A contribution to the vegetation history of upper Teesdale

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A CONTRIBUTION TO THE VEGETATIONAL HISTORY OF UPPER TEESDALE

By

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I declare that:

(a) No part of this work has previously been submitted for a degree at this, or any other, University.

(b) The work presented is wholly my own, except where due reference has been given.

R H Squires.

R. H. Squires.

A B S T R A C T

The Post Glacial vegetational history of the Upper Teesdale National Nature Reserve has been examined by peat stratigraphical and pollen analytical techniques in order to show the persistence of the characteristic rare plants throughout the Post Glacial period.

Although little direct evidence of the rare species (i.e. macro-remains or pollen) was found, the investigations show that conditions of instability, minimal competition and the presence of soils or water with a high base status were prevalent in certain localities throughout the Post Glacial period and probably enabled the Teesdale 'rarities' to survive through a period during which processes inimical to their survival were predominant.

The late cessation of solifluxion which aided in the expansion of hazel, followed by the immigration of pine, elm and oak under conditions of fluctuating water levels in the late Boreal period (zone VI) indicate the persistence of instability from Late Glacial times. At the time of the maximum expansion of woodland in the Atlantic period, although a fairly dense woodland of oak, elm and alder existed in the Upper Tees valley, Cronkley and Mickle Fells carried a heterogeneous vegetation ranging from birch-hazel and oak-birch scrub to woodland, similar to that which existed in the valley, with some peat deposits (both soligenous and ombrogenous). The disposition of these communities was influenced by edaphic factors therefore no altitudinal limit of tree growth can be

demarcated although the closed woodland limit was approximately 1700 ft (517 m). Anthropogenic activity has affected the area since Atlantic times and human interference was a major factor in the degradation of the scrubland and woodland, especially on Cronkley and Mickle Fells, and the development and spread of blanket peat, especially in localities adjacent to the limestone outcrops.

The present day environment of the Teesdale 'rarities' is the result of continued instability since the Late Glacial period, particularly after the appearance of man in the Atlantic period.

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'In the heath's barreness to the farmer

lay its fertility to the historian'.

(Hardy).

GENERAL INTRODUCTION

1. The Problem and Hypothesis.

From the mid nineteenth century onwards following the writing of Backhouse (Backhouse, 1843,1844), the area between Middleton-in-Teesdale (fig. 20) and Cross Fell, including the surrounding hills, has become famous for its rare plants and plant assemblages. Within a small area (fig. 1), predominantly between the 1000 ft (304 m) and 2000 ft (608 m) contours, occur many communities containing flowering plants, Pteridiophytes, Bryophytes and lichens, which show large disjunctions in their areas of distribution. Elkington (1962) calculated that in six 10 kilometre squares, covering the upper part of the Tees valley, there are 500-550 species of flowering plants. The distinctiveness of this flora is principally due to the diversity of geographical elements shown by the different species which range from those with a southern and continental distribution (Helianthemum canum) to arctic-alpine species (Dryas octopetala, Draba incana, Thalictrum alpinum, Polygonum viviparum). In addition certain of the species present are rare in Britain, either being confined to Upper Teesdale (Minuartia stricta) or to other phytogeographically remarkable localities, such as the Burren region of Co. Clare (Potentilla fruticosa, Kobresia simpliciuscula, Tofieldia pusilla), Ben Lawers (Kobresia simpliciuscula, Tofieldia pusilla), the Breckland of East Anglia (Carex ericetorum, Rhytidium rugosum) and the Craven Pennines (Rhytidium rugosum). In Teesdale also several species are represented by local races (Myosotis alpestris, Polygala amara).

PLATE 1

Minuartia stricta. Confined to Widdybank Fell, Upper Teesdale (Durham), at 1500-1650 ft (456-502 m). (Clapham, Tutin & Warburg, 1962).

The Status of the Teesdale flora. Forbes (1846) first put forward the theory of the immigration of plants since the Ice Age to explain the distribution of the British flora, and this was later developed by Darwin (1859) in his Origin of Species. The Teesdale flora and like assemblages presented problems for such an explanation since as described above, diverse geographical elements and species with disjunct distributions are represented, both of which are apparently inconsistent with Forbes' theory. Because of these peculiar plant assemblages the theory of perglacial survival was put forward and the arguments for and against this theory were set out in the Royal Society discussion in 1935 (Royal Soc. B 1935). In this discussion Willmott concluded that 'any fact of distribution which can be related to topographic fact of one period only of earth history, must be regarded as a product of that period' (p.220). He suggested that the rare species in Teesdale are present because they survived glaciation there. Arguing against the presence of 'peculiar ecological conditions' for the survival of these plants he said, 'it is impossible that Teesdale should produce a series of unique and peculiar habitats' (p.221). Diametrically opposed to Willmott's point of view, Salisbury pointed to the possibility of the northern component of the British flora representing early Post Glacial immigrants and suggested that ice-free areas upon which the disjunct species might have survived might have been snow covered. His view of the underlying causes of the distribution of the British flora is summed up on p.223. 'The association of uncommon species in special locations in Britain has been

PLATE 2

'Sugar limestone' outcrop, White Well Green, Cronkley Fell. The Dryas octopetala site can be seen in the top right-hand corner.

advanced in support of the survival hypothesis. Since however, such 'sanctuaries' are not confined to unglaciated areas, it is much more probable that the reasons for such occurrences are ecological and not historical'. Summarising the available evidence Elkington (1962) concluded that if Manley's (1959) suggestion of a firn line in the post Allerød glaciation at 2300 ft (699 m) was correct then it was extremely unlikely for many of the species now present in the dale to have survived.

The question of the status of the Teesdale flora in immediate post valley glaciation times, is not of direct importance to this work. Of greater importance is the status and survival of the plants throughout Post-Glacial times because, whether one regards the plants as per-glacial survivals or Post-Glacial immigrants, the problem raised by their existence is essentially historical (Godwin, 1956). The development of vegetation through time has been examined by methods which use plant and animal remains as indicators of past environmental conditions. From these methods, particularly from pollen analysis, sub-fossil records of nearly all of the rare Teesdale species have been found in deposits laid down during the Late Glacial period in Britain and Continental Europe, well outside the localities in which they occur today (Godwin, 1956). The Teesdale assemblage therefore 'is to be interpreted as a relict flora - fragments of vegetation types which existed in Britain and north-west Europe some 10,000-12,000 years ago' (Godwin and Walters, 1967: 349.)

Since that period the vegetation has been greatly

PLATE 3

Cronkley Scar. A quartz dolerite Hercynian intrusion resulting in spectacular topography.

modified by the spread of forests over much of the land, the development and extension of acid bogs over much of the non-forested land and the podsolisation of the soil. All of these processes were inimical to the Late Glacial flora, which consisted predominantly of high demanding species adapted to growing on alkaline or neutral soils of relatively high base status. Thus, during the Post Glacial period, many of these species became extinct, or at least severely restricted. Elkington (1962) suggested that a number of montane species including Saxifraga oppositifolia and Oxyria digyna, which might be expected to occur in Upper Teesdale and do not, became extinct in this way.

Examination of the present habitats occupied by the rare plants in Upper Teesdale shows that they are characterised by the absence of competition from trees and the presence of soils or water with a high base status. Often both of these factors are the product of an unstable environment.

The correlation between the 'sugar limestone' and the rare communities was noted in the nineteenth century (Godwin and Walters, 1967). Many of the species contained in these communities require a very short turf or a more or less bare calcareous soil (e.g. Minuartia verna, Gentianella amarella), conditions which are provided by the heavy grazing pressure on the grassland cover maintained by sheep and rabbits. Cliffs and exposed rock faces provide unshaded conditions often with immature base rich soils which are suitable for the propogation of certain rare plants, whilst small calcareous marshes and flushes, subjected to considerable grazing and trampling from domesticated animals, are also

PLATE 4

Cronkley Scar and the glacial lake of Tarn Dub which frequently dries out in summer. The lateral moraine is on the right.

characterised by a distinct flora (see Shimwell, 1968,1969).

Recent work by Bellamy et al. (1969) in Upper Teesdale appears to confirm that the reason for the existence of the "Teesdale rarities" in climatic conditions which seem marginal for their survival is instability which is partly effected by herbivores (Pigott, 1956), in addition to frost action and wind and rain erosion, partly due to their location in a boundary complex which ensures minimal competition (Coombe and White, 1951; Pigott, 1956).

Although Bellamy et al. (1969) suggested that it was dubious to argue the existence of the rare species over long periods of time involving appreciable climatic change in such restricted local habitats only with the finding of 'traces of the plants or their present ecological associates throughout Post-Glacial deposits close to their present-day habitats and thus demonstrating the local persistence of open conditions' (Pigott, 1956: 577), can their present status be fully evaluated. The supposition of persistent open or unstable conditions, suitable for the continued existence of these 'rarities', during Post-Glacial times at present lacks empirical data, although Pigott (1956) pointed out that a scrub cover did not necessarily preclude the growth of certain species whilst the cliffs, exposed rock faces and calcareous marshes would probably have remained free from forest cover, ombrogenous peat and podsolisation.

There is a clear hypothesis regarding the existence of the Teesdale rarities, since their widespread distribution in Late Glacial times. From our knowledge of the present vegetation it has been postulated that the habitats in

PLATE 5

Limestone flush communities, Cronkley Fell.

which these plants survive today provided similar conditions during Post-Glacial times. The continued presence of the assemblage of species offers a chance for ecological methods to be used to discover their present determinants (Bellamy et al., 1969) and palaeoecological methods to be used to trace their Post Glacial vegetational history.

2. The Approach.

Palaeoecological methods, involving analyses of the extensive peat deposits of Upper Teesdale (fig. 19) at selected sites, have been used to provide evidence for the Post Glacial vegetation development of the area. The evidence consists of both pollen and stratigraphic data and from this the interaction of topography, soils, climate, vegetation and biotic influences through time can be studied, the product of which is the present landscape. Principally, this research is the study of an area and emphasis is therefore on presented palaeoecological data. The development of new pollen analytical techniques is limited to a note on the application of computers to the presentation of pollen data (Appendix C).

Fig. 1 shows the extent of Upper Teesdale. Not all of this area was considered when selecting sites for examination. The Upper Teesdale National Nature Reserve provided an ideal area for consideration because, in addition to properly furthering knowledge of a Nature Reserve, the evidence obtained from sites over a fairly wide area (8,600 acres - 26305 ha) provides a regional picture of vegetation history into which the local vegetation development studies of Widdybank Fell[1] and Cauldron Snout[2] may be placed.

PLATE 6

Cetry Bank, an unstable alluvial bank, on which grow many of the Teesdale "rarities".

Already work of a similar nature has been completed by Johnson (1963) on the Moor House National Nature Reserve, so that with the present work the high fells of the northern Pennines have been fairly thoroughly investigated. Within the Upper Teesdale N.N.R. most of the disjunct species occur, therefore the hypothesis set out above could be examined.

Although the methods used in this work are similar to those of other palaeoecologists in the area (see footnotes 1 and 2), the conceptual approach is somewhat different. Current reseachers are examining deposits in a limited locality so that the chances of finding the remains of the rare species or their associates are probably higher than where isolated sites are subjectively selected over an area[3]. Only by the analysis and interpretation of evidence from a fairly wide area can a chronology of forest history be put forward, thereby allowing the assessment of the present status of the 'rarities' in terms of the Post Glacial history of the vegetation. This is particularly relevant in the light of Pigott's (1956: 584) statement on the possible Post Glacial diminution of suitable habitats where the rare plants and communities survived.

The use of selected sites to construct a relative chronology for an area is not a new method of analysis. This method provides the basis for pollen zonation schemes (Godwin, 1940a,1940b) and has been used with success by others, notably Pearsall and Pennington (1947), Conway (1947,1954), Oldfield (1960), Dimbleby (1962), Simmons (1962,1964,1969), Donner (1962), Pennington (1964,1965), Tallis (1964a,1964b), Newey (1965), Walker (1965,1966), Moore (1966), Durno (1966), and Moore and Chater (1968,1969). All use the analysis and interpretation of evidence from a number of sites to show the regional relationships of the vegetation in a particular area at a particular time. Other pollen analytical studies invariably use this approach in the latter stages of interpretation, which usually involves the placing of a study into a spatial framework.

In general the lack of work done in upland areas is very noticeable. This is perhaps surprising in view of the comment by Pearsall (1950: 1), who wrote:

> 'highland Britain is of surpassing interest because in it there is shown the dependence of organism upon environment on a large scale. It includes a whole range of habitats with restricted and much specialised fauna and floras. At times these habitats approach the limits within which organic life is possible, and they are commonly so severe that man has avoided them. Thus we cannot only study the factors affecting the districutions of plants and animals, but we can envisage something of the forces that have influenced human distributions. Moreover in these marginal habitats, we most often see man as part of a biological system rather than lord of his surroundings'.

The avoidance of upland areas by workers is undoubtedly due to the difficulties involved in the collection, analysis and interpretation of data. Difficulties in collecting samples are provided by the unfavourable nature of the environment, the prevalence of the dampness and other extremes of climate and the subjective choice of sites. Analysis is hindered by the scarcity of pollen (particularly of trees) in rapidly growing blanket peats and also by the lack of identifiable plant remains to accompany pollen analytical results. The greatest difficulty however, lies in the interpretation of analysed data. In deforested country the wide area from which pollen can be derived at any one site, makes the division into local (i.e. plants growing on or near the site) and regional components tentative, especially where strong winds prevail, a factor which appears to have received scant attention in published works. The metachronous growth of blanket peat, even over very short distances, and the frequent absence of some of the characteristic features of Godwin's (1956) zonation scheme also hinders interpretation. The obvious attraction of upland sites is inherent in Pearsall's statement (above). The relationship between organisms and the physical environment are most apparent in upland areas and often there is permanent tension between various landscape elements, tension, which does not exist at lower altitudes, such as that between topography and soil, topography and vegetation, or vegetation and soil.

3. The Layout of the Thesis.

The thesis is composed of two volumes. Volume 1 contains the text, including tables and plates, whilst Volume 2 contains the figures and data sheets. Volume 1 consists of three sections and three Appendices. Section A comprises an introduction to Upper Teesdale[4], Section B the results of the palaeoecological investigations, and Section C the discussion and conclusions. The Appendices contain a note on the use of computers in producing scaled pollen diagrams and tabulated pollen data.

All places to which reference has been made fall on sheets 83 and 84 of the Ordnance Survey seventh series one inch sheets (1964), part of which are reproduced in fig. 20. Heights are given in feet above sea level along with their metric equivalents. In the analysis of data, metric units only are used.

The nomenclature for species is as follows:

flowering plants	-	Clapham, Tutin & Warburg (1965).
mosses	-	Warburg (1963).
hepatics	-	Paton (1965).
lichens	-	James (1967).

[1]Miss V. P. Hewetson, formerly of the Botany Department, University of Durham.

[2]Dr. J. Turner, Botany Department, University of Durham, Dr. F. A. Hibbert, Sub-Department of Quaternary Research, University of Cambridge.

[3]A further difficulty exists in identifying many pollen grains to species level.

[4]Although the main concern of the thesis is in the cause and process of Post Glacial vegetation change in Upper Teesdale, an introduction, outlining the distribution of present landscape elements, is necessary, firstly because these elements provide the evidence for vegetation change, secondly the relationships of these elements are predominantly those which have evolved during Post Glacial times, and thirdly because their distribution provide a datum from which the Post Glacial changes may be assessed.

SECTION A.

INTRODUCTION TO UPPER TEESDALE.

Chapter 1. THE PHYSICAL ENVIRONMENT

1.1. Geology

The solid geology of Upper Teesdale is dominated by the Carboniferous Limestone which Johnson (1963) has estimated is 2-3,000 ft (600-900 m) thick, along with limited, but striking, exposures of igneous rocks (fig. 3). The main stratigraphic horizons are shown in fig. 4.

Pre-Carboniferous. The pre-Carboniferous foundation rocks are exposed in two localities (fig. 3), firstly between the Pennine Escarpment and the Outer Pennine Fault, the Cross Fell Inlier, and secondly below Cronkley Scar, the Cronkley Inlier. From an examination of these exposures and comparison with similar rocks in the Lake District Dunham (1948) concluded that Ordovician Skiddaw Slates or Borrowdale Volcanics underlie the Carboniferous Limestone. Recent gravity surveys (Bott & Masson-Smith, 1953, 1957) indicate substantial anomalies in the northern Pennines which Johnson (1963: 96) has suggested are due to a deep seated granitic intrusion of pre-Carboniferous age.

Carboniferous. These deposits have been comprehensively described by Dunham (1948). The conglomerates, sandstones and shales of the Basement Group rest unconformably on the older Palaeozoic rocks and are exposed in the deep escarpment valleys and around the Cronkley Inlier. Above this Basement Group is the Lower Limestone Group which includes the Melmerby Scar Limestone, particularly well exposed on Widdybank Fell, where a maximum thickness of 115 ft (35 m) has been found (Dunham, 1948). The Middle Limestone Group consists of alternating sequences of shales, sandstones and limestones belonging to the Yoredale series of deposition. The complete cycle of this was described by Hudson (1924) and Brough (1929) and occurs at least eleven times within this Middle Group with only slight erosion between the individual cycles. The basal member of the Upper Limestone Group is the commercially important Great Limestone in which many of the workable mineral veins occur.

Above these Carboniferous Limestone strata, belonging to the Visean stage of deposition, coarse grits appear for the first time and Millstone Grit becomes the predominant rock type. Although this rock is poorly represented in Upper Teesdale, its distribution in the Alston Block can be seen in fig. 2.

The Whin Sill. Intruded into the Carboniferous succession is the Great Whin Sill, considered by Dunham (1948) to be series of connected or related sills, or phaccoliths, of quartz-dolerite (sill = persistent bed in the stratigraphic succession). This intrusion is Hercynian in age and is best exposed in Teesdale where a continuous outcrop runs along the south side of the valley north-westwards from Middleton. In Upper Teesdale it forms the impressive Cronkley Scar and Falcon Clints, whilst it also causes the two major obstructions in the long profile of the River Tees, at Cauldron Snout and High Force.

The strata in contact with, and adjacent to, the Whin Sill have become metamorphosed: the shales are turned into whetstone, a smooth porcellanous rock, whilst the limestones are recrystallised to form a coarse marble. This marble readily weathers into a fine granular deposit to form the 'sugar limestone soils' (Johnson, 1965: 19). These can be seen in Upper Teesdale on Cronkley and Widdybank Fells, where the grass covered white sandy deposits contrast sharply with the surrounding heather dominated blanket peats.

Minerals. Mineralisation of the Carboniferous sediments is fairly extensive (fig. 5) and appears to be associated with the Hercynian orogeny (Dunham, 1952; Moorbath, 1959), although Trotter (1944) attributed it to the Tertiary earth movements. The occurrence of the minerals fluorite, barite, zinc and galena, an important factor in the history of the whole area of the Alston Block, is mainly confined to small fissures of ca. 40 ft (12 m) displacement (Dunham, 1948), with notable exceptions of the Henrake and Dun Fell faults both of which exceed 100 ft (30 m). In addition to the presence of mineral veins mainly within the Great and Tyne Bottom Limestones, metasomatic deposits formed by the replacement of limestone adjacent to the veins and known as flats, are found. These are generally confined to the Great Limestone.

Dunham (1948) showed a lateral zonal distribution of primary minerals in the northern Pennines. Fluorite and barite are the principal minerals, the former being predominant over much of the area from east Allendale to Teesdale, whilst barite occurs on the margins of this area. Galena is abundant along the limits of the fluorite zone.

1.2. Structure

Most of the structural details of Upper Teesdale date from Carboniferous times since when the Alston Block has been a structural and morphological unit (Dunham, 1948). The pre-Carboniferous foundation rocks have been affected by the Caledonian orogeny which has caused both the general east/west and east-north-east grain and the high dip of the strata found in rocks to the west of the Alston Block. Johnson (1963) suggested that the effect of these earth movements on the foundation rocks of the Block might have influenced subsequent fault patterns.

The western and central parts of the Block are arched to form a gentle asymmetric dome ('half dome' of Dunham 1959) which is truncated in the west by the Pennine Faults. The nature of the Teesdale Dome (Dunham, 1948), as this is called, was first described by Hickling (1928), who showed a more or less flat dome lying beneath Great Dun Fell, Cronkley Fell and Mickle Fell although Dunham (1959) later suggested the maximum elevation of the strata occurred near Cross Fell. Northwards and eastwards from the crest of the dome the beds dip under the western edge of the Durham coalfield, although small north-west trending faults and folds may locally interrupt this general pattern. Southwards the strata dip into the Stainmore Syncline.

The Alston Block as a whole shows little folding of any magnitude, unlike the marginal areas which show the effects of the Hercynian orogeny. The lack of major structural features is thought to be due to the stability of the Block and the folding that did occur is mainly limited to the area surrounding the Cross Fell Inlier. However, one major structural feature of the Block is the Burtreeford Disturbance, a north-south monocline with a displacement of approximately 500 ft (152 m), which cuts across Teesdale (fig. 3).

Within the Block there occur a number of small faults and associated folds whose dominant direction is north-westerly or easterly. Johnson (1963: 92) suggested that these are adjustment fractures related to the doming mentioned above and have subsequently become mineralised. These relatively minor structural features, the distribution of which is shown in figs. 5 and 6, are of significance in the history of mining in the area. The most important of the north-west faults is the Teesdale Fault which extends from the neighbourhood of Middleton-in-Teesdale to Alston in South Tynedale. The displacement of strata in this fault is greatest in Teesdale where the prominent Whin Sill scarp of Holwick Scar outcrops along the south-west side of the valley with a displacement to the north-east. The eastward trending faults include the Dun Fell Vein and the Great Sulphur Vein (fig. 5).

