British Vegetation. Modern Biology Series, English Universities Press Ltd., London.

Pennington, W. and Sackin, M.J. (1975).
An application of principal components analysis to the zonation of two late-Devensian profiles. 1. Numerical analysis. New Phytologist, 75, 419-453.

Pigott, C.D. and Huntley, J.P. (1978).
Factors controlling the distribution of Tilia cordata at the northern limits of its geographical range. 1. Distribution in north-west England. New Phytologist, 81, 429-441.

Pigott, C.D. and Huntley, J.P. (1980).
Factors controlling the distribution of Tilia cordata at the northern limits of its geographical range. 11. History in north-west England. New Phytologist (in press).

Rempe, H. (1937).
Untersuchungen über die Verbreitung des Blütenstaubes durch die Luftströmungen. Planta 27, 93-147.

Seal, F. (1964).
Multivariate Statistical Analysis for Biologists. Methuen, London.

Simmons, I.G. (1971).
Yorkshire Dales. National Parks Guide, No. 9. H.M.S.O., 1971.

Tansley, A.G. (1968).

Britain's Green Mantle, Chap. 1. George Allen and Unwin Ltd., London.

Tauber, H. (1965).

Differential pollen dispersion and the interpretation of pollen diagrams. Danm. geol. Unders. IIR, 89, 1-69

Tauber, H. (1967a).

Investigations of the mode of pollen transfer in forested areas. Rev. Paleobotan. Palynol. 3, 277-87.

Tauber, H. (1967b).

Differential pollen dispersion and filtration. Proc. Cong. mt. Ass. Quatern. Res. 7, 131-41.

Troels-Smith, J. (1960).

Ivy, mistletoe and elm. Climatic indicators: Fodder plants. Danm. geol. Unders. IV, 4,(4).

Turner, J. and Hodgson, J. (1979).

Studies in the vegetational history of the Northern Pennines. 1. Variations in the composition of the early Flandrian forests. Journal of Ecology, 67 (in press).

Webb, T. (1973).

Corresponding patterns of pollen and vegetation in lower Michigan: a comparison of quantitative data. Ecology, 1974, Vol. 55.

West, R.G. (1968).

Pleistocene Geology and Biology. Longmans, London.

West, R.G. (1971).

Studying the Past by Pollen Analysis. Oxford University Press, London.

Wright, J.W. (1952).

Pollen dispersion of some forest trees. U.S.Forest Service, North-Eastern Forest Exp. Station, Paper, 46.

*Davis, M.B. (1963).

On the theory of pollen analysis. Am. J. Sci. 261, 897-912.

*Hibbert, F.A.,Switsur, V.R. and West, R.G. (1971).

Radiocarbon dating of Flandrian pollen zones at Red Moss, Lancashire. Proc. Roy. Soc., Lond. Series B. 177, 161-176.

APPENDIX A

TABLE I. POLLEN SAMPLE COUNTS: TREES AND SHRUBS

SITE	Level in cm	Betula	Pinus	Ulmus	Quercus	Tilia	Alnus	Fraxinus	Corylus	Salix
1. Fleet Moss	230	10	49	27	45	0	32	0	49	0
	220	6	13	27	61	2	53	0	151	7
	210	5	8	25	52	0	62	8	108	0
	200	0	4	25	74	1	53	6	117	3
	190	15	5	23	63	0	49	2	71	5
	180	24	3	4	58	4	88	0	146	4
2. Cotter End Tarn	200	42	21	33	39	0	23	3	175	4
	190	35	13	23	45	2	53	2	239	0
	180	37	3	25	56	0	58	6	223	3
	160	22	2	17	53	0	57	6	87	1
	140	16	1	14	49	4	71	2	142	5
	120	18	1	0	43	1	75	8	180	4
3. Shaking Moss	240	39	26	34	45	1	18	0	176	7
	220	45	11	26	50	0	33	0	186	4
	200	23	7	37	54	1	50	0	204	3
	180	28	7	32	57	0	68	1	221	1
	160	25	4	28	54	3	55	2	132	2
	140	22	1	34	61	4	86	7	150	2
	120	18	1	21	52	2	65	2	107	7
	110	29	2	3	57	3	59	2	97	0

APPENDIX A TABLE I contd.

SITE	Level in cm	Betula	Pinus	Ulmus	Quercus	Tilia	Alnus	Fraxinus	Corylus	Salix
4. White Beacon Hags	280	27	23	18	59	0	25	0	205	8
	270	25	10	23	59	2	51	0	174	0
	260	25	6	27	57	1	54	4	175	1
	240	22	6	27	56	3	60	8	133	3
	220	21	4	29	67	3	53	1	151	7
	200	20	7	20	54	3	64	3	136	1
	180	23	2	7	49	3	65	10	241	2
5. Fog Close	260	46	26	22	45	0	24	1	180	4
	250	26	22	28	50	0	48	4	265	4
	240	33	9	21	54	0	46	0	221	3
	230	19	10	27	55	0	49	3	202	1
	220	17	5	30	68	3	57	0	155	1
	210	7	2	31	55	4	53	4	147	0
	200	24	3	12	55	2	75	3	102	0
6. Little Pun-chard Head	460	27	38	26	45	0	23	0	118	19
	440	34	9	29	52	1	36	0	120	11
	420	33	3	29	44	3	40	7	192	6
	400	39	4	18	54	1	44	0	131	3
	380	7	5	21	70	0	46	7	74	10
	370	44	3	19	35	3	43	7	110	19
	360	13	12	16	59	0	60	6	69	10