1.3. Relief

The Alston Block contains several dales with similar physical landscapes (Smailes 1961: 271) which is not surprising since the entire area has experienced similar stages of morphological development. In general the Block has extensive tracts of country in excess of 1500 ft (456 m), very little ground below 700 ft (212 m) and summits around

3000 ft (912 m) (fig. 7).

The Alston Block is a plateau (fig. 8), uplifted along its western margin, tilted eastwards and dissected by rivers. This causes a 'fell and dale' relief (Dunham, 1948), which is dominated by gentle interfluves sloping eastwards, alternating with steep-sided valleys of deeply incised rivers. The amplitude of relief is on average 300-400 ft/km^2 (Wright, 1955) (fig. 9).

Using trend surface analysis, King (1969) showed the surface of the Block sloped northwards and eastwards, with increasing gradient, from a high area centred on Cross Fell and Mickle Fell. The cubic and quadratic maps showed a relatively flat surface sloping away from the area of maximum uplift, along the Pennine Escarpment. This corresponds to the Teesdale Dome, the structure of which has been outlined above.

The most comprehensive work on the relief of this area, especially with regard to the presence of (such) flat surfaces which have been interpreted as planation surfaces, has been carried out by Wright (1955). His generalised contour map, part of which is presented in fig. 10, shows an extensive, more or less flat, surface at ca. 2300-2100 ft (699-638 m) with distinctive platforms at 2100-1700 ft (638-517 m). Above this extensive area are the three monadnock areas of Cross Fell/Great Dun Fell, Dufton Fell, and Mickle Fell, which may be the remnants of a 2900-2400 ft (882-730 m) surface. Other features shown in fig. 10 are the marked platforms along the Wear/Tees interfluve and the large area between 1500-1400 ft (456-426 m) in Stainmore.

In his analysis Wright (1955) showed:

(i) the presence of an important surface at and above 2000 ft (608 m) along with parts of surfaces between 2900 ft (882 m) and 1750 ft (522 m). These may be one surface, a theory which Linton (1933, 1951) supported, the surfaces representing portions of an ancient land surface of subdued relief with few monadnocks. Linton (1933) suggested that the west/east fall of the summit levels is the relict feature of an inclined Sub-Cenomanian surface which sloped from 3500 ft (1062 m) in West Cumberland to below 1500 ft (456 m) in the North York Moors, an hypothesis which Sissons (1957) did not substantiate.

(ii) distinct platforms 1900-1700 ft (578-517 m). Common (1954) in the Cheviots and Hollingworth (1936, 1938) in the Lake District both emphasised the importance of a planation at 1700-1600 ft (517-487 m).

(iii) less pronounced platforms at 1500 ft (456 m) and at 1400-1200 ft (426-364 m).

Although the overall relief corresponds to the major structural features variations in the dip and the lithology of the strata are also important in determining relief. Many of these lithological differences are not apparent because of the extensive peat mantle. Similarly, variations in slopes caused by differential erosion or structure are obscured. Wright (1955) postulated that breaks of slope and platforms were structurally determined although Atkinson (1968) concluded that the breaks of slope above 1000 ft

(304 m) were due to resistant scarp formers, which may or may not correspond with structural features (fig. 11).

The main drainage lines (fig. 12) appear to have a close relationship with structure, especially the Rivers Tyne, Wear and Tees (Wright, 1955). All three rivers rise from the crest of the dome and radiate outwards, following the dip of the strata and the general trend of the surface form. The tributaries of the main streams also follow this dip whilst the long profiles of most of the streams can be explained partly in terms of structural characteristics and partly by lithological differences. The pattern of the minor streams is extremely complex. The extensive, flat interfluves, usually covered by blanket peat, may possess an intricate network of small streams which has a greater relationship with blanket peat erosion than with the structure or the relief.

1.4. Climate

The north Pennine moorlands have been described as the most consistently elevated and chilly part of England (Manley, 1936). As early as 1570 Homberstone commented on the bleakness of the Raby lands, north of the Tees, which were exposed to the winds from Cross Fell.

Temperature records for Upper Teesdale have only been kept since 1936 when recording instruments were established at Moor House (1840 ft 559 m) which thus became the highest place in England where temperatures were recorded. More or less continuous rainfall records for various stations in Teesdale (fig. 15) have been kept since early this century but only with the establishment of Moor House were continuous data made available for a high altitude station (table la-e). Any account of the present climatic conditions of the northern Pennines therefore suffers from a lack of statistical data.

Precipitation. In compiling his map of the rainfall of the Tees valley (fig. 14), Glasspoole (1932) commented that there was ample information to draw isohyetal lines over the whole area, apart from the extreme south-west and in the north-west, from Mickle Fell to Cross Fell. For these areas he used interpolated values based on the general principles he outlined earlier (Glasspoole, 1928).

A rainfall of under 35 ins (889 mm) is almost entirely restricted to those parts of Teesdale lower than 1000 ft (304 m) whilst 60 ins (1524 mm) occurs where the altitude is in excess of 2000 ft (608 m). On the summit of Mickle Fell and also on the area between Dufton Fell and Cross Fell the rainfall may exceed 70 ins (1778 mm). In the north, along the Tees/Wear watershed, over 60 ins (1524 mm) occurs whilst in the south no large area receives this amount. According to the Wear and Tees Hydrological Survey in 1961, the period 1916-1950 showed higher average values than the period 1881-1915, although the broad distribution remained the same. This may account for the discrepancy between the values for Mickle Fell estimated from the map (70+ ins 1778 mm) and calculated from the regression formula (fig. 16) (90+ ins 2388 mm). The effect of the tilted plateau surface of the Block is very noticeable on the distribution of rainfall (fig. 15), there being a highly significant correlation (.001 > P)

TABLE 1. Climatic Data

	January	February	March	April	May	June	July	August	September	October	November	December	Year
(a)	6.5	6	5.75	4	3.75	4	6	7	4.5	7.5	6.5	8.8	70
(b)	17	17	17	8	1	.1			.1	2	6	12	80
(c)	45 15	45 16	50 16	56 20	65 25	70 31	72 36	72 35	66 30	57 26	50 21	46 16	75 11
(d)	36.6 29.4	36.6 28.6	38.9 29.3	44.1 31.9	51.8 37.6	57.0 41.8	59.6 46.0	58.6 46.0	54.3 42.3	47.3 37.1	40.4 32.4	37.2 30.6	46.9 36.1
(e)	49 0	53 9	59 11	64 16	68 19	79 29	80 32	79 30	73 25	60 22	55 14	49 10	80 0

(a) Moor House, estimated average monthly precipitation, in ins. (± 10%) (after Manley, 1943)

(b) Moor House, frequency of snow cover, average number of days/month (after Manley, 1942).

(c) Moor House, average monthly extremes 1906-1935, °F (after Manley, 1942).

(d) Moor House, average daily extremes 1906-1935, °F (after Manley, 1943).

(e) Moor House, maximum monthly extremes 1906-1935, °F (after Manley, 1942).

between altitude and precipitation, which was also found by Atkinson (1968) in Weardale. One of the principal reasons for the pronounced west/east diminution of rainfall is of course the high ground in the west. The main moisture source for the northern Pennines is the Atlantic Ocean therefore the bulk of the precipitation occurs as orographic rainfall on these higher parts.

Manley (1942) noted a significant increase in the quantity and duration of the snow cover on land over 1000 ft (304 m). He attributed this to the wide expanse of chilly undrained moorland and the effect of the wind which reinforced the consequences of altitude, particularly between January and May. The annual average snow cover at Moor House between 1906-1931 has been calculated as 80 days (table 1b), although on the basis of temperature snow should lie for 140 days. Manley (1934) ascribed this feature to the prevalence of the high winds, causing drifting and melting. Despite this drifts may be visible on Cross Fell until June.

Temperature. The main characteristics of the temperatures are the coolness of the summers and the shortness of the growing season. A comparison with Continental stations shows that the average summer temperatures at approximately 2000 ft correspond to those found at 3500 ft (1064 m) in central Norway.

As sunshine amount is small and extremely variable, cloud cover high and winds on average force 5, it is not surprising that there is a rapid diminution in the length of the growing season with increasing altitude (fig. 18).

The figures in table la-c strikingly reflect the bleak and windy nature of the high moorland.

On examination of the limited data presented it is obvious that climatic conditions on the higher fells of the northern Pennines are extreme compared with surrounding areas (see Manley, 1936: 110). There is an excessively windy and pervasively wet autumn and a very variable and stormy winter with long spells of snow-cover, high humidity and bitter wind alternating with brief periods of rain and thaw. The short and cloudy summer is not quite warm enough to support the growth of trees (Manley, 1942: 151). Manley (1942) noted that a relatively slight increase in the frequency of anticyclonic summer weather would allow a rise in the mean temperature almost sufficient to permit the growth of trees to high altitudes. He regarded the climate of these fells to be comparable with that of southern Iceland although both temperatures and precipitation are higher.

Chapter 2. GEOMORPHOLOGICAL HISTORY

Despite the conclusion of Atkinson (1968) that the basins of the Rivers Tyne, Wear and Tees have been subject to different geomorphological histories since late Tertiary times it cannot be denied that the Alston Block has a unity, based on geology and structure, and expressed in relief, which as already stated can be partly explained in terms of a common evolutionary process.

Although the broad outline of the structure of the Block is known its geomorphological history is not clear, a fact which Maling (1955) partly ascribed to the extensive drift cover which tends to obscure the structural features. Accounts of the structural history are numerous, including: Davis (1895), Cowper Reed (1902), Woolacott (1903, 1907), Merrick (1915), Trotter (1927), Wright (1955), Maling (1955) and Sissons (1960). However, none is wholly accepted and no work has been done on the area which compares with the work done by Hollingworth (Hollingworth, 1936, 1938) in the Lake District.

2.1. Pre-Quaternary Period

Maling suggested the following post-Carboniferous geomorphological history.

(i) The Block was relatively depressed in Hercynian times along its northern, southern and western margins; accompanying folding produced overthrust folds in, and around, the Cross Fell Inlier. At the same time the Whin Sill was intruded and the Burtreeford Disturbance was formed.

(ii) Considerable thicknesses (ca. 2000 ft 608 m) of

Mesozoic sediments were deposited onto the Permo-Carboniferous surface.

(iii) The whole area was uplifted during Tertiary times, causing the doming of the Block. Following this both the Alston Block and its southern counterpart, the Askrigg Block, were uplifted and tilted eastwards with consequential faulting. Trotter (1927) suggested that erosion took place, then folding in late Tertiary times, as a result of two uplifts, the first causing the peneplain to be differentially uplifted, the second causing the formation of the Dome and the Stainmore Syncline during the Pliocene period. Dunham (1948), whilst admitting the possibility of some warping of the Block in Tertiary times, argued a Hercynian initiation of the Dome as a counterpart to the Durham Coalfield basin in the east.

(iv) Erosion of the Mesozoic cover, possibly with the removal of some of the Carboniferous cover in the west, causing the formation of a peneplain which Woolacott (1907) held to account for the present gradient of hill top surfaces.

(v) The formation of the present drainage pattern which is either radial, centred on the crest of the Dome, or trellised and modified by later folding. There are many conflicting views on the origin of this pattern, all of which are outside the scope of this work.

2.2. The Quaternary Period

During the Quaternary period, when the pre-Glacial landscape was modified rather than radically altered, large amounts of superficial material were deposited onto the surface. This period is divisible into two: the Glacial and Late Glacial periods when features formed during the previous millenia were smoothed or accentuated, and the Post Glacial period, during which time there was a progressive modification of the landscape by contemporary weathering processes, including mass movement, solifluxion, stream incision and colluviation. The vegetation history presented in this thesis is largely the result of these contemporary processes therefore will be dealt with later. Here it is proposed to limit discussion to those relevant features of the Glacial and Late Glacial periods which might have affected this history.

The volume of literature published on the glaciation of north-east England, which was one of the most ice congested areas in Britain according to Trotter (1929), has been ably summed up by Beaumont (1968). Dwerryhouse (1902) has produced the most comprehensive account of the glaciation of the Alston Block (fig. 13). His conclusion was that foreign ice never invaded the upper parts of Teesdale and Weardale which he considered to be occupied by local glaciers, ~~although~~ and the higher parts of the watershed stood out as nunataks. This picture of local glaciers, acting more or less independently, has given rise to difficulties in correlating glacial features between the Block and other regions.

Deposits. The deposits laid down by the ice are almost exclusively composed of local material, so that the different valleys often have dissimilar drift deposits, the nature of which is dependent on the local geology. Dwerryhouse (1902) identified four different deposits on the Block:

(i) Red clay with scratched stones. This is very widely distributed and is more or less confined to the main valley.

(ii) Black loamy clay with few scratched stones, found only in the tributary valleys.

(iii) Reddish gravelly deposits of the Tyne valley, containing waterworn stones, which continue into the Eden valley.

(iv) Stiff boulder clay which takes the place of the red clay in Upper Teesdale.

Unfortunately there are no maps of the distribution of these deposits.

The importance of these superficial deposits is two-fold. Firstly, the drift provides the parent material from which many of the soils of the Alston Block are derived, either boulder clay overlying the Carboniferous strata or solifluxion deposits. Secondly, from an examination of the distribution and nature of the drift ice limits may be inferred. Apart from the difficulty of examining deposits which, especially on the interfluves, are overlain by extensive peat deposits, other problems are encountered. The present arrangement of the deposits may bear little relationship to former ice limits, primarily because of the removal of considerable amounts of material after the ice retreated, but also because of the presence of an upper layer of clear ice in glaciers which is devoid of transported material.

Although Lewis (1904a & 1904b) wrote of a 'glacial clay' underlying many of his moorland communities it is now accepted that true boulder clay is much less extensive than was formerly thought, many of the deposits (form) previously described as 'glacial' being the product of in situ weathering or periglacial activity[1]. The highest levels at which boulder clay has been found in Teesdale is 2200 ft (669 m) on Cross Fell (Raistrick, 1931), and 2000 ft (608 m) on Mickle Fell and Warcop Fell (Trotter, 1929). Recently Shimwell (1968) suggested drift material at 2400 ft (730 m) on Mickle Fell, but this may be a soliflucted material rather than a true boulder clay. The maximum thickness of the deposits has been noted as 180 ft (54 m) (Harbord, 1962).

The characteristic U-shaped valley of Upper Teesdale contains drift sheets along with drumlins and moraines. Johnson (1963) gave the following account of the drifts. The headwaters of the Tees occupies a basin shaped hollow which is covered with drift. This drift becomes masked downstream, around the Trout Beck confluence and Cauldron Snout, by blanket peat. On the west side of Herdship Fell drift extends up to 1900 ft (578 m) and continues over the Cow Green col to join the Harwood Beck deposits. East of the river at Cauldron Snout there is little drift although recent work (Hewetson, unpub.) suggests that it occurs in patches beneath the peat mantle. To the west of the river are several large mounds of superficial material whose origin is uncertain. Below Cauldron Snout the drift cover is patchy and more angular material becomes incorporated. On the summits of Widdybank Fell and Cronkley Fell are basalt erratics, along with scattered drift patches. Two well developed moraines are present on either side of the river, to the south a lateral moraine circles the foot of Cronkley Scar whilst to the north a terminal moraine exists in Harwood Beck. Other writers (e.g. Haynes, 1967) noted occasional rock drumlins on the main valley floor below Cronkley Scar. Below High Force, where the drift cover becomes more extensive, the rolling topography produced by the ice becomes a noticeable feature of the landscape.

Nunatak Areas. The question of multiple glaciation is not of concern in this work. However, the amount of ice free areas during the maximum glaciation is of particular relevance to those who propound pre-glacial survival of the relict species mentioned in the General Introduction. As already stated Dwerryhouse (1902) argued that the highest parts of the northern Pennines were not ice covered during the maximum glaciation. Trotter (1929) found Lake District erratics at 2200 ft (669 m) on the western face of the Pennine escarpment and although Johnson (1963) did not find foreign erratics over 1875 ft (851 m) in the same area, he cited evidence of glacial plucking and overriding up to 2800 ft (851 m)[2]. In the opinion of Trotter (1929) only small areas were free from ice at its maximum extension; he suggested that the land above 2200 ft (669 m) was covered with ice similar to that which exists at present on the highlands of the Antarctic, masking the topography but not obliterating it. Raistrick (1931), whilst supporting the nunatak theory, pointed to contemporaneous nunatak areas which are all clothed in partial snow fields. The most recent work substantiates the idea of ice free areas which Wright (1955) suggested were limited to the summit areas of Cross Fell, Mickle Fell and two high areas west and south of Wearhead.

Periglacial Activity. The final aspect of this period to be considered is that of periglacial activity, consisting of both erosion and deposition. Johnson (1963: 108) quoted evidence for solifluxion at Moor House during Late Glacial and early Post Glacial times when continued saturation of the ground existed, accompanied by a freeze-thaw process. He concluded that solifluxion became an important agent in the removal of material down slopes as little as 2-3° and resulted in the disappearance of much of the unconsolidated material at high altitudes during, and immediately after, the retreat stages of the last glaciation. Thus pockets of drift are all that remains as evidence of the former widespread cover. Solifluxion is still a very active agent in high altitudes where there is abundant moisture and often a persistent permafrost layer, and even at 1700 ft (514 m) on Cronkley Fell evidence of frost heaving can be seen. (Upper Teesdale and Weardale fall into the 'active frost' zone of Radforth (1962) where the micro-topography is influenced by seasonal piprake and slope movement.) This means that even after the final retreat of the ice following the valley glaciation of zone III, periglacial activity, particularly solifluxion, remained a dominant agent in the modification of the landscape (table 2).

Since the retreat of the ice the story has been one of progressive modification of the Late Glacial landscape by weathering processes, similar to those which are at work today, under an ameliorating climate.

[1] Johnson (1963: 106) pointed out the difficulty of distinguishing between locally derived boulder clay and periglacial solifluxion deposits. The latter is usually composed of the reworked former.

[2] Johnson (1963: 106) acknowledged the difficulty of distinguishing between nunatak and overridden peaks.

<u>TABLE 2.</u> Glacial and Post-Glacial Chronology in Northern England (after Charlesworth (1957) and Godwin (1956)) with contemporary nomenclature from Scandinavia and Britain (after Pennington (1969)).

Period	Northumberland & Durham (Charlesworth 1957)	Weardale	Zone
Post-Glacial		Peat erosion	VIII
		Peat formation	VII
		Birch 'forest'	IV-VI
		Solifluxion	
Late-Glacial	Valley glaciation	Valley glaciation	III
		Solifluxion	II
Würm (Weichselian, Devensian)	Northern boulder clay (Cheviot & Scottish ice)		I
Eemian	'Last' Interglacial		
Riss (Saale, Gipping)	Western boulder clay (Lake District, Pennines, Southern Uplands)	Local glaciers, dynamics & duration not known.	
Holstein, Hoxnian	2nd Interglacial		
Mindel (Elster, Lowestoft)	Northern boulder clay (Scottish ice)		
Cromerian	Interglacial (Cromer Forest Bed series)		

Chapter 3. THE BIOTIC ENVIRONMENT

3.1. Soils

The influence of soil type on vegetation is an important consideration in any ecological study. This is especially so in upland areas where the present-day distribution of soils is often reflected in the distribution of vegetation. Despite the fact that 'soil genesis in upland areas is poorly understood' (Atkinson, 1968: 1), leaching is known to be one of the foremost pedogenic processes, due to the excessive precipitation and low evaporation.

Soil is 'a constantly changing function of five soil forming factors: climate, parent material, organisms, topography and time' (Bunting, 1965: 22). However, 'in a given region the influence of one factor is usually predominant and the variations in soil development can be mainly attributed to that factor' (Bryan, 1967). In Upper Teesdale although climate is predominant, parent material and slope are important pedological influences.

In Upper Teesdale the climate is such that organic soils are predominant, along with other waterlogged and podsolised soils. The low annual temperatures contribute to the effect of high rainfall by decreasing evaporation and transpiration and reducing chemical and biological activity which are necessary for the production of an A and B horizon[1] in any soil. Bryan (1967) showed how, in the early stages of soil development climate was subsidiary to parent material as a soil forming factor. In his climosequence he showed that with time climate gradually superceded parent material as the major influence of soil differentiation. In Upper

Teesdale the generally immature soils reflect the influence of parent material although climate plays the major part in the widespread waterlogged and podsolised nature of them. The 'actual character at the soil sequence is determined by the degree to which the regional influence of climate has overcome the local influence of parent material' (Bryan, 1967).

A convenient division of parent material (table 3) is into weathered base rock and derivatives of this base rock. The base rocks are principally Carboniferous as shown in Chapter 1.1 and result in soils with different characteristics even with a similar climate. Sedentary soils over sandstone are acid and base deficient, over shales they are base rich but usually have impeded drainage, whilst over limestone they are base rich, although slightly acid. The base rock derivatives consist of boulder clays and solifluxion deposits which Johnson (1963: 117) has described as 'geologically very young, pedologically immature and agriculturally sterile'. These range from boulder clays rich in limestone fragments to soliflucted deposits devoid of limestone which have themselves been derived from the boulder clay. The potential of this drift as a medium for plant growth varies depending on its composition. Other parent materials, such as alluvium and spoil heaps, are of local significance only.

Local topography may play a significant part in the development and distribution of soil types. Johnson (1963: 117) showed a variation of soil with relief at Moor House. Despite the predominance of waterlogged soils, where drainage

TABLE 3. Soil Parent Material Classification (after Atkinson, 1968).

Parent Material	Genetic Process
Weathered rock (limestones, shales, sandstones, Whin)	Weathering, hill wash contamination
Solifluxion deposits	Mass movement (Late Glacial and contemporaneous)
Till	Transporation and Deposition by local ice
Alluvium	Fluvial processes
Spoil	Man-made processes

was absent or restricted, he noted podsols on the better drained ground whilst on the steepest slopes brown earths were found.

The history of the area helps in understanding the present soil pattern. After glaciation periglacial activity persisted for some time in the Pennines, as shown by dated solifluxion deposits (Johnson, 1963: 107). It was under these conditions, which can still be observed at the highest altitudes on Cross Fell, that the soils began to form. The impervious nature of the drift deposits allied to the high precipitation, low temperatures and other factors (see chapt.12.3) caused widespread waterlogging so that eventually blanket peat covered all but the steepest slopes and rock outcrops. In Upper Teesdale this has taken place at altitudes over 1500 ft (452 m). Since then erosion has proceeded to uncover the mineral soil, which sometimes reflects the pre-peat surface (see below).

The soils of Upper Teesdale may be divided for convenience into the following categories although there are many gradations: skeletal soils, calcareous soils, podsols, gleyed soils, brown earths and organic soils (peats). Table 4 shows the schematic relationships of these.

Skeletal soils show little or no horizon differentiation. They may be subdivided into:

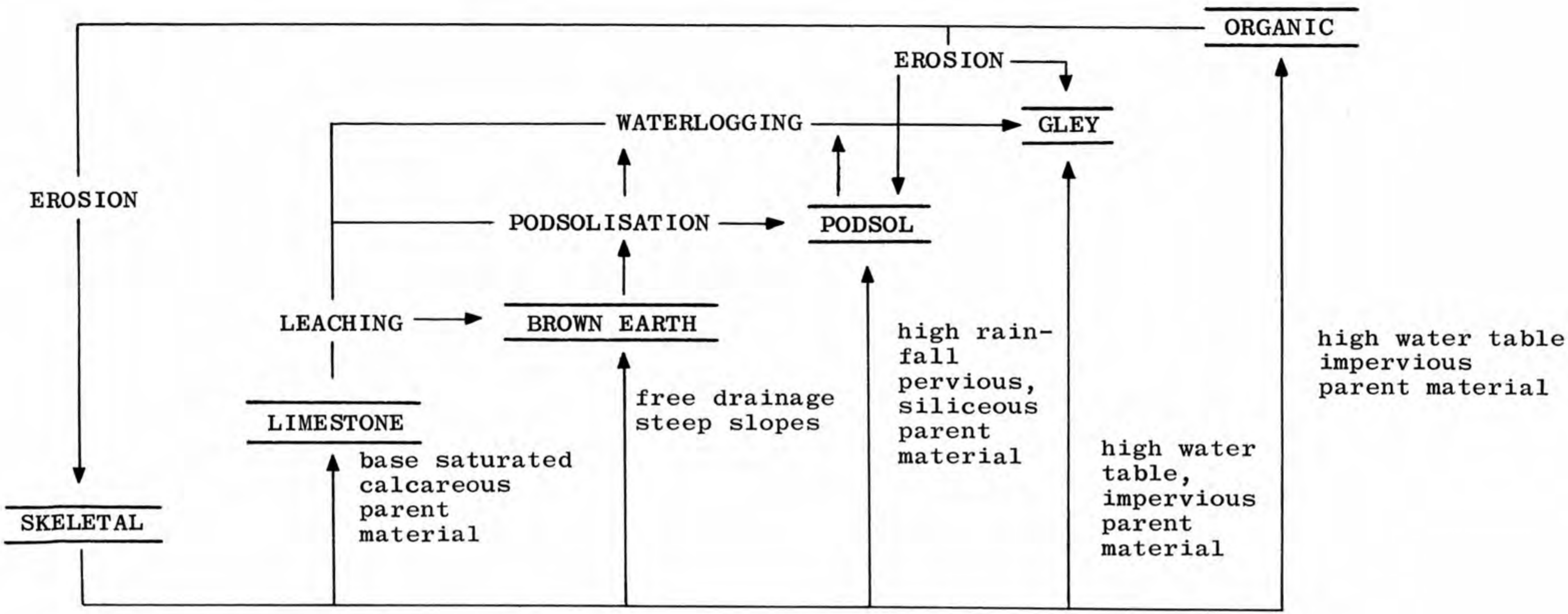
(a) Calcareous syrosems (Shimwell, 1968) which occur in the vicinity of the 'sugar limestone' outcrops and consist of an intermixture of roots, organic matter and coarse limestone grains. This limited soil type is extremely unstable and is liable to erosion, but carries the notable 'sugar limestone' grassland communities in which there occur many of the restricted species.

(b) Ranker soils[2] are found in scree areas or areas where mining has disturbed the surface. Atkinson (1968) classed these, according to the underlying solid rock, as: whin rankers, ironstone rankers, sandstone rankers and tip rankers all of which were unstable.

(c) Solifluxion soils are the product of a severe climate and are chiefly to be found on the crest and slopes of the western summits. These soils were almost certainly ~~formerly~~ more widespread in early Post-Glacial times. Johnson (1963: 129) subdivided these into: unstable solifluxion or creep soils which occur on sloping ground under the influence of soil wash and soil creep, and stable solifluxion soils which occur on the flat fell tops of the Moor House Reserve.

Calcareous soils are chiefly associated with the outcrops and structural benches of the Carboniferous Limestone. In Teesdale and Weardale Hornung (1968) and Atkinson (1968) respectively, recognised two types, a rendzina and a brown calcareous soil. The rendzinas are shallow and simple in morphology. Although they have an extremely variable nature there appears to be very little true rendzina soils in Upper Teesdale. The brown calcareous soils, more or less equivalent to the red-brown limestone soils of Johnson (1963: 125), are fairly widespread, especially where the influence of drift becomes noticeable. In Teesdale a lower pH (5.5-5.8 as opposed to the 6.4-6.8 in Weardale)

TABLE 4. Schematic relationships of the major soil types.



perhaps reflects the higher rainfall. The vegetation of these soils has been described by Pigott (1956: 571-573) as 'grasslands of unaltered limestone'; although limestone grasslands have soils which range from rendzinas to peaty gleyed podsols (Hornung, 1968).

Podsols[3] are formed under conditions of high rainfall and are developed on sloping ground (Johnson, 1963: 122) where the parent material is deficient in bases. Atkinson (1968) distinguished a wide range of podsol from a humus iron podsol to a podsol with gleying. Here however, it is proposed to subdivide them into podsols and sub-peat podsols, the latter as their name suggests occurring beneath the variable peat cover although they may be exposed in places. A high correlation has been found between Calluna moorland and podsols (Atkinson, 1968) but in Teesdale it is the drift covered valley sides, characterised by improved pastures, that have been subject to podsolisation (Pigott, 1956: 549). The presence of podsol soils under the peat suggests that podsolisation was active prior to the formation of the peat. Pearsall (1950:61) concluded, 'in mountainous Britain, podsols have almost always tended to become peat covered bog soils'. Duchaufour (1960) has propounded that the increased rainfall in Atlantic times (ca. 5000 B.C.) initiated this process and in areas with a high rainfall and a siliceous parent material, where peat did not develop for some reason, this process has continued unchecked until the present. There is a difference of opinion as to whether this process of podsolisation has continued to affect the sub-peat podsols. Proudfoot (1958) and Dimbleby (1962) concluded that these were relict soils and were the product of processes which acted upon the soil prior to the deposition of the peat. Atkinson (pers. comm.) however, suggests that thick peat induces intense leaching in the underlying mineral soils, the rate of loss of elements increasing with peat depth and time. This raises the question of the base status of soils prior to the formation of the peat and may be of particular relevance in a consideration of the pre-peat communities of the moorlands.

Gley soils are principally caused by the presence of an impervious parent material which promotes the prolonged or intermittent retention of water in suitable topographic situations. In Teesdale the predominance of heavy drift deposits, the high precipitation and the flat topography provide ideal condition for the production of waterlogged soils, including blanket peat. Although in other regions gley soils have been associated with Eriophorum spp., Nardus, Molinia and Deschampsia spp. in Teesdale this soil type is associated with Calluna and Eriophorum dominated blanket peat. A distinction can be made between those gleys which have a thin peat cover, the peaty gley (Johnson, 1963: 119), and those which are overlain by a thick peat cover, the sub-peat gley. The peaty gley soils 'occur in level areas and areas of gentle slope where there is impeded drainage' (Johnson, 1963: 119). The sub-peat gleys occupy extensive areas under the blanket peat and become important where erosion has removed the peat cover. Perhaps the most common type of sub-peat soil is that which shows evidence of podsolidation but which also shows the mottling, so characteristic of gleyed profiles. Atkinson (1968) suggested that the process of gleying was a response to changing ecological conditions, which indicates that the gley soils are of recent origin compared with the podsols.

Brown Earth soils have been found by Johnson (1963: 124) on the steeper slopes of the Pennine escarpment. They occur mainly on freely drained slopes under conditions of better drainage than the podsol, particularly where base rich water drains over the sloping ground. These soils, of limited extent, are characterised by a uniform brown colour where leaching is the dominant process. Atkinson's (1968) High Pennine Brown Earth is within the 'sub-Alpine podsol zone .... of variable profile morphology' of Romans *et al*. (1966).

Organic soils (peats) are found wherever water accumulates and there are plants which can grow in a waterlogged substratum, (Bellamy, 1966: 12). They may be divided into a. flush peats, b. basin peats and c. blanket peats.

a. Johnson (1963: 140) subdivided the flush peats of Moor House into: lime-rich flushes, which occur in the vicinity of limestone outcrops where springs from the bottom of the limestone drain over the surface of the bog, supplying base rich waters and causing a more eutrophic vegetation; iron-rich flushes which occur where the soluble ferrous compounds formed under anaerobic conditions in blanket peat become oxidised and ~~XXXXXX~~ are often found when water, draining from deep blanket peat, reaches the surface; peaty flushes which often occur where water drains across a bog surface without forming a channel.

b. Basin peats are topogenous features and are found where water draining from relatively acid rocks stagnates in flat bottomed valleys or depressions, the water level remaining permanently more or less at ground level. Little in general is known about these deposits (Tansley, 1939: 675). Several small deposits of this type have been found at the foot of Cronkley Scar, occupying depressions in the moraine.

c. Blanket peat covers the surface of the land like a blanket (Tansley, 1939: 676) and in Upper Teesdale generally stretch from 1500 ft (456 m) to 2500 ft (760 m). This peat type is characteristic of all flat or gently sloping surfaces ($< 15^{\circ}$)[4] in moist environments where high rainfall, high humidity and poor drainage, allied to low temperatures, predominate (Simmons, 1963: 180). Tansley (1939: 718) concluded that these ombrogenous peats were the climatic climax in regions of cool summers, high rainfall and high humidity; in extremely oceanic cool temperate climates.

Blanket peats can exist on a variety of substrata ranging from relict soils to unweathered rock. Similarly the plant remains within the peat and are often of considerable variety as will be demonstrated in Section B. A feature of some blanket peats in Britain is the presence of a basal wood layer.

There are conflicting views on the age of the Pennine blanket peats. Lewis (1904) described an interglacial peat on Cross Fell whilst at the other extreme Moss (1904) and

Burrell (1924) regarded the peat as 'recent'. It was Erdtman (1928) who showed that the peats were entirely Post-Glacial and were generally in agreement with the climatic schemes propounded earlier by Blytt and Sernander. He concluded that most of the deposits were of Atlantic age, although some were earlier. Raistrick and Blackburn (1931, 1932), working in north England, came to a similar conclusion whilst Conway (1947, 1954) more specifically found that at altitudes over 1200 ft (365 m) in the southern Pennines blanket peats began to form at the Boreal/Atlantic transition. Conway's work thus substantiated earlier work by Woodhead and Clark (1926) who suggested an Atlantic start for the Yorkshire Pennine peats. The anomalous situation of the interglacial peat on Cross Fell was resolved by Godwin and Clapham (1951) who showed this to be of Boreal age, therefore in agreement with other findings. Johnson (1963: 134) found that the main period of peat formation in the Pennines was during Atlantic times and that only in favourable localities did peat deposits begin earlier. Tallis (1964), working in the southern Pennines, discovered differences in the time of blanket peat initiation, depending on local topography. He suggested that no single date could be given for the onset of peat growth but that the earliest dates were ca. 5000 B.C.-3000 B.C. Where deposits prior to this general date were found he noted that they were either lake muds or fen peats underlying the ombrogenous blanket peats. Thus, there is general agreement on the age of these peats.

Blanket peats have already been described as climatic climaxes in oceanic cool temperate climates. Whether or not one believes in the theory of a climax state the mere fact that they have been considered as such indicates their climatic origin. In the Pennines the inception of ombrogenous peat at the B.A.T., or early Atlantic period, at a time when the climate of the British Isles became pronouncedly more oceanic (Godwin, 1956: 331) is further evidence of this. There are, however, some suggestions that biotic activity has played a significant part in blanket peat inception. Pearsall (1950: 197) showed that soil leaching led to the formation of peat in the Pennines. Elsewhere, on Dartmoor, Simmons (1962) suggested that there was no evidence to support a climatic change during zones VIIa/VIIb when most of the blanket peats started to form. He tentatively suggested that biotic activity during early VIIb might have been the cause of soil leaching, through the destruction of the existing vegetation, which allowed ombrogenous peat growth to start.

Erosion is a common feature of the upland peats. Bower (1959) stated that erosion was the inevitable outcome of accumulation under upland and northern climatic conditions although she recognised that biotic factors might initiate erosion in certain circumstances. Tallis (1964b) concluded that no single cause could be invoked to explain erosion in the southern Pennines. He found that the main pattern of erosion was established prior to the human settlement of the uplands although he found evidence of increased erosion in the Middle Ages, paralleling increased human activity, whilst Johnson (1963) attributed erosion at Moor House to the sub-

PLATE 7

Headwater erosion occurring in a small stream on the northern slopes of Long Crag.

Atlantic climate deterioration. Tallis (1964b) summarised the main causes of erosion:

(i) Major stream courses may develop prior to peat formation. Increased precipitation causes peat formation and leads to an increased discharge or surface water runoff, resulting in headwater erosion.

(ii) Undisturbed blanket peat may develop its own drainage system (Johnson, 1963: 142), therefore becoming inherently unstable.

(iii) The vegetation cover may become disrupted by: grazing, burning, draining, wind action, frost and shrinking and cracking leading to the surface of the peat becoming channelled by rainfall.

[1]A horizon - the horizon of maximum biological activity.

B horizon - the horizon lying between the above and the weathered parent material of the soil (C horizon).

[2]Ranker soils were defined by Kubiena (1953) as soils with an A/C profile on parent material low in lime, which were divided on the basis of humus type, the region where it developed, the major soil group towards which it was evolving, or colour.

[3]The term 'podsol' is used here to denote a specific soil category. Under the influence of high precipitation many soils tend to become podsolic.

[4]On the north slopes of Mickle Fell blanket peat can be seen on slopes in excess of 15°.

3.2. Vegetation

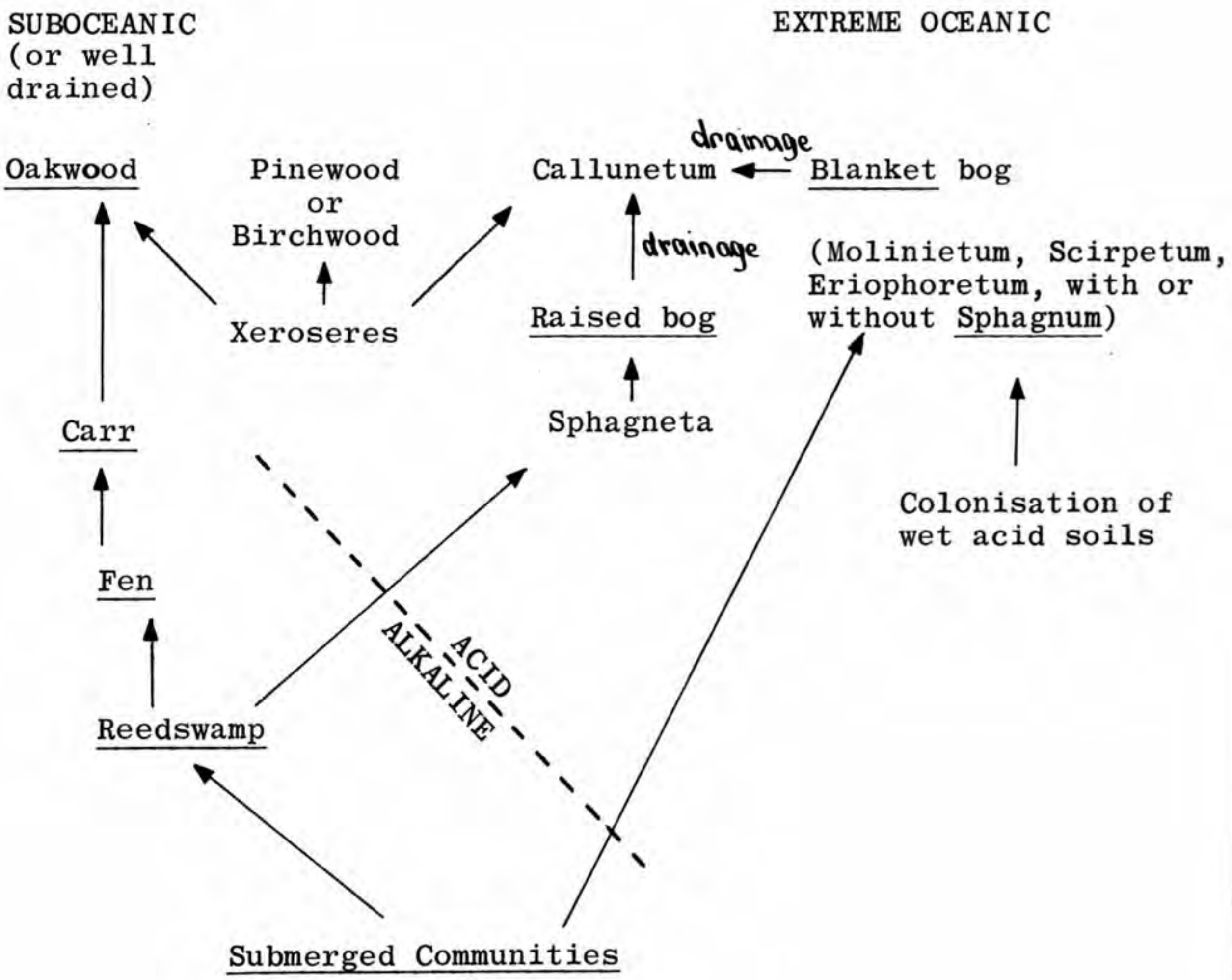
Smailes (1965: 65) described the vegetation of the northern Pennines as 'a complex and essentially unstable pattern of moorland[1] vegetation'. Interspersed amongst these moorland communities are patches of grassland and woodland (fig. 19). Thus a classification into grasslands, woodlands and moorland has been used in this work, firstly because it is convenient, and secondly, because these three classes of vegetation can be distinguished most readily by palaeoecological methods. No genetic relationship is necessarily implied although as Tansley (1939: 720) showed there might be (table 5).

Perhaps the most comprehensive account of the vegetation of the northern Pennines has been given by Lewis (1904). Since that time many workers have limited themselves to a study of the distinctiveness of the Upper Teesdale flora including: Backhouse & Backhouse (1843); Backhouse (1844); Baker (1863, 1906); Baker, Tate & Tate (1868); Temperley & Cooke (1920); Peacock (1925); Pearsall & Mason (1925); Nicholson (1930); Temperley (1934); Pearsall (1941); Ramsden (1947); Pigott (1956); Elkington (1962); Godwin & Walters (1967) and Shimwell (1968). Of these Shimwell paid particular attention to the limestone grasslands of the region. As it is within this category of vegetation that most of the distinctive species of the Teesdale flora occur and because of the relevance of these peat free and often base rich areas to the present and past ecology of the dale these are considered in some details.

Grassland

Most of the grasslands of Upper Teesdale may be described

TABLE 5. Scheme of Hydroseres in relation to Fen, Bog or Moss, Callunetum and Forest (after Tansley 1939: 720).