SITE	Level in cm	Betula	Pinus	Ulmus	Quercus	Tilia	Alnus	Fraxinus	Corylus	Salix
7. Askrigg Common	Bedrock									
	329	49	9	29	96	1	81	8	147	3
	325	6	8	5	19	0	13	2	21	0
	320	26	10	8	57	0	48	6	78	3
	265	51	0	1	33	0	61	7	29	1
8. Summer Lodge Tarn	210	30	3	6	53	2	51	12	157	1
	260	43	7	33	69	1	26	0	72	2
	250	29	0	20	44	1	55	4	134	2
	240	49	4	22	43	0	34	3	73	0
	230	28	9	18	46	1	45	4	117	5
	220	27	5	23	46	2	54	1	175	0
	280	29	16	25	63	0	15	3	125	5
9. Beldon Bottom	215	24	19	21	74	1	24	1	91	3
	210	26	4	21	68	1	30	4	92	3
	200	20	4	25	53	41	44	3	86	19
	190	51	1	13	47	2	35	1	95	0
	180	35	1	12	44	6	52	4	134	5
	172	23	0	3	48	0	76	7	120	11

APPENDIX A TABLE II

POLLEN SAMPLE COUNTS FOR ERICALES AND HERBS.

SITE	Level in cm	Gramineae	Cyperaceae	Ericales	Compositae (tub.)	Caltha	Caryophyllaceae	Chenopodiaceae	Cruciferae	Filipendula	Leguminosae	Plantago	Polemonium	Potentilla	Ranunculaceae	Rosaceae	Rubiaceae	Rumex	Succisa	Umbelliferae	Pteridium	Polypodium	Sphagnum	Filicales	Melampyrum
Fleet Moss	230	18	343	4	2			3			1			1						2		5	25	66	
	220	50	870	184	1		3			12				1	1	1				1		6	28	64	
	210	54	256	2	1	3	5						1				1	1	3	3		6	1	24	
	190	69	94	5	2		3		4	9	3			13		1						4	37	24	1
	180	96	34	17										10						1	2		132	2	
Cotter End Tarn	200	7	7	30																			17	3	
	190	19	12	36						1	1			2									16	7	
	180	52	26	10																		7	40	8	
	160	28	13	13							1			3								2	36	5	
	140	22	12	174					3	1				1								3	17	10	
	120	15	7	123														1				3	23	5	

APPENDIX A TABLE II contd:

SITE	Level in cm	Gramineae	Cyperaceae	Ericales	Compositae (tub.)	Caltha	Caryophyllaceae	Chenopodiaceae	Cruciferae	Filipendula	Leguminosae	Plantago	Polemonium	Potentilla	Ranunculaceae	Rosaceae	Rubiaceae	Rumex	Succisa	Umbelliferae	Pteridium	Polypodium	Sphagnum	Filicales	Melampyrum
Shaking Moss	240	19	6	100						1	1			3								1	20	14	
	220	16	48	4						1	1												44	1	
	200	24	12	2							1								1			1	181	4	
	180	51	34	1										1								3	111	4	
	160	31	8	1										4							4	1	265	12	
	140	60	37	14						1	3	1		5	4						2	1	67	14	
	120	80	5	12			2			3	1			14								5	33	5	
	110	34	31	31							1	4		3									26	5	
White Beacon Hags	280	98	94	17			7				2			9				3	8	1			54	38	2
	270	82	99	9						1				5				3					26	7	
	260	30	74	5					2	1				3								2	40	5	
	240	52	39	14										1	11			10				4	138	1	1
	222	12	30	31						3				5							5	3	192	14	
	200	5	17	62		1																3	69	2	
	180	5	19	371							1												554	18	

APPENDIX A TABLE II contd:

SITE*	Level in cm	Gramineae	Cyperaceae	Ericales	Compositae (tub.)	Caltha	Caryophyllaceae	Chenopodiaceae	Cruciferae	Filipendula	Leguminosae	Plantago	Polemonium	Potentilla	Ranunculaceae	Rosaceae	Rubiaceae	Rumex	Succisa	Umbelliferae	Pteridium	Polypodium	Sphagnum	Filicales	Melampyrum
Fog Close	260	2	7	81	2						1	1		1	2					1		4	780	4	
	250	2	19	81						1	1												310	9	
	240	8	35	37			1			1												1	57	11	
	230	13	16	55			1			1					1							3	280	2	
	220	3	8	109										2								1	6	11	
	210	6	4	184			2			1					2							2	295	10	
	200	12	37	99											3							4	25	8	
Little Punchard Head	460	11	52	15	1	16				4				6	3							2	5	34	
	440	95	120	26		34					15			17	14				20			4	146	10	
	420	16	19	10				2		3	3			2								2	4	23	
	400	27	45	34	1	10	5			3	1											1	140	5	
	380	67	45	20			2	7		1	3			8					3	5		2	6	7	
	370	22	8	33		28	1			6	4			4	17		6		10	1		2	5	9	1
	360	32	500	14						2	4			4				1	1			5	44	30	

* Data not available for Askrigg Common, Summer Lodge Tarn and Beldon Bottom