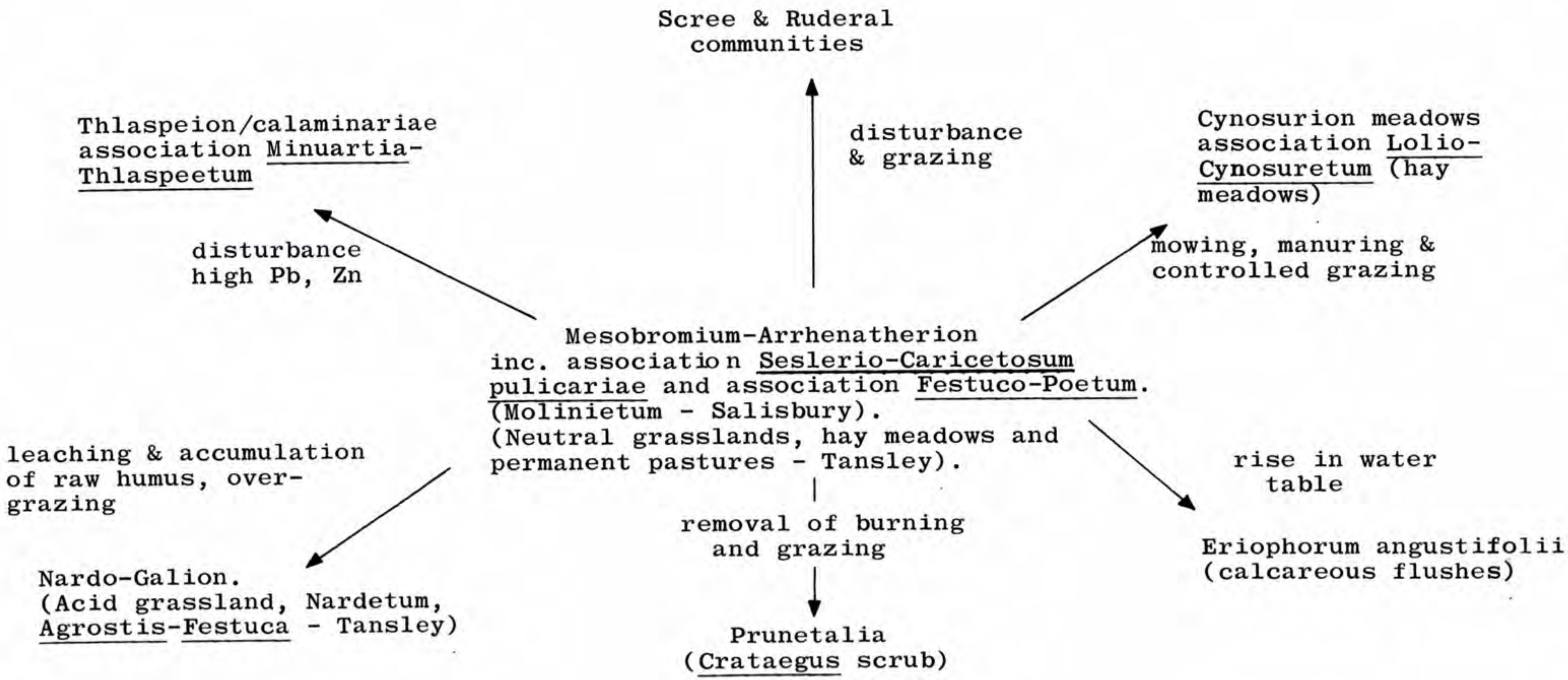
as limestone grasslands in their broadest sense (see table 6). These grasslands exist as windows in the general moorland cover and fringe the moorland at lower altitudes and have been described by Shimwell (1968). They are generally regarded as being maintained in a plagioclimax by grazing (Tansley, 1939: 206). Tansley (1939) envisaged them as playing a role in a dynamo-genetic classification of:

Scree ⟶ grass ⟶ scrub ⟶ climax woodland

but Shimwell pointed out that these grasslands are almost stable (see also Bellamy et al., 1969), although short term changes may be caused by climate especially pedogenic manifestations (Bryan, 1967; see 3.1 above), drainage and grazing (table 6). The limestone grasslands of the northern Pennines are similar to those in other comparable areas of Carboniferous limestone in the British Isles (e.g. Derbyshire, Perthshire) but contains several anomalies. Upper Teesdale is one such anomaly and provides one of the classic areas of limestone grassland, where the picture is complicated by the presence of irregular patches of drift and the presence of the quartz-dolerite intrusion of the Whin Sill.

1. The Seslerio-Caricetosum pulicariae association of Shimwell (1968; 1969) previously called 'sugar limestone grassland' (Pigott 1956; 563 ff), 'limestone grassland' (Sinker, 1960) and 'natural pastures ' (Lewis, 1904 pro parte), is fairly widespread on the limestone uplands of the northern Pennines from the Craven District to the Teesdale Fells. Communities of this association are found predominantly on steep south-west facing slopes where the influence of drift is minimal and there is no accumulation of raw, peaty humus.

<u>TABLE 6.</u> Summary of Short-term seral relationships of limestone grasslands (after Shimwell 1968) (Zurich-Montpellier nomenclature & comparative names)



The soil types show a gradation from rendzinas to brown earths with some podsolisation, although into this category come the 'Calcareous Syrosems'. The general features of this association are: the dominance of Sesleria caerulea, the dampness of the climate and the altitude of much of the area. Carex pulicaris, C. hostiana, C. capillaris and Primula farinosa are often present. In Upper Teesdale four sub-associations can be recognised:

a. Sub association typicum is widespread on the sugar and unaltered limestone of Cronkley and Widdybank Fells above 1700 ft (560 m) where Sesleria and Carex pulicaris dominate, often with Festuca ovina. Where there occurs some accumulation of raw humus, resulting in a slightly podsolised red-brown calcareous soil, Calluna vulgaris and Empetrum nigrum become co-dominant. Near the margins of the sugar limestone outcrops occur the calcicole Ditrichum flexicaule and Rhytidium rugosum.

b. Sub association Kobresietosum is restricted to Widdybank Fell. Kobresia simplicuiscula, a plant of calcareous flushes in the central Alps, takes over the dominance from Sesleria in damp grasslands. Carex capillaris replaces C. pulicaris in places and Gentiana verna and Polygonum viviparum are frequently found.

c. Sub association Dryadetosum only occurs at White Well Green on Cronkley Fell. Dryas octopetala gives these communities a characteristic structure.

d. Sub association of Saxifraga hypnoides and Cochlearia alpina occurs above 2100 ft (690 m) on Mickle Fell, Great Dun and Little Dun Fells and at one locality on Widdybank Fell. Although both species are fairly common in open communities at lower altitudes (e.g. gravel flushes), they only become dominant at high altitudes where the climate becomes damp and humid. Festuca ovina, Thymus drucei, Carex caryophylla, C. pulicaris become dominant and Myosotis alpestris and Draba incana appear as indicator species.

These grasslands are heavily grazed and several nitrophilous weed species, such as Cirsium vulgare and Bellis perennis, are abundant. Heavy grazing often causes such a reduction in the vegetation cover that the prevalent strong winds initiate erosion.

2. The association Lolio-Cynosuretum (Br.-Bl. & de Leeuw, 1936) is common in the higher pastures of Teesdale and Weardale. 'These rye grass-white clover pastures show more clearly than any other community the effects of human management' (O'Sullivan, 1965). The rich riverine hay meadows of Upper Teesdale, characterised by Cynosurus cristatus, Trifolium repens, Phleum pratense and Lolium perenne which are favoured by the continuous pasturing and mowing on a rotation system, indicate the long and intensive grazing. The distribution of these meadows in Upper Teesdale has been attributed to the system of part-time farming practiced by the miners of the area in the mid- and late-eighteenth century (Pigott, 1956: 553). The typical soil is a brown earth or a meadow soil (Tansley, 1939: 88) whilst variations in the composition of the turf are due to the presence of flushed areas (Pigott, 1956: 544-545).

3. Shimwell suggested that many of the grasslands in the northern Pennines between 1250-2200 ft (400-700 m) belong

to the association Festuco-Poetum (Agrostis-Festucetum typicum of Eddy, Welch & Rawes, 1968), the dominant species being: Festuca ovina, F. rubra, Anthoxanthum odoratum, Agrostis tenuis and Poa subcaerulea. Here climate is characteristic of adverse mountain zones and soil types range from rendzinas to podsolised brown earths, from drift free to drift covered areas. At the highest altitudes the sub-association Sub-Alpinum predominates and grades into the sub-association of Saxifraga hypnoides and Cochlearia alpina (see above) where limestone exerts a greater influence.

4. The influence of mining on the landscape is considerable as can be seen by the derelict buildings, ancient mine shafts and numerous hushes. In addition to the visible obsolescence which will be discussed later, mining has left its mark on the pattern of farming and on the vegetation. Many of the abundant spoil heaps, composed of limestone and Whin Sill are grassed over with Agrostis-Festuca communities. However, where there are high concentrations of lead and zinc, communities belonging to the association Minuartia-Thlaspeetum sub-association Cladonietosum are found with Minuartia verna, Thlaspi arvense, Cornicularia aculeata and Cladonia spp. (dominant). The presence of zinc appears to be the limiting factor on the distribution of these communities.

5. In addition to those associations described above which are the grasslands normally considered as 'limestone grasslands', are several related communities.

a. Calcareous flush communities (Pigott, 1956: 556). In northern England are a range of communities which are dependent on the level of the water table:

Caricetum lepidocarpae-hosteanae

Schoenetum nigricantis
Eriophorum angustifolii

Increasing
water level

Gymnostomum-Crataneuron
(bryophyte flush)

Crataneuron spring head

These flush communities also occur within the blanket peat area (see 3.1. above) where spring waters produce a more eutrophic vegetation. The characteristic species vary depending on the movement of the water and its basicity.

b. Communities of leached grasslands and calcareous heaths. The acidic grasslands of Tansley (1939: 499-524), the *Agrostis*-*Festuca* grassland, the *Nardus* grassland and the *Molinia* grassland all belong to this category. These occur in many parts of sub-montane Britain on non-calcareous soils whilst in limestone regions they occur on slopes where precipitation is high and podsolised brown earths occur. In fig. 19 these grasslands occupy most of the land below the limit of the blanket bog and are designated as 'Natural Pastures and Grass Heaths'. The dominant plants are: *Agrostis tenuis*, *Nardus stricta*, *Festuca rubra*, *Deschampsia flexuosa*, *Galium saxatile* and *Potentilla erecta*. Some heath plants may be present (e.g. *Calluna vulgaris*, *Vaccinium vitis-idaea* and *V. myrtillus*) but never attain dominance. *Molinia caerulea* becomes dominant only with increasing dampness resulting in the accumulation of humus.

c. Communities of calcareous scrub. In the doleritic rock crevices or on the alluvium which is periodically flooded by the river, the *association Potentilletum fruticosae* is found (Shimwell, 1968). This community is characterised by the dominance of *Potentilla fruticosa* with *Sesleria caerulea*, *Brizia media*, *Thymus drucei* and *Festuca ovina*. The extremely damp nature allows species such as *Succisa pratensis*, *Filipendula ulmaria* and *Deschampsia caespitosa* to thrive. Shimwell (1968) suggested that these are relics of the former widespread, Late Glacial flora.

d. Communities of scree (Pigott, 1956: 572-574). Such communities include species which grow on the thin humus of crevices and ledges. On the high limestone cliffs and outcrops the grassland is dominated by *Sesleria caerulea* and includes such rare species as: *Draba incana*, *Saxifraga hypnoides*, *Sedum rosea* and *Tortella tortuosa*. In rock crevices shade tolerant species more commonly associated with a woodland flora can be found: *Poa subcaerulea*, *Oxalis acetosella*, *Anemone nemorosa*, *Cystopteris fragilis* and *Taraxacum* spp. Where the outcrops are more acid a dry heather moor of the '*Vaccinium-edge*' type (Pearsall, 1950: 141) is present with *Calluna vulgaris*, *Deschampsia flexuosa*, *Vaccinium myrtillus*, *V. vitis-idaea* and locally *Arctostaphylos uva-ursi* co-dominant with *Sphagnum* spp. (occasional).

Although the 'grassland' communities described above are not as extensive as the moorland communities they are extremely significant features of the vegetation pattern in Upper Teesdale. In some of these communities there is the minimal competition for growth required by many of the rare species whilst all of these grasslands have a higher base status than the surrounding areas of blanket peat. If, as Pigott (1956: 576) suggested, these 'grassland' communities were more extensive in former times their importance would obviously be greater in any palaeoecological record. During the period when blanket peat growth was a dominant agent in the modification of the landscape these communities would offer stable, perhaps base-rich conditions for the propagation of the rarer species found in restricted localities at present.

Moorland

Extensive areas of the interfluves of Upper Teesdale are covered by blanket peat in various stages of dissection. The considerable variety of vegetation which may be found in areas of blanket peat, summed up by Pearsall (1950: 152) who described the term blanket bog as 'a conveniently vague term for peat forming vegetation', depends largely on the extent of burning, draining and grazing.

The most characteristic type of vegetation of the blanket peat in Upper Teesdale is dominated by Calluna vulgaris and Eriophorum vaginatum. Communities dominated by these species are found growing on varying thicknesses of acid peat (0.5m-3.0m) which, as already noted, often overlie a podsolised soil. Either Calluna or Eriophorum may become the sole dominant. Where the peat has become dry as a resulting of draining or burning heather becomes the major species. As a result of this practice over the centuries large areas are dominated by Calluna in Upper Teesdale, particularly on the Yorkshire side of the River Tees, in the Upper Teesdale National Nature Reserve but also on

Widdybank Fell. Occurring with the heather are: Erica tetralix, Empetrum nigrum, Juncus squarrosus, Vaccinium myrtillus, V. vitis-idaea, Rubus chamaemorus, Eriophorum vaginatum, Potentilla erecta, Nardus stricta, Polytrichum commune, Hypnum cupressiforme, Cladonia spp. and Sphagnum spp. In extremely damp habitats Sphagnum spp. may become dominant but this only occurs in isolated localities (see Pearsall, 1941). More usually Eriophorum vaginatum, E. angustifolium, Juncus effusus and Sphagnum spp. become abundant where the water table is high. Large areas are dominated by Eriophorum spp. above Cauldron Snout.

The blanket peat communities are floristically simpler than the grassland communities. However, the lack of detailed studies on the extensive areas covered by peat make a definitive account similar to that presented for the limited grassland areas impossible. In terms of palaeoecological interpretation the many communities encompassed by the term 'blanket bog' (see footnote) may be categorised into one habitat.

Woodland

There is abundant evidence for the former widespread extent of woodland. A basal forest layer is persistent in blanket peats (see Chapter 3.1). The remains of birchwoods can be traced for considerable distances on Mickle, Murton, Hilton, Dufton, Neldon, Knock and Cross Fells up to 2500 ft (760 m) (Johnson, 1963). This wood layer is such a consistent feature that Lewis (1904) concluded that more or less all of the blanket peat areas appeared to have supported birchwoods at some Post-Glacial period a conclusion that Pearsall (1950: 146) extended to most of the heather moors of the British Isles. The remains of pine suggest at least the scattered existence of these trees at high altitudes during the Boreal period which disappeared because of the processes of soil degradation and peat growth during subsequent periods (Pigott, 1956: 549). In addition to birch and pine, alder and aspen (Populus tremula) have also been found. The cause of the soil degradation which is thought to have resulted in the disappearance of these trees has already been discussed but here it is pertinent to note that Pearsall (1934) regarded sheep as the principal agents of woodland destruction.

The present treeline is approximately 1700 ft (517 m) although at this altitude the trees occur in sheltered localities and are stunted and scrubby. The planted conifers can be found up to 1900 ft (577 m) at Moor House. Pigott (1956) recognised three categories of woodland.

a. Herb-rich birchwood exists on the slopes above High Force. Here Betula pubescens, Alnus glutinosa, Fraxinus excelsior, Corylus avellana, Prunus paduus and Salix atrocinerea are found along with a herb cover reminiscent of the herb rich birchwoods of the Scandinavian mountains (Nordhagen, 1927: 127).

b. Fragments of healthy birchwood occur on the screes, below Cronkley Scar and Falcon clints on moss covered doleritic blocks. Characteristic plants include: Betula pubescens, Corylus avellana, Agrostis stolonifera, Holcus lanatus, Luzula pilosa and Oxalis acetosella (Pigott, 1956: 552).

PLATE 8

Juniper woodland, High Force.

c. Juniper woodland is fairly extensive, if somewhat scattered. Below High Force, it exists in a dense woodland but it also occurs as isolated bushes on Cronkley and Mickle Fells.

In addition to these fragmentary remains trees of birch and aspen are found on Cronkley Scar and Falcon Clints.

[1] Some discrepancies exist about the definition of moorland. Tansley (1939: 673) uses the term to describe a series of oxyphilous communities from bog to acid grassland and this appears to be the definition used by Smailes (1965: 65).

[2] Relevant aufnahme in Shimwell (1968):-

45-55	Widdybank Fell.
55-61	Cronkley Fell.
63, 93	Lang Hurst.
64, 65, 94, 95	Mickle Fell.
72, 79, 80	Dufton Fell.
L27, 28, 30	Moor House N.N.R.
LM21, NP101, 104, 108	Widdybank Fell.
LM24	Windy Brow, Alston.
NP85	Cronkley Scar.
NP82-86, NP90	Upper Tees valley.

3.3. The Human Occupation of the Area

So far this thesis has dealt with the features of Upper Teesdale which may justifiably be described as the 'resources' of the area. These man can appraise and utilise or disregard and subsequently conserve or destroy. The results of the various appraisals by human groups can be clearly seen in a study of their occupation. The general story of this occupation is one of the gradual spread from the cultivated valleys to the uplands, although paradoxically it was these upland routeways which first brought man to the region (Roberts, unpub.).

Man's occupancy began in the Mesolithic period which spans from ca. 8000 B.C.-3000 B.C. in north-west Europe, from the beginning of the Pre-Boreal to the spread of the Neolithic economy. During this period there existed a variety of hunting and food gathering peoples whose economy was based on the forest, freshwater and coastal habitats (Hallam, 1960). In the context of Upper Teesdale the most important of these belonged to the Tardenoisian culture, the microlithic culture of the highland areas (Clark, 1936). Because these were the first agents of environmental change which were not purely physical and therefore natural it is considered of relevance to discuss these people and the environment into which they came, particularly as more and more evidence is coming to light on the influence of these primitive economies on the vegetation pattern.

Microlithic remains of these peoples have been found throughout the northern Pennines, mainly above 1000 ft (304 m) (Raistrick, 1931), and in Upper Teesdale Johnson (1963) found flint and chert remains at Moor House which were associated with the remains of indigenous wild cattle.

Woodhead (1929) was the first to date these microlithic remains by methods other than typology. Since then Raistrick (1933), Godwin (1940), Clark (1954) and Walker (1956) have all used pollen analytical techniques, the last named complementing the results obtained by radiocarbon dates. The first firm date for the Pennine Mesolithic culture was 6500 $\pm$ 310 BP. (Godwin & Willis, 1959: 69), although Johnson (1963: 154) concluded: 'It now seems clear that the Pennine microlithic industry may be contemporary with the Boreal age records of other regions but they extend well into the succeeding Atlantic period, at least to the latter part of zone VIIa'.

From an examination of various Mesolithic localities[1] in Britain and on the Continent, Hallam (1960) suggested that there were three main conditions which governed the selection of camping sites for the nomadic Tardenoisian hunters, firstly a well drained surface with only a light scrub vegetation, secondly the presence of an adjacent spring or stream, and thirdly a nearby river or waterway. These conditions could be fulfilled in the Pennines, especially above 800 ft (243 m) (Walker, 1957: 26; Hallam, 1960; Johnson, 1963: 155).

The state of our knowledge concerning these hunting groups may be summed up:

'At present it may be permissible to postulate small bands of hunters moving around the Pennines from one camping site to another in pursuit of game, principally red deer. Under the more congenial climate of their day the highlands would be clothed in heaths and woodlands, making suitable feeding grounds for deer in the summer months when the denser woods of the lower slopes and valleys would be filled with parasitical insect life. As hunters with no fixed settlements they would carry about with them their essential materials' (Hallam, 1960: 100). Thus the microlithic remains which, especially at Moor House, appear to be valuable hunting tools, might have been accidentally lost at a resting place during a hunting trip.

Although artefacts of the Mesolithic peoples are fairly clearly distinguishable, therefore a period of Mesolithic 'occupation' may be defined in the northern Pennines, Raistrick (1933) pointed out that Neolithic remains were contemporary with Bronze Age remains. He suggested that the late Mesolithic, Neolithic and early Bronze Age periods were telescoped in Yorkshire and the Durham Pennines. Fell (1953) found most of the microliths in Weardale to be of late Tardenoisian in type and concluded, as did Clark (1954), that the microlithic tradition survived in certain areas long after the Mesolithic period. Hildyard (in Fell, 1953) collected flints which appear to date from the Neolithic or Bronze Age period, whilst a site on Redburn Common suggests the re-use of a Mesolithic locality in Neolithic or Bronze Age times. The sporadic finds of flint arrowheads at Park End, Holwick, Cronkley Scar, Harter Fell and Mickle Fell, and the tumulus at Kirk Carrion in Teesdale (Proctor, 1965: 6) denote the presence of Neolithic and Bronze Age man in the area still carrying on the hunting tradition, probably in much the same environment as the Mesolithic peoples. Roberts (pers. comm.) suggested that the dale bottom and hillslopes were occupied at this time although the amount and composition of the woodland was only slightly altered (see Section C).

In northern England most of the early beakers of the Bronze Age lie north of the River Aln or on the Yorkshire Wolds (Raistrick, 1931). The infrequent Bronze Age finds in Teesdale: a beaker sherd on Holwick Fell, beads of jet[3] at Holwick, a bronze axehead at Middleton and a burial mound at Mickleton, appear to indicate little penetration of these peoples into the upper parts of the dales. Of importance amongst finds of this period is that of a bronze hoard at Heathery Burn Cave near Stanhope in Weardale. Here implements belonging to a Bronze Age smith have been found. This find also shows that cattle, sheep and horses were present at this time in Weardale. These scattered remains substantiates the view that the agricultural Beaker peoples, who immigrated during this period, remained on the drier lower land whilst the higher slopes and the uplands, which were probably peat covered, remained the domain of the hunters and pastoralists.

The relative absence of Iron Age remains in both Teesdale and Weardale is undoubtedly a reflection of the number of archaeologists although Stanwick in Teesdale is known to have been a fortress of the Brigantes (Proctor, 1965: 7). The distribution of cultivators/pastoralists is a matter for conjecture, and whilst Pigott (1958) placed emphasis on a pastoral economy, Jobey (1966) is not as definitive. The presence of substantial areas of cultivation in Weardale and Teesdale would fit in with other areas. The present scatter of small fields may reflect the presence of man in clearings by the river at this time (Roberts, unpub.).

From the various finds it is known that the Romans were aware of Teesdale and Weardale and although Petch (1925) refuted evidence which pointed to Roman mining in the area Roberts (unpub.) suggests some slight evidence for mining from Rookhope. North England lies within the area of Roman military occupation so that permanent settlements would be limited to those areas where conditions were both favourable for agriculture and suited to settlements, on the lower ground to the east of the Pennines, probably along the roads principally built to supply the forts of Hadrian's Wall. Petch (1925) described the main road in the area running from Piercebridge via Binchester and Lanchester to Ebchester, probably with branch roads to the forts of Chester-le-Street, Jarrow and South Shields. Boyce (quoted in Petch, 1925) suggested a road from Barnard Castle to Ferryhill via Raby Park but there is little concrete evidence for its presence. In Teesdale itself Backhouse (1896) described a road which joined the Maiden Way, the main north/south road to the east of the Pennine Escarpment, near Alston, whilst Roberts (unpub.) suggests that a trans-dale road from Bowes to Corbridge may have evolved because of ore exploitation.

From available evidence no permanent occupation of Teesdale by Romans in Roman times can be suggested. Elgee (1930) concluded that there was no permanent Roman station east of a line joining Thirsk and Northallerton. The use of Roman implements and even coins by native peoples might well account for the scattered finds of Roman times in Upper Teesdale. A shield boss, a spear head and coins found near High Force and the essentially military remains found in of north Yorkshire, north of a line between Newburgh and Malton, clearly show the frontier nature of the whole region. Other remains in Teesdale, such as the possible signalling station near the crest of Little Dun Fell (Johnson 1963: 161) may also indicate the unsettled nature of the native Brigantes. The weight of opinion at present is that during Roman times both Weardale and Teesdale were areas set aside for hunting, a recurrent theme during subsequent centuries, although possibly with substantial areas of cultivation. The presence of several altars, dedicated to Silvanus a god of hunting, in Weardale, Teesdale and Stainmore appear to substantiate this view. Within this area, there may have existed native peoples in small groups (Elgee, 1930).

After the Roman period the area was occupied successively by the Picts, the Anglo-Saxons and the Normans (Wallace, 1890: 4), although the Anglo-Saxons founded the first settled communities in Alston and Garrigill in the sixth century. These were predominantly a pastoral people and occupied the South Tyne valley using the more accessible slopes as summer pasturings, a migratory population (Wallace, 1890: 4). There was little or no encroachment onto the uplands. Roberts (pers. comm.) suggests that in Teesdale and Weardale Anglian farming communities had probably established themselves by the mid-seventh century in settlements such as Wolsingham, Stanhope, Egglestone, Middleton, Mickleton and Cotherstone, utilising earlier cleared sites. On the higher fells the hunting practised by previous peoples continued but it is from this time that game laws are first recorded (Wallace, 1890: 50 et seq.). This is the first attempt to prevent wholesale killing of the animal population. It would seem reasonable to suggest that these laws arose partly because there was no need to supplement their crops by hunting and partly because of the tradition of hunting in the dales, a tradition which still exists despite the absence of the formerly hunted red deer.

With the influx of Scandinavian peoples in the ninth and tenth centuries came further nuclei of settlements: Raby, Staindrop, Romaldkirk and Hunderthwaite and by the time the Normans arrived in the eleventh century the pattern of land exploitation was fairly consistent over a large area; settlements surrounded by cultivated fields (often cultivated in common) and upland summer grazings. By the twelfth century Upper Weardale was used extensively for hunting purposes and it is not unlikely that Upper Teesdale was used in the same manner. The consistent name of 'forest' in the dales would appear to indicate former areas of considerable woodland, possibly used for hunting. Wallace (1890: 40) however, pointed out that this name did not always indicate a covering of trees during historical times, 'these forests were hunting grounds on which few or no trees were growing and were probably created after the Conquest'. Often areas marked as 'forest' were covered by blanket peat which had been growing since the B.A.T. (for example Milburn Forest). The creation of these hunting preserves in Norman times therefore did not necessarily mean that there were extensive tree covered areas in either Teesdale or Weardale, although it is difficult to obtain any information regarding the status of the woodland at this time.

After Norman times the history of Weardale and Teesdale is obscure in detail, although the broad pattern is clear and to a large extent reflected the policies of the various landowners. Durham was established as a County Palatine under a Prince Bishop in the late twelfth century whilst Teesdale became the property of the Neville family who retained possession until it was forfeit to the Crown in the sixteenth century. During the twelfth century are the first records of cattle, horses and sheep grazing in Upper Teesdale, although there is evidence for their presence in Bronze Age times (above), and permission to cut the woodland. ~~and~~ Throughout the thirteenth century there occurred woodland destruction along the valley, predominantly below 1000 ft (304 m). This process undoubtedly continued throughout succeeding centuries but probably reached its maximum during the eighteenth and nineteenth centuries when mining was at its height. During this long period of extensive mining and progressive woodland destruction the typical land use pattern of the dales was established. In the upper parts of the dales are numerous small farms, many of which are now abandoned. A large proportion of these are the dwellings of former miners who were also part-time farmers and it was often the policy of mineowners to provide these holdings. This means that at the present time can be seen farm units along the frontiers of cultivation where the profit margins are very slight. The'raison d'etre' for such a pattern of land exploitation has gone but the evidence in present and derelict farms still remains. As a consequence of this the usual definite boundary between improved land and the fell country has become blurred and on the fell slopes can be seen the relics of a former pattern of land use.

At the same time as the lower slopes were enclosed during the eighteenth and nineteenth centuries the unenclosed moorland became subject to careful usage rights. Since enclosure the land use pattern has remained essentially the same except for the mines which have been abandoned, the remnants of which can still be seen. (Johnson, (1963: 162) described mining as being one of man's conspicuous contributions to the general scenery of the northern Pennines). The present pattern of land use may be summed up as: permanent pasture (unseeded) below 1300 ft (395 m), whilst above 1300 ft (395 m) rough pasture and grouse moor occur.

No account of man's occupation of the dales could be complete without a short discussion of the history of mining. Before the Romans the Bronze Age peoples used lead as an alloy, and bronze remains containing a proportion of lead have been found at Heathery Burn Cave (Greenwell, 1894). During the Iron Age lead objects became more common in the Pennines although Raistrick & Jennings (1965) concluded that there were very few mines prior to the Romans. Backhouse (1896) however suggested that native mining might have been carried out similar to the native mining of tin in Cornwall before the Roman occupation.

There is evidence of lead being produced in Yorkshire in AD81. There is no evidence to support Roman exploitation of the lead deposits of Weardale and Teesdale apart from the few objects at Rookhope (above) although metal objects from Corbridge contain silver which has been connected with the Alston Moor lead mines. After the Romans it was not until the building of the Anglian monasteries that lead became important and between the fifth and tenth centuries the only records of mines in the north were those of mines in Derbyshire. Despite this however, Raistrick & Jennings (1965) concluded that in Yorkshire and further north mines which were in existence in Roman times continued to be used but that little prospecting took place until the Middle Ages. Evidence of this, they suggested, came from the Anglo-Danish origin of the names and terms used in the north Pennine mines.

During the thirteenth centuries the demand for lead was such that a fairly stable lead trade had evolved partly on Boston, although the general picture was very disjointed and widely scattered mines used different markets at different times.

Mining was first noted in Weardale in 1130 (Wallace, 1890: 99). In Teesdale however, the development of mining was slow until the London Lead Company leased mines at Newbiggin in the mid-eighteenth century. The only record of ore explitation before this was at Eggleshope, which although neglected in 1550, had formerly been very productive. During the late eighteenth century a smelting mill was built

PLATE 9

Park Level Mill in Weardale. A well preserved example of a tip landscape.

at Egglestone which dealt with Teesdale ore and part of the Weardale ores and by the opening of the nineteenth century mining was a flourishing industry, particularly mining for lead (Hutchinson (1794) noted over 800 men constantly employed in Upper Weardale). In the 1830's the Teesdale mines produced 50% of the total output of the London Lead Company and the whole district remained the Company's main producer until the late 1870's. With the decline in prices the mines went out of production and despite the decline in Weardale being partly offset by the development of quarrying the picture was one of 'grumbling buildings and barren waste heaps of mines' (Raistrick & Jennings, 1965: 327). A new lease of life was provided by fluorspar and barytes but the last mine in Teesdale, Cow Green, was closed in 1930, whilst in Weardale the Boltsburn mine was closed in 1940.

[1]Localities where Mesolithic remains have been found. This avoids defining whether the remains indicate a permanent camping site, a resting place during hunting trips, or merely the accidental loss of tools.

[2]Assessment of early anthropogenic (Mesolithic) interference of the vegetation is difficult in many instances because of the nature of the evidence concerning the distribution of the inhabitants. Artefacts discovered in the sub-soil underlying the blanket peat deposits of the Pennines are highly unlikely to represent the total amount of areas which have possibly been subject to Mesolithic interference because there are few experienced workers in these areas, therefore there is a low probability of discovery. In previous times the significance and importance of the often unpretentious remains were not fully appreciated. Thus in the Pennines and indeed in any upland zone there are several interpretations of areas which have no finds:

1. The area was never occupied.

ii. The remains perished or were removed.

iii. The remains are present under unbroken blanket peat.

iv. The remains were found and never recorded.

v. The area has never been adequately searched.

[3]Jet - a kind of lignite or anthracite often cut and polished for ornaments. Abundant in Britain in the Bronze Age.

Chapter 4. SUMMARY

1.1. The geology of Upper Teesdale is dominated by Carboniferous deposits which, in addition to limestones, contain alternating sequences of sandstones, shales and limestones belonging to the Yoredale series of deposition. Intruded into these deposits is the Hercynian quartz-doleritic Whin Sill, which results in pronounced resistant scars and the metamorphosis of the adjacent limestone into 'sugar limestone'. Many of the small faults which occur have been mineralised.

1.2. The Carboniferous strata have been warped to form the Teesdale Dome whose crest lies beneath Cross Fell and Mickle Fell.

1.3. The highest altitudes in the area are found in the west, thus corresponding to the crest of the Teesdale Dome, and the land slopes eastwards. A marked feature of the topography are the extensive tracts of country in excess of 1500 ft (450 m) with a fairly low amplitude of relief, the many planation surfaces (relicts of pre-Quaternary erosive activity) and the numerous platforms which are partly structural and partly lithological.

1.4. Areas receiving over 70 ins. (1778mm) of rainfall are confined to the high western summits and the tilted plateau surface causes a pronounced west-east diminution in rainfall and snow cover, and conversely an increase in temperatures and length of growing season. Upper Teesdale is comparable with Southern Iceland.

2. During the Ice Age local glaciers deposited boulder clay to at least 2200 ft (669 m) in Upper Teesdale. Much of this drift is calcareous because of the predominant Carboniferous Limestone. After glaciation solifluxion became a significant agent in the modification of the Pre Glacial landscape resulting in the removal of much unconsolidated material, so that the present distribution of drift deposits is irregular in addition to being obscured by blanket peat.

3.1. In the upland climate leaching is the predominant pedogenic process, therefore leached and organic soils are widespread. Because of the immaturity of many of the inorganic soils parent material plays an important part in their differentiation, especially where the limestone is covered by irregular drift patches. Topography often plays a significant part in the distribution of such soils. Blanket peat covers extensive areas of low amplitude, masking variations in topography and lithology which were important in the formation of sub-peat soils. Most of this peat is Atlantic in age, although earlier peats are to be found in special topographic situations, which formed as a result of increased oceanicity and/or human interference. Many peat covered areas are subject to present erosion.

3.2. Many of the grasslands which form 'windows' in the blanket peat belong in the 'limestone grassland' category, being formed on limestone or drift covered limestone with a variety of soils, and are maintained in a plagioclimax by grazing. These grasslands are distinctive from those of other limestone areas because of the communities found on the 'sugar limestone soils'. Moorland is dominant everywhere over approximately 1500 ft (450 m) and isolated patches of woodland occur at lower altitudes.

3.3. These uplands provided a routeway from the south for prehistoric peoples. Mesolithic hunters and food gatherers existed in the northern Pennines long after Neolithic and Bronze Age peoples colonised lower altitudes. This theme of fell land use, hunting and pastoralism, has been continuous since these times. At lower altitudes the first cultivators belonged to the Iron Age although the Romans merely used Upper Teesdale for hunting purposes. The Anglo-Saxons founded the first settled communities in South Tynedale whilst by the seventh century the Angles had established themselves in Teesdale with substantial cultivated areas. Although continuous woodland destruction is almost certain since this time, the process probably increased after the twelfth century, when there is evidence of cutting timber and reached a maximum during the period of mining activity.

The present vegetation of Upper Teesdale is the product of a series of interrelated changes in the environment over the past two millenia which, prior to 3000 B.C., were primarily climatically induced. The brief summary above points to the pertinent factors which influence or have influenced the present habitats in which the vegetation communities, described in chapter 3.2., exist, and which are considered to be of relevance in an interpretation of pollen curves.

SECTION B.

PALAEOECOLOGICAL INVESTIGATIONS.

Chapter 5. METHODS

5.1. Sites

Sites for analysis were chosen bearing in mind the altitudinal variation and variety of present vegetation types of the Reserve. An altitudinal transect from the River Tees to the summit of Mickle Fell enabled the Post Glacial development of the vegetation, on an extensive north-facing slope to be examined (see also Donner 1962: 6). Possible east-west vegetation differences were examined by means of basal peat samples which also served to complement the major profiles. No Late Glacial deposits were discovered. The sites which were analysed are shown in fig. 21.

5.2. Collection of samples

Samples for laboratory analysis were collected by monolith tins, Macaulay-type peat sampler (Jowsey, 1966) or Hiller peat sampler.

Wherever possible, and this was the case for most of the blanket peat sites, monolith tins were used. The tins, constructed of stainless steel, were pushed vertically into a carefully cleaned peat face. They were found to have certain advantages: they, and the samples contained in them, were easily carried over rough terrain, contamination was avoided as samples for preparation could be taken away from any working faces, a large enough block of peat could be taken to enable both a thorough laboratory examination of the macrofossils contained in the peat and samples to be taken for radiocarbon dating, and the complete stratigraphy of the deposit could be seen in the field thereby allowing accurate description and precise measurement.

Where monoliths could not be taken, the Macaulay-type peat sampler was used. This was preferred to the Hiller peat sampler because it took a more suitable core. The major disadvantages of it were its inability to sample fibrous or compact deposits and on encountering a solid obstacle the basal 15 cm of a deposit were often lost (see Chapter 6). The Hiller sampler was only used when other methods were unsuitable, i.e. in compact wood peats, fibrous *Eriophorum* peats or coarse sub-peat inorganic sediments.

5.2. Preparation

Peats. The digestion of humic acids by boiling a sample of peat with dilute alkali, originally devised by Langerheim and adapted by Von Post (Faegri and Iversen, 1964: 67) was used. This process is recommended by Brown (1960) due to its simplicity and the excellent condition of the pollen grains after treatment, and has been used by both Conway (1947) and Simmon (1962 *et seq*) on blanket peats. The only modification to this method was the use of 5% KOH, instead of 10% KOH thus avoiding any distortion of the pollen grains noted by Faegri and Iversen (1964: 69) when the concentration of alkali exceeded 10%.

Acetolysis was tried with disappointing results. It was found that the main disadvantage of the KOH method, that of incomplete digestion of extraneous material, recorded by Assarsson and Granlund (1924) and Erdtman (1957), could be overcome by judicious staining. In view of this and with regard to Wenner (1924: 101) who suggested, 'The minor differences of pollen spectra of the KOH method and those of acetolysis .... seem to be dependent more on contingencies and real differences in the pollen content of the sample ...... rather than the different methods of preparing slides for the microscope; acetolysis was avoided whenever possible'. Where acetolysis was attempted the method described by Dimbleby (1957) was used.

Siliceous material. Where large amounts of quartz were present HF was used. The methods followed were those of Dimbleby (1957) and Franks (1965), omitting the acetolysing process.

All preparations were mounted in glycerin. This enabled slides to be made quickly and difficult grains to be rolled to aid identification. A small amount of clear nail varnish on the diagonal corners of the cover-slip kept the slide intact whilst grains were being rolled. After counting the slides were sealed and stored flat with no pressure on the surface for later identification of unknown grains.

Initially samples were taken every 10 cm for the major profiles and every 5 cm for the basal profiles. After examination of the diagrams thus produced further samples were taken, as necessary. Sample points can be seen in the tabulated percentages in the map folder at the back of Volume II. Because all of these tables have been produced by a computer and have been used to develop computer programmes, basal samples are tabulated from the datum shown (e.g. Dufton Moss C (M3) 500 cm = 0). Approximately 1 cm vertical depth of sample was used each time except where stated.

The plant remains found during the above procedures were carefully examined and these records were combined with the field notes to produce the complete stratigraphy. It will be noticed that only at sample points is there a complete list of plant remains, the intervening deposit usually being assigned to peat types on the basis of field notes and an examination of the cores after the samples for pollen analysis had been removed.

5.4. Counting

The more grains counted the greater the probability of the percentage occurrence of each pollen type reflecting the actual vegetation cover at any one point in time. The various statistical tests which have been applied to the problem of the best estimate of a population (Barkley, 1934; Ording, 1934; Westenburg, 1947; Faegri and Hestad, 1948; Dimbleby, 1957) have not satisfied all workers who have to consider the aims of their research, the methods employed and the type and availability of data.

Different counts of total pollen have been advocated by various authors: 150-250 Erdtman (1931), Hansen (1938) and Sears (1930, 1931); 300-500 Hansen (1939); 800 Lewis and Cooke (1929); 1000 Bowman (1931). More recently it has become the custom to count a certain number of grains from specified taxa which constitute the pollen sum. Other figures are expressed as a percentage of this sum. Pearson (1960) counted 150 tree pollen, as does Simmons(1962), but both West (1964: 364), and Jørgensen (1967: 493) mention, 'the total number required'. This places the onus on the investigator to choose a total which, based on his experience, best represents the vegetation at any point in time.

In this work the general aim in terms of vegetation history, especially forest history, requires a fairly high count. This is particularly the case in the upper layers of blanket peats where tree pollen is scarce. A pollen sum of 150 tree pollen (excluding Alnus) or a total pollen count of 1000 grains, was initially employed for the major profiles. For the basal peat profiles and the intercalated horizons of the major profiles, a pollen sum of 100 tree pollen (excluding Alnus) or a total count of 500 grains was used. In some cases the practice of counting individual grains was stopped where there was a predominance of a certain taxon. This particularly applies to Ericales and Sphagnum, when an estimate, based on proportional representation, was used.

5.5. Expression of results

Pollen data. The data obtained from counting are presented in the form of diagrams (figs. 25-52). Two diagrams have been drawn for each profile examined, one based on the pollen sum described above and one based on the total pollen count. Although the latter was primarily intended for confirming evidence provided by the former, it proved invaluable in the interpretation of changing vegetation patterns, particularly when non-tree pollen persistently exceeded the pollen sum.

The suitability of any given pollen sum is debatable although it can be argued that any method of expressing results which is based on research experience, is of value. The pollen sum used in this study has the following justification:

firstly, the mode of existence of the rare species and communities is highly conjectural if closed forests covered the area at one time or another; secondly, it is held that trees are the most direct indices of past climates (Godwin, 1934) and they appear to have been the vegetation dominants during Boreal and Atlantic times. Thus, the most valuable method of using the pollen data is to express counts as a percentage of a pollen sum consisting of the pollen of forest trees, so helping to establish the amount of forest cover at any one time.

Under investigation is the regional relationship of the vegetation of part of Upper Teesdale through Post Glacial times. What is ideally required therefore, is a division of the pollen spectra into the local and regional component. The exclusion of Alnus from the pollen sum is an attempt to prevent local over-representation of this species distorting the regional picture. According to McVean (1953) alder can grow on fen peat and at present reaches 1600 ft (486 m) in the Cairngorms. This being so the areas of fen peat, dominated by Phragmites communis, which underlie some of the ombrogenous peats, might provide suitable habitats for local alderwoods at the maximum forest extension. The large amounts of pollen found during the investigations show that the tree was present in some localities in the area, even allowing for the fact that Alnus is a high pollen producer. The lack of alder wood remains is not very surprising in view of the limited number of sites examined. The presence of alder in the mixed oakwoods of the main valley during Atlantic and

Sub Boreal is almost certain, where it was probably limited to the damper situations, by the river or in hollows where organic deposits are found today. On the fell tops alder would probably grow in small depressions where the greatest depths of blanket peat are found. Whether the large amounts of pollen found at the higher sites are due to local growth or transference from lower altitudes is debatable, but whilst there is a likelihood of the pollen being locally derived, a pollen sum which excludes alder is thought to represent a truer regional picture of the vegetation, particularly as the deepest sites on the fell tops have generally been examined.

The diagrams have been drawn using bars proportional in width to the depth of the sample taken, whilst the vertical scale has been chosen for clarity of interpretation. The horizontal scale changes from taxa to taxa but the divisions are constant within each taxon. The pollen sum is usually blocked in although in fig. 25 capital letters are used. Despite the fact that no Myrica remains were found it cannot be stated with certainty that Myrica was not present, especially at the Dufton Moss site. All pollen of the Corylus-Myrica type has therefore been designated as Coryloid, although in interpretation the pollen frequencies have been attributed to Corylus. Instead of the more usual Ericaceae notation, Ericales has been used[1] as the distinction between Empetrum and Calluna in an eroded state is regarded as tenuous. By far the major part of Ericales pollen found belonged to Calluna and during interpretation is often expressed as such . The other major grouping is that of classing plants which frequently invade areas that have been cleared of their original vegetation. These are termed 'Ruderals', and in addition to lessening the amount of data contained in the diagrams, allow possible clearance phases to become more distinct. The composition of this curve is given on each diagram as are any other groups used.

The general arrangement of non-tree pollen types is from equivocal local/regional pollen (Gramineae, Cyperaceae and Ericales), through dry land flowering plants to those favouring damp habitats and aquatics. Conventions used in the diagrams are as follows:-

- . indicates less than 2% of the pollen sum and less than 1% of the total pollen.
- x indicates a grain recorded in the scan but not in the count, and is represented in the data sheets by the number 9001.

Abbreviations: AP - arboreal pollen; SP - shrub pollen; NAP - non-tree and shrub pollen; PS - pollen sum; EP - total pollen; monocot - monocotyledon.

All numerical data relating to the pollen counts can be found in the data sheets which are contained in the map folder at the back of Volume II. These data are arranged into four parts:

a. The actual pollen counts.

b. Percentage of pollen sum.

c. Ruderals as a percentage of the pollen sum.

d. Percentage of total pollen.

Stratigraphy. Stratigraphic details, compiled from field and laboratory notes, are shown on the left of the diagrams. The symbols used are explained in fig. 22. A monocotyledon peat, generally described as a monocot peat, contains grass and sedge remains which are largely unidentified except where specified. A wood peat is usually fairly dry and friable, and, in addition to wood remains, contains monocot or Phragmites remains. A moss peat contains remains of bryophytes, other than Sphagnum. Although generic terms have been avoided purposely, the term ' fen peat' has been used to describe peat in which Phragmites remains are predominant. In the stratigraphic descriptions (Chapters 6-10) the remains of mosses are leaves unless specified, and where a moss is dominant its record is followed by a letter d (e.g. Sphagnum recurvum (d)).

5.6. Pollen Analysis

The zonation scheme put forward by Godwin (1956) has been used. Although Alnus has been removed from the pollen sum and is tentatively regarded as dominantly local, the VI/VII boundary has nevertheless been drawn where the falling Pinus curve crosses the rising Alnus curve. The features used by Oldfield and Statham (1963) to demarcate this boundary are not sufficiently pronounced to use their zonation scheme. Deviations from this scheme have been unavoidable, especially in dividing diagrams after the well-marked VIIa/VIIb boundary. Because of uncertainties concerning the exact status of tree species during this period, no zone VIII has been distinguished. In the place of a VIIb/VIII boundary, denoting a synchronous horizon between diagrams, a Calluna horizon has been drawn similar to that used by Pennington (1964: 215). This Calluna horizon has been drawn for each diagram independently, therefore at the lowest sites this is placed where the Ericales, Gramineae and Cyperaceae curves rise, but at the highest sites it is placed where the Ericales curve reaches its maximum values. Thus, it is not intended that this horizon should denote a synchronous vegetation zone, although it shows similar processes at work (Conway, 1947, 1954; Pearson, 1960). At this horizon the AP/NAP ratio reaches its lowest values and often there is a stratigraphic change, although not as violent a change as noted by Pennington (1964).

5.7. Interpretation

Interpretation has been usually attempted in a chronological manner, although a particular theme has been followed in parts. It has already been pointed out that one of the major difficulties of interpreting any upland pollen diagram is the probable wide source area for some components of the pollen spectra. Although this problem becomes acute after deforestation of upland areas, it is by no means absent in forested areas. If the tree cover was only slight even at the maximum forest extension the pre-Atlantic pollen spectra might reflect vegetation conditions over a larger area than if the tree cover were more dense. Similarly, if local dense stands were present the pollen spectra would reflect these conditions. To a certain extent therefore, interpretation of upland diagrams may be conditioned by pre-conceived ideas of the investigator.

The validity of these subjective interpretations is borne out by the high degree of correlations between upland areas but ultimately this problem may be solved by quantitative studies similar to those carried out by Turner (1964) and Tauber (1965). At present however, discrepancies between workers are commonplace, so that definitive statements concerning pollen spectra and source area are lacking. In view of this largely unknown relationship few contemporary moss samples have been analysed.

During interpretation fluctuations in the pollen curves have been attributed mainly to local causes (e.g. changes in base status and water levels). Only in Chapter 12 (Discussion) have these local changes been examined in terms of regional significance (e.g. climatic change).

[1]The term Ericales has also been used in pollen diagrams by Donner (1962).

Chapter 6. DUFTON MOSS (profiles M1,M2,M3)

Grid reference:	NY 872293.
Altitude:	1200 ft (368 m).
Sampled:	Macaulay-type and Hiller peat sampler.
Length:	M1 504 cm, M2 8 cm, M3 24 cm.
Diagrams:	Figs. 23,24. M1 figs. 25-27, M2 fig. 28, M3 fig. 29.
Data sheets:	1-3. 2. 200 cm = 0, 3. 500 cm = 0.

6.1. Site

Approximately five metres depth of organic deposits occupy a small depression (fig. 24) some 100 yards (100 m) south of the B6277 Middleton/Alston road, and is situated at the foot of the Whin Sill exposure at Force Garth. The general appearance is of a convex-surfaced heather-dominated area within a *Juncus* infested meadow. The vegetation is dominated by *Calluna vulgaris* and *Eriophorum vaginatum*. Also occurring are: *Trichophorum caespitosum*, *Erica tetralix*, *Eriophorum angustifolium*, *Narthecium ossifragum*, *Drosera rotundifolia*, *Empetrum nigrum*, *Prunella vulgaris*, *Sphagnum* spp., *Dicranum* spp. and *Cladonia* spp. On the immediate surrounds of the bog standing water occurs with *Carex* spp. dominant. The present biotic influences consist of sheep grazing although in the past peat cutting and perhaps trampling during former local quarrying of the Whin Sill, might have affected the surface.

6.2. Stratigraphy

The general structure of the deposit is shown in fig. 24. A major portion of the depression is underlain by a blue-grey solifluxion material with a low calcium carbonate content (1.5%). Over this is a variable thickness of wood peat containing Betula, Salix and Pinus fragments with discontinuous Betula and Salix layers, above which lies a fairly thick layer of fen peat, dominated by remains of the reed Phragmites communis, along with Betula and Salix layers. At the top of the deposit is an ombrogenous peat composed of Eriophorum, Calluna, Sphagnum and unidentified monocot remains, which is capped by a substantial living root mat.

During sampling the following stratigraphy was observed at M1.

0-10 cm

Dark brown surface peat with many Calluna and monocot roots. Sphagnum recurvum (d), S. tenellum and S. cuspidatum at 10 cm.

10-34 cm

Dark brown fibrous surface peat with small monocot roots. Fibrosity decreases downwards as Eriophorum fibres increase. E. vaginatum 'spindle' at 20, 25 cm, Calluna twig (4 mm) at 24 cm, Sphagnum palustre (d) and well preserved S. acutifolia group at 30 cm.

34-50 cm

Dark brown wet Eriophorum peat with abundant monocot and Sphagnum remains. Sphagnum recurvum, S. cuspidatum, S. acutifolia group, and Aulocomium palustre at 35 cm; Calluna charcoal, well preserved Sphagnum subsecundum, S. cuspidatum, S. palustre and S. plumulosum at 40 cm; Eriophorum vaginatum 'spindle', Sphagnum recurvum, S. cuspidatum and Dicranum scoparium at 45 cm.

50-74 cm

Dark brown wet monocot peat with few well humified Eriophorum fibres. Calluna twigs 3 mm at 57,61,62,70 cm. Well preserved Sphagnum squarrosum (d), S. tenellum and S. palustre at 50 cm; Sphagnum recurvum, S. cuspidatum, S. acutifolia group (cf. S. plumulosum) and Molinia at 55 cm; Sphagnum recurvum, S. cuspidatum and S. acutifolia group (cf. S. plumulosum) at 70 cm.

74-76 cm

Eriophorum band.

76-87 cm

Dark brown Sphagnum peat with abundant monocot remains. Large Carex remains and Calluna 3 mm 79-81 cm; Eriophorum vaginatum 'spindles', Sphagnum recurvum (d) and S. acutifolia group (cf. S. rubellum) at 80 cm.

PLATE 10

Dufton Moss Site.

87-100 cm

Dark brown monocot/Sphagnum peat with small Eriophorum fibres. E. vaginatum 'spindles', Sphagnum recurvum (d), S. cuspidatum, and S. acutifolia group at 90 cm; Calluna twigs, Sphagnum cuspidatum (d), S. recurvum and S. acutifolia group at 100 cm.

100-110 cm

Dark brown monocot peat. Calluna < 3 mm at 105,109 cm; <5 mm at 108 cm; Sphagnum sp. at 110 cm.

110-116 cm

Sphagnum peat with abundant monocot remains.

116-119 cm

Monocot/Sphagnum peat. Calluna < 5 mm at 119.5 cm.

119-131 cm

Monocot peat. Calluna <3 mm at 126,128 cm; < 5 mm at 130.

131-141 cm

Eriophorum/Sphagnum peat. Calluna bark at 140 cm.

141-150 cm

Monocot peat.

150-171 cm

Sphagnum peat with some monocot remains and occasional Eriophorum fibre. E. vaginatum 'spindle' at 160 cm.

171-176 cm

Monocot/Sphagnum peat.

176-201 cm

Sphagnum peat with some monocot (cf. Molinia) remains, occasional Eriophorum (E. angustifolium) fibres. Badly preserved Sphagnum recurvum and S. subsecundum at 190 cm; Eriophorum vaginatum 'spindle' at 200 cm.

201-230 cm

Monocot/Sphagnum peat. Sphagnum papillosum at 216 cm; Polytrichum strictum at 230 cm.

230-234 cm

Monocot peat with few Sphagnum sp. leaves.

234-237 cm

Sphagnum peat.

237-271 cm

Monocot peat with Sphagnum remains. Betula, Calluna and Sphagnum acutifolia group at 240 cm; badly preserved Sphagnum recurvum and Polytrichum sp. at 245 cm; Sphagnum cuspidatum (d), S. recurvum, and S. palustre at 250 cm; Eriophorum node, E. vaginatum 'spindle' and Eurhynchium sp. at 255 cm; Sphagnum recurvum (d), S. magellanicum and Polytrichum strictum at 260 cm; Sphagnum rubellum (d), S. cuspidatum and S. recurvum at 265 cm.

271-286 cm

Monocot peat with abundant Polytrichum commune stems giving a fibrous nature to the stratum. Sphagnum recurvum at 280 cm; Calluna 2 mm at 281 cm; Carex radicle at 284 cm.

286-307 cm

Fen peat. Phragmites and other monocot remains abundant. Few Sphagnum leaves and capsules. Sphagnum cuspidatum (d), S. recurvum and unidentified wood at 290 cm; Polytrichum cf. commune stems at 290-293 cm.

307-312 cm

Monocot/Sphagnum peat. Badly preserved Carex debris, occasional Phragmites stem. Sphagnum recurvum at 310 cm.

312-315 cm

Fen peat. Phragmites present in quantity.

315-317 cm

Sphagnum peat. S. acutifolia group.

317-427 cm

Fen peat, dominated by Phragmites and other monocot remains. Carex debris abundant, especially at 330,335,380 cm; Carex rostrata radicle sheath at 370 cm; Molinia remains at 410 cm; abundant moss remains:

- 320 cm Sphagnum recurvum (d) and S. rubellum.
- 325 cm Sphagnum acutifolia group (d), S. papillosum, Mnium sp., Dicranum sp. and Paludella squarrosa.
- 330 cm Sphagnum recurvum.
- 335 cm Sphagnum cuspidatum (d), S. recurvum (d) and S. rubellum.
- 340 cm Sphagnum recurvum, S. plumulosum and Camptothecium nitens.
- 350 cm Sphagnum recurvum (d), S. cuspidatum, S. teres and S. acutifolia group.
- 360 cm Sphagnum recurvum (d), S. cuspidatum and S. acutifolia group.
- 370 cm Sphagnum tenellum, Paludella squarrosa (d), Camptothecium nitens and cf. Thuidium sp.
- 380 cm Sphagnum recurvum, S. teres and S. acutifolia group.
- 390 cm Sphagnum recurvum (d) and S. acutifolia group.
- 400 cm Sphagnum recurvum (d), S. teres, S. cuspidatum and S. acutifolia group.
- 410 cm Sphagnum acutifolia group.
- 425 cm Drepanocladus fluitans.

Occasional Betula and Equisetum remains.

427-430 cm

Wood layer. Highly humified Betula and Salix with fen peat in the interstices, mainly Carex debris. Sphagnum recurvum and S. acutifolia group remains.

430-492 cm

Dry fen-wood peat. Phragmites and other monocot remains still dominant. Abundant large Betula remains. Well preserved Sphagnum palustre (d) at 465 cm; Dicranum cf. spurium at 470 cm; Sphagnum palustre (d) at 475 cm.

492-497 cm
Wood layer, Salix and Betula.

497-504 cm
Wood peat, highly humified almost black. Very few recognisable remains, quartz grains incorporated at the base.

At M2 the stratigraphy was:

238-241 cm
Highly humified wood peat. Betula remains frequent. Abundant monocot remains with some Eriophorum fibres. Quartz grains frequent; Caryophyllaceae seed at 238 cm.

241 cm
Blue-grey inorganic sediment with very few monocot remains.

At M3 the stratigraphy recorded was:

400-452 cm
Dark brown fen peat. Abundant large Phragmites remains and other monocot remains. Betula twigs <2 mm at 409 cm; <1 cm at 425 cm; Betula charcoal 416-417 cm; Pinus fragments at 430 cm; Pinus and Salix at 438 cm.

452-532 cm
Wood peat. Abundant Betula remains <2 mm and monocot remains including Phragmites; Salix at 496 cm; flakes of unidentified charcoal 485-502 cm and Betula charcoal at 517 cm.

6.3. Pollen Analysis

Diagrams. Samples for analysis were collected as follows:

M1 5 cm intervals 5-60 cm, 240-270 cm, 460-504 cm.

10 cm intervals 60-240 cm, 270-460 cm.

M2 Contiguous 1 cm samples.

M3 5 cm intervals 506-514 cm, 520-530 cm.

1 cm intervals (.5 cm vertical samples) 514-520 cm.

Zonation and Description.

Because of the high Corylus values and the dominance of Betula and Pinus along with the low values for Quercus and Ulmus, the base of fig. 25 has been assigned to zone VI. This is divisible into two subzones. In VIa the Betula/Pinus dominance quickly gives way to a *Pinus* maximum and the AP:NAP ratio becomes considerably increased. *Quercus* and *Ulmus* are present in increasing amounts, particularly the latter. Early high values are recorded for: *Salix*, Cyperaceae, *Filipendula*, Filicales and *Sphagnum*. A composite sub-zone VIb+c has been described at 410 cm. *Pinus* frequencies decline steadily after a maximum in VIa, the *Alnus* curve becomes continuous and *Corylus* values are much lower than in the preceding sub-zone. Thus features of both sub-zone VIb and VIc are present.

The VI/VII boundary has been drawn at 345 cm where *Alnus* commences its expansion, and the *Pinus* frequencies decline to extremely low values. During VIIa the thermophilous mixed oak forest species, *Quercus* and *Ulmus*, dominate the pollen spectra with an increasing *Alnus* and *Corylus* component. Here is the first occurrence of *Fraxinus* and *Tilia*.

The well documented decline in the *Ulmus* frequencies at 240 cm demarcates the VIIa/VIIb boundary. *Betula*, *Quercus*, *Alnus* and *Corylus* comprise most of the woodland in VIIb whilst *Fagus* appears in small amounts and *Ulmus* temporarily re-establishes itself.

The *Calluna* horizon has been drawn at 35 cm.

The M2 diagram (fig. 28) clearly shows the reciprocal relationship between *Betula* and *Pinus*, which is found at the base of the M1 diagram and therefore has been assigned to VIa.

The Dufton Moss C diagram (fig. 29) shows a different situation. The preponderance of *Betula* suggests that this should be placed chronologically before M1 which shows *Betula* and *Pinus* co-dominant. Other features substantiate a pre-M1 therefore a pre-VIa date: the absence of Ulmus (the occasional grain of Quercus is difficult to explain), the very high frequencies of Salix, the relatively low Corylus values and the high frequencies for Rosaceae, Filipendula and Filicales. Despite these features a zone V date has not been given because there is insufficient evidence.

6.4. Interpretation

Stratigraphic sequence and bog development (Table 7)

The basal unstratified coarse blue grey clay found underlying the organic deposits is probably a solifluxion deposit laid down between the retreat of the valley glaciers in zone III and the Boreal period. The few monocot remains found incorporated into this sediment along with high values for the Betula, Corylus, Gramineae, Cyperaceae, Filipendula and Filicales curves suggest that open Betula-Corylus woods grew round the margins of the hollow and a damp fen flora grew on the surface with some open water, in which grew Potamogeton sp. and Myriophyllum alterniflorum (stage 1, table 7).

As already stated, the M3 pollen diagram (fig. 29) suggests a pre-zone VI inception for organic deposition. According to the M2 diagram (fig. 28) however, which shows the interface between the organic and inorganic deposits, this is dated as sub-zone VIa. Despite the fact that the basal deposits are likely to have been fairly unstable and some reworking of them might have occurred, it appears that the hollow might not be single depression, as is portrayed in fig. 24. This would account for the discrepancies in the pollen spectra between fig. 29 and the lowest levels of fig. 28.

It is possible therefore for a variety of communities to have existed in early Boreal times in this depression, the nature of each depending on the microtopography. Pollen and stratigraphic evidence, seen in figs. 28 and 29, points to three communities, one a Betula-Salix carr with a rich damp herb cover indicated in fig. 29, and another, a drier grass and sedge community, with a similar but poorer herb cover indicated by the pollen spectra found in the inorganic sediment in fig. 28. A third, aquatic, community was also present, showed by the pollen of aquatic species.

The start of organic deposition over the entire hollow in sub-zone VIa is probably associated with a rise in the water table, although the burning, for which evidence in the form of charcoal was found at M3 (fig. 29), might have influenced this in some way. Overlying the solifluxion deposits is a wood peat with Betula, Salix and Pinus fragments, which points to the continued existence of the Betula-Salix carr. The high frequencies of Corylus are attributed to its presence on the drier swamp surrounds, which may have been fairly base rich at this time (see Chapter 12.1). Phragmites communis became abundant in the depression with Potamogeton spp. forming communities, similar to those fringing some present day lakes (see Tansley, 1939: 591), although stratigraphic evidence suggests that the Betula-Salix carr occupied other, drier, places in the depression (stage 2). Rising water levels, shown by the increasing abundance of Phragmites remains in the peat, encroached on this carr and this is reflected in the change of the peat type, from wood peat to fenwood peat. Consistent with rising water levels the pollen spectra suggest

TABLE 7. Dufton Moss: Stratigraphic interpretation.

Zone	Stage		Community postulated	Evidence
VIIb	6	Rising water levels	Oxyphilous communities dominated by Sphagna	Sphagnum dominated ombrogenous peat
	5	↑	Grass-sedge-heather community	Monocot peat, Eriophorum vaginatum 'nodes', abundant Calluna remains and pollen
VIIa	4	?Drying out	Acidification of fen communities	Camptothecium nitens & Paludella squarrosa leaves, Phragmites & Carex spp. remains, Polytrichum commune & Calluna stems. Pollen of Rumex & Cruciferae, spores of Sphagnum and Filicales
VIb+c	3	↑	Fen communities	Phragmites rhizomes, Carex spp., including C. rostrata, Molinia & Equisetum remains. Drepanocladus fluitans, Camptothecium nitens, Paludella squarrosa, Thuidium sp. and Sphagnum spp. leaves.
VIa	2	Rising water levels	Betula-Salix carr with increasing Phragmites. Poor fen comms.	Betula and Salix wood, Phragmites rhizomes. Decreased variety of NAP types.
Early Boreal	1		Betula-Salix carr with rich ? fen communities	Betula & Salix wood. Gramineae, Cyperaceae Umbelliferae & Rosaceae pollen, fern spores & Phragmites rhizomes.
			Grass-sedge comms. on higher ground	Similar pollen spectra to above in sub peat inorganic sediments. No wood remains.
			Open water	Potamogeton spp. & Myriophyllum alterniflorum pollen

that the former rich fen communities which existed under the Betula-Salix carr and also on the swamp surrounds gave way to a Phragmites dominated community. Although such an explanation for the decreased variety of NAP types in the pollen spectra is feasible, it is also likely that this decrease is partly a reflection of the increased AP values from the surrounding woodland at this point. The high Sphagnum frequencies with S. recurvum and S. palustre remains indicate the abundance of these species possibly on the swamp and swamp surrounds.

The continuing rising water levels indicated by the increasing dominance of Phragmites and Carex rostrata remains appear to have restricted tree growth considerably and in the fen peat Betula remains become infrequent (stage 3). The declining base status of this fen which existed until the mid-Atlantic period may explain the presence of layers of bryophyte rich peat in this peat. Paludella squarrosa, Camptothecium nitens, Drepancladus fluitans, Mnium sp., Dicranum sp. and Thuidium sp. remains all occur, their presence marking the end of the rich fen of the Boreal period at this site (stage 4). This stratigraphic feature has also been noted at Burtree Lane, further down the Tees by earlier workers (Bellamy et al., 1966). Towards the end of this fen stage of bog growth, temporary peaks of Cruciferae pollen and Sphagnum spores, along with Molinia caerulea and Sphagnum recurvum and S. cuspidatum remains in the peat mark the end of the 'soligenous peat' and the start of the 'ombrogenous peat' stage of organic deposition, during which time the bog may have become dry enough to support the local growth of

Rumex cf acetosella indicated by a temporary peak in the pollen curve (end of stage 4), although Bridgewater (pers. comm.) suggests that such a community might indicate human activity.

During Atlantic times Phragmites peat gave way to a monocot peat (stage 5). This phase appears as a precursor to the main ombrogenous peat which is dominated by Sphagnum remains (stage 6) and shows the increasing acidity of the deposit. The Sphagnum peat contains most of plant remains which are commonly found on ombrogenous peats today: Calluna vulgaris, Eriophorum vaginatum, E. angustifolium, Carex spp., Molinia caerulea, Polytrichum commune, P. strictum, Eurhynchium spp., Aulocomnium palustre and Dicranum scoparium, as well as an increased variety of Sphagna. The pollen curves closely parallel this development: Calluna frequencies initially increases at the expense of Gramineae pollen, possibly Phragmites, which is consistent with a heather invasion of a dry bog surface (stage 5), whilst the Cyperaceae and Sphagnum frequencies fluctuate widely. The occurrence of pollen of Drosera rotundifolia, Caltha palustris, Campanula and Vicia type in the ombrogenous peat, point to the establishment of these plants on the bog surface or surrounds.

Forest Development (Table 8)

1. Birch-hazel woods (The early Boreal period).

The presence of Betula and Salix wood remains in the peat and the dominance of Salix pollen in the spectra suggest that initially this hollow was covered in parts by Salix bushes and Betula on an extremely damp substratum, (stage 2, table 7).

TABLE 8. Dufton Moss: Interpretation of regional vegetation.

Zone	Vegetation
	More or less permanent clearance.
Calluna horizon	Extension of ombrogenous peat on the fell top. Regeneration in the valley woodlands except for Ulmus and Fraxinus.
VIIb	? Fire used as a clearance mechanism. Clearance of the valley slopes or secondary communities in the valley woodland. Decline of Betula, Alnus and Corylus.
	Human interference. Decline of Ulmus, rise of Fraxinus and start of Corylus decline. Betula, Alnus and Quercus remain the dominant woodland species.
	Re-establishment of Ulmus, appearance of Fagus.
	Ulmus decline. Alnus, Quercus, Betula and Corylus are predominant. Increase of Fraxinus.
VIIa	Quercus, Alnus and Ulmus dominated woodland with Betula and Corylus. Small amounts of Fraxinus and Tilia.
	Declining Pinus, increasing Quercus, Ulmus and Alnus.
VI	Increased representation of Quercus, Ulmus and Pinus. Betula-Pinus woods with ?pure thickets of Corylus or a fairly dense Corylus understorey. ? Isolated Alnus.
? V	Betula-Corylus woods with immigrating Pinus and probably scattered Quercus and Ulmus.

The marked decline in the _Salix_ pollen frequencies at 520 cm in fig. 29, which is paralleled by a rise in Cyperaceae frequencies appears to be the product of rising water levels. Under these conditions _Salix_ gave way to Cyperaceae and there was also a decline in the majority of the herb species. If the high _Salix_ values found in the lowest samples were merely over-representation due to the scarcity of tree pollen, then a rise in NAP, other than Cyperaceae, would be expected. This does not occur and thus the _Salix_ values seem to represent the local dominance of the species.

Fire, denoted by a _Betula_ charcoal layer approximately 0.5 cm thick at 517 cm, appears to upset the pattern caused by rising water levels. There is no way of deciding whether the fire was man-made or not, but the effects on the pollen spectra are quite marked. _Corylus_ frequencies, which previously had not been a major component of the spectra, increase sharply, whilst both _Betula_ and _Pinus_ values show diminished rates of increase. This would seem to indicate that fire affected both of these tree species to a limited extent and encouraged _Corylus_ to expand at the expense of the Cyperaceae dominated areas in the drier situations. This adds weight to the supposition that open woods with a grass and sedge ground flora predominated over considerable areas during this period. Whether _Corylus_ invaded this damp hollow is not known.

At the end of 'pre-zone VI' (fig. 29) _Betula_ and _Corylus_ are co-dominants of the pollen spectra, although a clear regional picture is not obtained because of the local dominance of _Betula_, _Corylus_ and _Salix_ pollen, which results in a high AP + SP/NAP ratio (but *Betula*-*Corylus* woods with immigrating *Pinus* would be consistent with the picture presented by the spectra in the basal parts of fig. 25).

During the early part of sub-zone VIa, similar, although slightly damper, conditions to those seen in 'pre-zone VI' are envisaged. The *Betula*-*Corylus* woods were still predominant with the *Corylus* curve attaining its maximum values indicating the rapid spread of the shrub at this time. *Pinus* frequencies increase whilst the slight decline in AP might reflect the rising water table reducing the former local occurrence of trees. The amount of *Quercus* and *Ulmus* pollen point to the existence of these trees in scattered localities. A picture is thus given of *Betula*-*Corylus* woodland with *Pinus* and the more thermophilous *Quercus* and *Ulmus* immigrating. The low AP:NAP ratio suggests that this woodland was open with considerable areas of grasses and sedges although extensive, fairly dense *Betula*-*Corylus* scrub might have had such a herb cover. The decline in the *Pinus* frequencies at 490 cm with a consequential rise in *Betula* frequencies points to its rather precarious existence at this time.

2. Pinewoods (The late Boreal period - zone VI).

The AP + SP/NAP ratio increases after 460 cm, principally because of increased *Pinus* frequencies but also because of rises in the *Ulmus* and *Quercus* curves. These increase at the expense of *Salix*, *Corylus* and Gramineae and point to the increasing density of the woodland canopy. *Pinus* increased its distribution in the *Betula*-*Corylus* woods of the early Boreal and *Ulmus* and *Quercus* become increasingly represented in the pollen spectra. The decline in the *Betula* curve does not reflect an actual decline in the distribution of the species but reflects the great increase in Pinus frequencies. This is clearly seen in the total pollen diagram (fig. 27), in which Betula values do not decline. Pinus appears to have taken over from Corylus as a major woodland component although Corylus was still present in large amounts, presumably as an understorey in the Betula-Pinus woods and perhaps as local pure Corylus thickets. The rare occurrence of Alnus indicates its existence in isolated localities. During this period of pine dominance the general absence of NAP, apart from Cyperaceae and Gramineae, might be attributed to the increasing acidity of the woodland humus under Pinus, although Calluna remains and pollen do not increase which might be expected. The absence of NAP might equally be due to rising water levels which, as has been suggested above, caused the decline of the rich fen communities which existed under the initial Betula-Salix carr in the hollow (stage 2, table 7).

After their maximum values in VIa Pinus frequencies decline throughout the composite sub-zone VIb + c and give ground before increasing Quercus and Ulmus frequencies. This period, during the late Boreal, probably represents the time of the greatest variety of trees and the greatest competition for space in the woodland. In addition to increased Quercus and Ulmus, Alnus gradually spread from its former isolated sites and both Fraxinus and Tilia make their first appearance. Thus there is a general trend of declining coniferous and rising deciduous constituents within the woodland, and although there is evidence, from the bryophyte layers in thefen peat at this site, that this was a time of slowly rising water tables and increasingly acid conditions on the bog, little can be concluded from the pollen curves about the nature of the climate and woodland soils. The increased NAP growth, particularly *Filipendula*, Filicales and *Pteridium* may reflect local growth, but in view of the evidence for continuing rising water levels it is perhaps more likely to reflect the less acid humus of the increasingly deciduous woodland in the valley.

3. Mixed oak woods (The Atlantic period).

During the first part of the Atlantic period the *Pinus* curve declines to very low values so that by 290 cm *Pinus* contributes less than 1% to the total pollen. Although initially *Quercus* and *Ulmus* frequencies increase, suggesting that these species invaded *Pinus* localities at an early date in VIb + c, *Alnus* probably competed with *Pinus* in the damper situation during VIIa. The maximum values reached by *Alnus* in VIIa are consistent with other changes both in the pollen spectra and stratigraphy, which are interpreted to reflect continuing rising water levels. The high Cyperaceae frequencies and the increased *Sphagnum* remains indicate the gradual change of the deposits from a soligenous to an ombrogenous peat, possibly brought about by these rising water levels. This same process might have caused *Alnus* to expand considerably in the damper localities and force *Quercus* (probably *Q. petraea*) onto the more acid hillsides. The typical Atlantic forest composition therefore, which at least in the early Atlantic fluctuated considerably, mainly because of the changing water levels, consisted of *Quercus*, *Alnus*, *Ulmus*, *Betula* and *Corylus*. *Fraxinus* and *Tilia* pollen appears in small amounts and the course of their pollen curves fluctuates little, which suggests the relatively isolated occurrence of these species. The process of rising water levels does not seem to affect their distribution.

The presence of Sorbus pollen, perhaps Sorbus aucuparia, suggests that certain areas within the woodland described above were not covered by a dense canopy. In view of the presumed rising water levels and the strong expansion of Alnus, it is doubtful whether many habitats would be available for the light-demanding Sorbus, although the few grains counted might indicate the local presence of wind blown gaps in the forest. One possible locality is the adjacent outcrop of Whin Sill to the south of the bog.

Alnus continued to expand in late Atlantic times and whilst there are indications both from the plant remains and the pollen spectra, that the bog surface dried out sufficiently for the establishment of Molinia caerulea, Rumex (perhaps R. acetosella) and Cruciferae spp., which might have been due to human activities (see table 7 and above), the increasing acidity resulted in a decreased herb cover pointing to the poorer nature of the woodland ground flora. By the end of the Atlantic period the woodland appears at its most stable with the tree pollen curves fluctuating only slightly, although Ulmus frequencies slowly decline. Alnus, Quercus, Betula and Corylus are the dominant species.

4. Post elm decline woods (The Sub Boreal period).

The Ulmus frequencies reach very low values at a point where there is a temporary decrease in the AP + SP/NAP ratio, along with the dominance of Sphagnaceous remains. This probably indicates the initiation of ombrogenous peat. Conditions favouring the start of ombrogenous peat growth, e.g. increased moisture, perhaps curtailed the local growth of Betula and Corylus and reduced the variety of NAP types, but at the same time allowed Alnus to expand in the increased damp localities. These changes are clearly seen in the pollen spectra in which Betula, Quercus, Alnus and Corylus dominate. The amounts of Alnus and Corylus suggest their local occurrence, and whilst it is not impossible for their co-dominance in certain areas, under increased moisture Alnus would probably dominate the vegetation in the wetter hollows at the expense of Corylus.

After the clear Ulmus decline and the rise in Fraxinus frequencies, the re-establishment of Ulmus and the appearance of Fagus pollen can be seen. If, as would seem apparent by the course of the curve, this Ulmus decline was gradual, its re-establishment implies either a reversal of the previous trend or the establishment of the species in different areas to those which it formerly occupied in VIIa, where this agency had not affected. Throughout the gradual decline in the Ulmus frequencies in VIIa Betula and Alnus values increase, which is consistent with either increased moisture or soil degradation or increased disappearance of some of the Atlantic woodland. Fraxinus pollen appears more frequent after the Ulmus decline, possibly as a result of it, and appears to suffer from the re-establishment of Ulmus. This suggests that Fraxinus was restricted to a narrow range of habitats which were not affected by deteriorating soil conditions, and

Ulmus invaded these areas in zone VIIb. During this period, (VIIb), the courses of the Calluna and Cyperaceae curves fluctuate. This, allied to the irregular Sphagnum curve and the changes in peat type, suggests that environmental conditions were far from stable in the Sub Boreal.

The secondary decline in Ulmus frequencies at 110 cm occurs alongside the first clear suggestion of anthropogenic activity. Here both the AP/NAP ratio and Corylus curve start to decline, while the Gramineae and Cyperaceae frequencies rise. Ulmus appears chiefly affected by these changes and above this level the Plantago lanceolata and Pteridium curves become continuous. The human activity which is possibly reflected here may have affected the bog surface in some way as this level coincides with a dry phase in the bog development. The rise in the Fraxinus curve after this secondary Ulmus decline, points to the tree initially invading the cleared Ulmus areas, although it is itself cleared later (see 5 below). The secondary woodland, defined as woodland which is derived directly or indirectly from human interference, may be said to have been established during the Sub Boreal period. Nevertheless it is apparent, from the pattern of the curves and the magnitude of the fluctuations in the AP/NAP ratio, that this human interference was initially on a fairly small scale. Betula, Quercus and Alnus appear largely unaffected by this clearance which is consistent with the idea that these species existed on the damper and poorer soils. Corylus frequencies start to decline indicating the clearance of the shrub, firstly where it existed with Ulmus and later where it existed on its own or as an understorey to the above trees, and Plantago lanceolata and Pteridium became well established. Thus the limited evidence from this site suggests that there might have been some clearance of the better soils during VIIb, although there is little indication of early agriculture. The occasional grain of Fagus is attributed to long distance transport.

5. The process of deforestation (Post Sub Boreal times).

At 55 cm the AP/NAP ratio shows the first changes of any magnitude since the late Boreal period. Tree frequencies, especially those of Betula and Alnus decline in favour of Gramineae, Cyperaceae, Plantago lanceolata, Rumex and Pteridium frequencies. Some of the increased herb flora indicated by these changes, may be due partly to human activity. The presence of Calluna charcoal in the peat points to the possibility of fire being used to remove parts of the woodland, although this charcoal might equally reflect purely local conditions. Betula and Alnus appear most affected by this human activity although Fraxinus values also decrease.

Betula probably occupied poorer soils both within the oak woodland and on the higher valley slopes (Chapter 7). Whilst there is no evidence to suggest the restriction of Betula clearance to these upper slopes the most likely target for primitive peoples, who wanted to clear the natural vegetation, might be the poorer soils which were prevalent at higher altitudes or in certain localities in the valley. In the valley areas of secondary woodland, established by earlier (i.e. Atlantic) clearances, where Betula and Fraxinus might exist, would offer certain advantages, such as a lighter vegetation cover, therefore would be more easily and effectively cleared. Such areas have been shown (4 above) to be present in the vicinity of Dufton at this time, so that the charcoal might be the result of these activities. Soon after this charcoal layer the Ulmus frequencies reach their minimum values which further points to some valley clearance. The decline in Alnus might reflect the purposeful clearance of this species, possibly for access to water, or incidental destruction by animals, trampling during regular visits to the same stretch of water for drinking.

After this period of human activity certain of the trees regenerated, although neither Fraxinus nor Ulmus appear to do so. This regeneration partly explains the decreased Gramineae, Cyperaceae, Ruderal and Pteridium frequencies above the charcoal layer. The Calluna horizon at 40 cm indicates the extension of ombrogenous peat growth or Calluna moorland, and the decline in a variety of NAP types can also be partly attributed to this process. This would also account for the lack of regeneration of the base demanding Ulmus and Fraxinus, and supports the theory suggested above that the earlier Betula clearance was, in fact, confined to the valley floor rather than the valley slopes. It will be shown in Chapter 7 that, at the Calluna horizon, few trees existed on the valley slopes above this site, which points to the inability of trees, except under very favourable circumstances, to regenerate on the podsolised soils of the valley sides, a feature which may be due to an overall climatic determinant or heavy grazing pressure at this time.

The top 20 cm of figs. 25 and 26 represent the time between the start of the widespread clearance of woodland at this altitude in the valley and the cessation of peat growth which may be recent, i.e. a few centuries ago. The AP/NAP ratio is extremely low portraying the more or less complete deforestation of the natural *Quercus*, *Betula*, *Alnus*, *Corylus* woods throughout this period of time, and the concomitant increase in the pollen of taxa showing a preference for disturbed ground. The increases in the *Pinus* and *Ulmus* frequencies presumably reflects the practice of planting, which some of the landowners have effected for some centuries.

SUMMARY

This site shows that organic deposition started before zone VI of the Boreal period, under a *Betula*-*Salix* carr.

A fen, dominated by *Phragmites*, formed in zone VI and under the influence of rising water levels the base status changed. During the Atlantic period the fen dried out and with increasing precipitation ombrogenous peat started to form, showing several 'drier phases' throughout the Sub Boreal period.

Corylus and *Pinus* immigrated into open *Betula* woods in the early Boreal. The open *Betula*-*Corylus* woods of VIa quickly gave way to more closed woodlands in which *Betula* and *Pinus* were dominant, although *Corylus* was abundant, and the thermophilous *Quercus* and *Ulmus* became established. Declining *Pinus* allowed *Quercus* and *Ulmus* to expand in VIb + c, whilst *Alnus* characteristically increased at the end of the Boreal period. Mixed oak woods consisting of *Quercus*, *Betula*, *Ulmus*, *Alnus* and *Corylus* with some *Fraxinus* and *Tilia*, dominated during the Atlantic although there is some evidence to suggest that there was not a complete woodland canopy.

There is no real evidence for human activity at the VIIa/VIIb boundary. Under fluctuating environmental conditions in the Sub Boreal period *Ulmus* re-established itself, and there are the first signs of human interference on the vegetation, which caused an increase in *Plantago lanceolata* and *Pteridium* and a gradual decline in *Corylus*. The first major clearance occurred before the *Calluna* horizon and principally affected *Betula* and *Alnus* on the valley floor. Regeneration of the woodland following this clearance coincided with the extension of the moorland 'after which general deforestation became prevalent' (see chapter 3:1).

Chapter 7. CRONKLEY PASTURES (profiles C1, C2)

Grid reference:	NY 857288
Altitude:	1300 ft (395 m)
Sampled:	Macaulay-type and Hiller peat sampler.
Length:	C1 300 cm, C2 66 cm.
Diagrams:	C1 figs. 30-32, C2 figs. 33,34.
Data sheet:	4, 5. 5. 100 cm = 0.

7.1. Site

This site occupies a depression in the lateral moraine at the foot of Cronkley Scar. Although it is by far the most extensive area of peat in this particular locality, other small deposits can be seen in basins on the moraine. These small basin peats appear to have formed due to the influence of spring water draining from the foot of the Scar. Apart from Cronkley Pastures, where the peat is approximately 3 metres deep, nowhere was found with a greater depth than 1.2 metres. Initially samples for analysis were collected from the centre of the basin (C1). At this point the peat surface slopes south-eastwards and carries a number of small streams draining from the moraine. Basal samples from elsewhere in the basin were necessitated by the inability to sample the bottom of the deposit and to check the date of the inception of peat growth (C2). Present biotic influences are grazing and draining, although peat cutting was formerly carried on. The present day vegetation of most of the small basins was similar. At Cronkley Pastures the following species were recorded: *Eriophorum vaginatum* (d), *E. angustifolium*, *Erica tetralix*, *Trichophorum caespitosum*, *Empetrum nigrum*, *Calluna vulgaris* (l.a.), *Juncus squarrosus*, *Potentilla erecta*, *Narthecium ossifragum*, *Galium saxatile*, *Poa* sp. (r), *Carex echinata*, *C. pulicaris*, *C. rostrata*, *C. demissa*, *Equisetum* fluviatile, Sphagnum spp., Polytrichum commune, Hypnum cupressiforme, Dicranum scoparium, Rhytidiadelphus loreus, R. squarrosus, Drepanocladus fluitans.

7.2. Stratigraphy

The following stratigraphy was recorded at C1:

0-5 cm

Dark brown surface peat with Eriophorum and Calluna roots. Fern annuli and Sphagnum papillosum leaves at the surface.

5-34 cm

Dark brown Eriophorum peat. Bands of pure Sphagnum at 6 cm, 9 cm and 15 cm with leaves of S. recurvum, S. cuspidatum, S. plumulosum and S. acutifolium.

34-64 cm

Dark brown monocot peat with Eriophorum fibres. Sphagnum recurvum leaves at 46 cm, Nardus at 56 cm and Betula at 57 cm. Increasing monocot with depth.

64-68 cm

Mid-brown moss peat. Pure Acrocladium cordifolium stems and leaves with few monocot remains.

68-295 cm

Dark brown monocot peat with Eriophorum fibres. Frequent Betula remains throughout. Few Sphagnum remains except for capsules. Unidentified leaf at 86 cm, fern epidermis at 116 cm, fern rachis at 186 cm, Eriophorum vaginatum seed at 236 cm, charcoal (cf. Betula) at 76 cm, 251 cm, Selaginella megaspore at 256 cm, Erica tetralix root and Calluna twigs at 281 cm, quartz fragments at 276 cm, 281 cm, and Equisetum stems at 295 cm.

295-300 cm.

Not sampled.

300 cm

Impenetrable.

The following stratigraphy was recorded at C2:

92-126 cm

Dark brown wood peat with abundant monocot remains. Dry and fairly friable, containing poorly humified Betula fragments <3 mm and bark. Quartz fragments throughout. Unidentified charcoal at 110 cm, Juncus cf. effusus seeds at 115 cm and Equisetum leaves at 116 cm.

126-129 cm

Wood layer. Betula with monocot remains in interstices. Some quartz.

129-143 cm
Dark brown wood peat with abundant monocot remains and some quartz fragments.

143-158 cm
Blue-grey inorganic sediment.

158 cm
Impenetrable.

Boring in other small peat deposits showed that below the top few cm of surface peat was a monocot peat with both Betula and Salix remains. The wood peat consisting largely of Alnus glutinosa which Pigott (1956: 549) noted was not discovered.

7.3. Pollen Analysis

The main features of the diagram are:

1. The sharp rise in most NAP frequencies at 283 cm, followed by an equally sharp decline at 256 cm.

2. The steady decline of Alnus frequencies throughout the diagram.

Quercus and Corylus dominate the AP + SP, with substantial amounts of Fraxinus, and varying amounts of Betula and Alnus. A variety of NAP is frequent throughout, especially Gramineae, Cyperaceae, Plantago lanceolata, Rumex and Filipendula with Filicales and Pteridium.

Comparison between the diagram from C1 (figs. 30-32) and the basal diagram from C2 (figs. 33 and 34) suggests that C2 should be placed chronologically before C1. Corroboratory evidence in the form of a wood peat under C1 was not found however. The most obvious correlative pollen analytical feature is the Ulmus curve which reaches 10-15% in fig. 33, values which are also found in the basal cms of fig. 30. In view of the steadily falling AP + SP/NAP ratio throughout fig. 31, the relatively constant ratio in fig. 33 appears to confirm a pre-Cl inception for C2 organic deposition. Quercus, Betula, Alnus and Corylus frequencies are all consistent with this hypothesis.

Despite the placing of C2 prior to Cl the Ulmus frequencies are too low for a pre-Ulmus decline date for the start of deposition. At the two sites which are closest in altitude to Cronkley Pastures, Dufton Moss (fig. 25) and Fox Earth Gill (fig. 35), the re-establishment of Ulmus can be clearly seen in Sub Boreal times. During this period Ulmus frequencies attain values similar to those found in the basal cms at Cronkley Pastures. Consistent with a post-Ulmus decline date are the amounts of Fraxinus and Plantago lanceolata pollen, which usually increase after elm has declined in many British diagrams (Oldfield, 1960; Birks, 1965).

An anomalous feature of the basal diagram from the C2 site (fig. 33) is the Pinus curve. The high frequencies of Pinus is uncharacteristic in the light of these diagrams being attributed to zone VIIb on the basis of the other tree curves. It appears therefore that pine was present on these upper slopes under Cronkley Scar late in zone VII.

7.4. Interpretation (Table 9)

1. Pre-interference vegetation.

Any interpretation of the basal cms of the Cl site (figs. 30-32) is dubious because only one sample was taken. As the C2 diagram (figs. 33, 34) has been chronologically placed prior to Cl both are considered together. Although, as noted above, both diagrams show comparable tree and shrub frequencies the types of peat found at the base are dissimilar. At Cl a monocot peat is present whilst at C2 a wood peat occurs. In the absence of evidence to suggest that a wood peat underlies the monocot peat of Cl and despite the possibility that a small band (under 15 cm in depth and therefore missed during sampling - see chapter 6) might be present, these sites could represent two areas of deposition which were contemporaneous. They would be spatially separated by a spring line which can be seen at present between the two sites.

The pollen and stratigraphical evidence from Cl, which is sited at a lower altitude than the spring line, suggests that the ground was initially covered by fairly acid vegetation in early Sub-Boreal times, in which grasses, sedges, Calluna, Erica tetralix, Eriophorum (perhaps E. angustifolium, although there is no direct evidence for this species) and Equisetum spp. (see 2 above) were dominant, along with a variety of mosses, including Sphagnum spp. and Selaginella selaginoides. Salix bushes might have also occurred (stage 1, table 9). The presence of quartz fragments both here and at C2 and Helianthemum pollen, points to the existence of some bare ground in the vicinity of the bog, possibly on the unstable banks of the moraine.

Above the spring line, at the C2 site, the stratigraphy indicates that a local birchwood existed, probably with some Corylus[1], (although there are no Corylus wood remains, there are large amounts of Corylus pollen), with a damp ground cover of grasses, sedges, Equisetum spp. and Juncus effusus. The pollen and spore record bear out the damp nature of the ground cover: Umbelliferae, Ranunculus, Filicales,

VIIb	Increased run-off	2	Destruction of bog comms. by fire	Extension of tree-less conditions. Destruction of local Alnus & Betula woods.	Charcoal, silt and Drepanocladus fluitans leaves. Increased NAP types.
				? Unstable morainic banks.	Helianthemum pollen.
				Local Betula woods with some Corylus. Damp ground flora.	Betula wood, Juncus seeds, Equisetum stems & quartz grains. Pollen of Gramineae, Cyperaceae, Filipendula, Umbelliferae & Ranunculus. Filicales & Polypodium spores.
		1	Acid damp comms.		Eriophorum fibres, Erica tetralix root, Calluna twigs & Equisetum stems. Quartz grains. Sphagnum & Selaginella spores.
				Local Alnus woods.	
				Remnant Pinus communities.	

*i.e. not on the bog surface.

TABLE 9. Cronkley Pastures: Pollen Diagram Interpretation

Zone	Mechanism	Stage		Bog Surface	Bog surrounds*	Evidence
Calluna horizon	?Increased moisture	4		Calluna becomes an important constituent in the flora. Extension of ombrogenous peat		Eriophorum becomes the dominant peat former. Increased Sphagnum and Selaginella spores
			f		Decreased amount of woodland in the valley	Declining AP/NAP ratio.
	Halting of soil deterioration. Increased run-off, causing local flushing		e	Flushed vegetation	Temporary establish. of local tree growth; Betula, Corylus & Fraxinus on the drier bog surrounds	Acrocladium cordifolium leaves. Potamogeton peak, Sparganium & Narthecium pollen.
	↑		d		Decline of trees	
	Depression of tree line by soil degradation.	3	c	Continued acidification. Establishment of oligotrophic comms.		Nardus remains, Cyperaceae pollen & fern spore peaks.
			b	Acid conditions.	Reduction of Alnus weeds, extension of grass & sedge comms.	Decline of Alnus frequencies. Increased Gramineae and Cyperaceae frequencies Eriophorum vaginatum and Molinia remains.
	Removal of human activity		a		Temporary re-establishment of Alnus woods.	

Filipendula and Polypodium appear significant.

The fairly high AP + SP/NAP ratio at both sites might be a reflection of the localised nature of the woodland in zone VIIb. Although the bog surface appears to be devoid of trees, there is evidence from the C2 site of fringing Betula-Corylus woods above the spring line. The high frequencies of Alnus suggests the local occurrence of an alderwood, probably in the depression between the moraine and Cronkley Scar where Tarn Dub currently exists. This could account for the low Betula values found at C1. Betula might be under-represented in the pollen spectra due to the local dominance of Alnus pollen, particularly if, as is suggested (table 9, stage 1), no trees existed on the moraine itself which separates the hollow from Tarn Dub. The high values of Fraxinus points to its probable existence on the scree slopes with Pinus.

It is difficult to assess the status of Quercus. The high values which it reaches in fig. 30 would appear to indicate its local presence. Throughout the period covered by the diagrams however, little change occurs in its frequencies until the Calluna horizon and at this point it is the last tree to decline. This suggests that Quercus was not affected by the falling AP + SP/NAP ratio, which is continuous throughout the diagram, and points to its absence or sporadic occurrence in the vicinity of the site, its abundance in the pollen spectra resulting from pollen blown in from lower altitudes. There is no real evidence for either premise but in view of the proposed local over-representation of Alnus at this site, to explain the low Betula frequencies the amounts of Quercus pollen suggests that

Quercus must have been present at least during the early part of zone VIIb on the acid soils of the drift covered valley slopes.

2. Human interference.

The extremely sharp changes in the pollen spectra at 283 cm can only have an anthropogenic cause. The presence of Drepanocladus fluitans leaves and silt layers in the peat indicate increased water run-off, which appears to have been caused by deforestation (stage 2). The Alnus curve declines most sharply but all other tree species, except Fraxinus, are affected and conversely all NAP frequencies increase as do Pteridium values. This process of deforestation, resulting primarily in the destruction of the local Alnus dominated woods (although causing Betula, Quercus and Corylus to contract), caused an extension of the treeless conditions, which were formerly restricted to the damp acid areas below the springs (stage 1). The course of the Betula curve substantiates the idea of local birchwoods. An initial increase in this species reflects the clearance of Alnus, Quercus and Corylus, the later decline reflecting its own clearance. Fraxinus, on the other hand, is not affected by this activity, which suggests its presence away from the cleared area and its inability to take advantage of the decreased tree competition.

The evidence thus points to the burning of the hillslopes at this site, resulting in an extension of the grass and sedge communities which previously existed on the bog surface and under the woodland canopy, and the increase of Calluna which might benefit from burning. The increased values of other NAP frequencies more likely reflect the low AP values than substantial increases in their distributions, since their frequencies do not rise in the total pollen diagram (fig. 31).

It is not clear why such an obviously damp site should be cleared, unless there were certain inherent advantages for prehistoric peoples. Although the effects of the clearance were drastic they appear shortlived, except for continued bog growth at this site which might have been initiated by this activity. The effect of what appears to be a fairly intensive clearance phase, using fire as a clearance mechanism[2], might easily have resulted in the paludification of the soil surface and initiated bog growth in an area where acid water was abundant and drainage was poor, which would continue to grow under the influence of drainage water (see chapter 12.3).

3. Declining tree lines.

At 246 cm the pollen curves change sharply. The *Alnus* frequencies become high and *Quercus*, *Betula* and *Corylus* values increase (stage 3(a)). This sudden increase in tree pollen frequencies indicates the complete removal of the forces which formerly acted on the vegetation and the pollen spectra revert more or less to their pre-interference values. No stratigraphic evidence was found to suggest that there is a hiatus in the deposit, although this is a possible explanation for such a sharp increase.

The increase in *Filipendula* frequencies, which is the only NAP to increase, is what might be expected. This species may have been abundant on the damp bog surrounds or under the damp woodland canopy. Gramineae values do not decline as much or as sharply as other NAP curves, which may reflect the decreased water content of the bog after the 'interference phase', resulting in more acid conditions with Eriophorum vaginatum and Molinia becoming important components of the herb flora.

The course of the Betula curve along with the Quercus and Fraxinus curves suggests that the local alderwoods gradually disappeared to be partly replaced by Quercus and Betula, but also by the grass and sedge communities (stage 3(b)). The rise in the variety of herbs which might be expected as locally dominant woods were reduced, does not occur and this may be attributed to the increased acidity of these slopes, although an alternative explanation could be that an open woodland of variable composition replaced the local alderwoods. This increasing acidity or changed woodland composition can perhaps be attributed to the anthropogenic activity already mentioned, but continued interference might also have caused these changed pollen spectra. It is interesting to note the peak of Onobrychis type pollen at 216 cm well above the clearance layer, which has been interpreted as a relict of cultivation (Clapham, Tutin & Warburg, 1962: 355), which might suggest continued human interference.

A sudden increase in the frequencies of Cyperaceae pollen and a peak in Filicales spores at 186 cm, points to the establishment of more oligotrophic vegetation on the bog surface with ferns on the damp surrounds (stage 3(c)). The presence of Nardus remains in the peat could reflect the acid nature of the vegetation either on the bog surface or surrounds, which by this time appears largely treeless. The occasional occurrence of Quercus, Betula and Corylus pollen and the decline in the local alder and birch woods suggest that the factors favouring their local existence become altered. A likely explanation is that local anthropogenic activity resulted in increased soil leaching, hence acidity, by removal of the tree cover which helped to depress the tree line. The behaviour of the Fraxinus curve, which is fairly constant, indicates a complete inability to colonise areas which were obviously free from competition, because of the acid and/or peaty nature of these drift covered slopes, although continued human interference might similarly ensure this phenomenon.

Despite the general decline in the tree line, which is apparent from the tree pollen curves, there is evidence for temporary re-establishment of trees which were the result of, or resulted in, a halt in the deterioration of soil conditions (stage 3(e)). A peak in Potamogeton pollen at 66 cm, along with occasional grains of Sparganium and Narthecium and Acrocladium cordifolium remains, suggests increased moisture which might have caused such an abatement. Immediately below this level, which consists of pure Acrocladium cordifolium, charcoal fragments occur. If the interpretation of this same phenomenon earlier (i.e. a sharp decline in the AP/NAP ratio followed by an equally sharp increase) is valid, then again here is an instance of human interference upon the vegetation resulting in increased surface water run-off. The indicative NAP curves, Plantago lanceolata and Rumex, and also the Pteridium curve, all rise, indicating interference in a generally treeless environment which resulted in disturbance and the immigration of the weed species at the expense of grasses and sedges. Following this clearance come peaks in the Betula, Fraxinus and Corylus curves. One explanation for this pattern is that the human interference resulted in the halting of the podsolisation process by causing increased run-off and hence some flushing (and the addition of phosphate from burning). Temporary local tree growth ensued, pioneer species quickly established themselves with a varied ground flora and gradually gave way to Quercus.

This temporary growth of trees is abruptly curtailed at 36 cm where the Calluna horizon has been drawn. At this site Calluna is not an important constituent in the ground flora until this point, and its rise in the pollen spectra suggests that its distribution became more widespread at this time mainly at the expense of the limited occurrence of trees on the fairly acid soils, perhaps as a result of the increased moisture which caused Eriophorum to become the dominant peat former and is reflected in increased Sphagnum and Selaginella frequencies. Whilst the rising values for most NAP probably reflects the continuing treeless nature of the vegetation at this altitude, it also reflects the decreased amount of woodland on the valley floor (stage 3(f)). The Ruderal and Pteridium curves attest to the continued presence of man in the area.

SUMMARY

The diagram shows Sub Boreal clearance of considerable magnitude in an area where local Alnus and Betula woods dominated. The clearance mainly affected Alnus, but Betula, *Quercus* and *Corylus* also suffered. After this phase *Alnus* re-established itself but gradually declined in response to deteriorating soil conditions, and *Betula* and *Quercus* partly replaced *Alnus* with an extension of moorland communities. Fluctuations in this general trend of a declining tree line allowed the temporary growth of trees, aided by some human activity. Man's actions can be seen through the diagram.

[1] There is a distinct possibility here that some of this pollen might belong to *Myrica gale*.

[2] In general terms however, fire can be an accidental concomitant of prehistoric man's presence.

Chapter 8. FOX EARTH GILL (profile F1)

Grid reference:	NY 842282 .
Altitude:	1750 ft (531 m).
Sampled:	Macaulay-type peat sampler and monolith tin.
Length:	320 cm.
Diagrams:	35-37.
Data sheet:	6.

8.1. Site

Fox Earth Gill flows north-westwards across Cronkley Fell from a spring approximately 600 yards (180 m) due south of the sugar limestone outcrop of Thistle Green. The valley of the Gill is a distinct morphological feature, the sides rising some 50 ft (15 m) on either side of the stream, with numerous outcrops of limestone on the north-east facing slope. Samples for analysis were taken from a peat face in the channel of the stream midway between the springhead and the sugar limestone exposure at White Well Green with its characteristic Dryas octopetala community. Here is an area of deep peat with unusual features. The surface of the peat is dominated by Calluna vulgaris, although Eriophorum vaginatum, E. angustifolium, Erica tetralix, Empetrum nigrum, Trichophorum caespitosum, Sphagnum spp. and Cladonia spp. are also present. This heather dominated community contrasts sharply with the vegetation in the channel of the stream where open water is present. Here the vegetation includes: Eriophorum angustifolium (d), E. vaginatum, Juncus effusus, Carex echinata, C. hostiana, Potamogeton sp. and Sphagnum spp. with Molinia caerulea at the stream edge.

8.2. Stratigraphy

During sampling the following stratigraphy was recorded:

0-20 cm

Mid brown surface peat. Calluna dominant with Eriophorum, monocot and Sphagnum remains. Calluna charcoal (stems), quartz fragments and Sphagnum papillosum at the surface; Sphagnum papillosum and S. cuspidatum at 10 cm; Calluna charcoal at 12 cm.

20-21 cm

Sphagnum peat.

21-22 cm

Calluna peat with monocot remains and Eriophorum fibres. Sphagnum papillosum and S. rubellum at 22 cm.

22-23 cm

Sphagnum peat.

23-32 cm

Calluna peat with monocot remains and Eriophorum fibres. Sphagnum rubellum and S. cuspidatum at 32 cm.

32-72 cm

Mid brown Eriophorum peat. Monocot remains abundant but few Sphagna. Occasional small Calluna twig. Eriophorum vaginatum 'spindle' at 42, 52 cm; Sphagnum cuspidatum and S. papillosum at 62 cm; Betula charcoal at 72 cm.

72-99 cm

Dark brown monocot peat with frequent Betula wood remains but few Eriophorum fibres. Fairly abundant moss remains including: Rhacomitrium cf fasciculare and Polytrichum commune at 82 cm; Selaginella megaspore and Sphagnum squarrosum at 92 cm. Phragmites piece at 96 cm.

99-102 cm

Sphagnum peat. S. recurvum abundant.

102-126 cm

Dark brown fen peat. Occasional Betula wood $<$ 2 mm, few Phragmites remains and large Carex stems. Sphagnum recurvum band 111-112 cm; fern annuli at 112 cm; unidentified charcoal (stems) at 122 cm.

126-134 cm

Dark brown fen peat, more fibrous than above. Increased Phragmites and other monocot remains. Sphagnum remains abundant, S. cuspidatum and S. recurvum at 132 cm. Few Eriophorum fibres.

134-176 cm

Dark brown fen peat, less fibrous than 126-134 cm. Dominantly Phragmites and other monocot remains. Betula twigs $<$ 3 mm become frequent below 143 cm. Indistinct Sphagnum banding, S. recurvum at 162 cm; Sphagnum recurvum, S. squarrosum and Polytrichum commune at 172 cm. Occasional Eriophorum fibre. Large Betula root lies across the boundary with lower horizon.

PLATE 11

Fox Earth Gill.

176-185 cm

Very wet dark brown fen peat. Distinct from above. Abundant Phragmites forms distinct layers. No Betula remains, frequent Sphagna. Sphagnum recurvum and Calluna twigs at 182 cm.

185-196 cm

Wood layer. Betula with interstices filled with fen peat. Sphagnum capsules, Carex nutlet, Caryophyllaceae cf Lychnis type seed at 192 cm.

196-222 cm

Dark brown fen peat. Phragmites and other monocot remains abundant. Occasional small Betula twig <1 mm and Calluna twig. Moss remains:

202 cm Sphagnum recurvum, S. squarrosum and S. palustre.

212 cm Sphagnum palustre, S. recurvum and Polytrichum strictum.

214-215 cm Camptothecium nitens.

222-245 cm

Moss peat. Almost pure Drepanocladus fluitans with Phragmites remains and occasional small Betula twig. Carex nutlet at 232 cm.

245-275 cm

Sphagnum peat. Pure Sphagnum recurvum at 252, 262 cm. Drepanocladus fluitans frequent, few Phragmites remains. Carex nutlet 262 cm.

275-284 cm

Moss peat. Abundant remains of Paludella squarrosa 279-282 cm, nearly 100% of the deposit at 281 cm. Other mosses:

277 cm Drepanocladus fluitans.

279 cm Drepanocladus fluitans and Sphagnum recurvum.

281 cm Drepanocladus fluitans, Sphagnum cuspidatum, S. teres and S. recurvum.

283 cm Camptothecium nitens, Sphagnum recurvum, S. teres, S. cuspidatum and S. squarrosum.

284-291 cm

Sphagnum peat. Sphagnum recurvum, S. cuspidatum, S. teres and S. palustre. Paludella squarrosa frequent. Drepanocladus fluitans remains at 290 cm; Carex nutlet at 291 cm.

291-313 cm

Dark brown fen peat. Abundant Phragmites remains with Drepanocladus fluitans throughout. Small amounts of Paludella squarrosa with Sphagnum teres and S. recurvum at 293 cm; Rosaceae seed at 303 cm; Sphagnum teres and Carex nutlet at 313 cm.

313-320 cm

Minero-organic layer. Monocot remains frequent. Drepanocladus fluitans and Polytrichum sp. stems at 320 cm.

8.3. Pollen Analysis

Diagram. The following samples were collected:

10 cm intervals	0-22 cm, 62-92 cm, 112-117 cm, 202-283 cm.
5 cm intervals	22-62 cm, 92-112 cm, 172-202 cm, 295-320 cm.
2 cm intervals	283-295 cm.

Zonation and Description

The base of the blanket peat has been assigned to zone VI because of the clear *Pinus* maximum and the frequencies of *Quercus* and *Ulmus*. This zone has been divided into two sub-zones, sub-zone VIb in which *Betula* dominates the pollen spectra with substantial amounts of *Quercus* and *Ulmus* and increasing *Pinus*, and sub-zone VIc in which *Pinus* and *Quercus* are the major tree components. The boundary between these two subzones has been drawn at 299 cm.

The declining *Pinus* frequencies and the rising *Alnus* frequencies demarcates the VI/VII boundary at 162 cm. *Quercus* and *Alnus* are the best represented trees, although *Ulmus* and *Betula* are present in zone VIIa and *Fraxinus* and *Tilia* become consistent contributors to the pollen spectra.

An *Ulmus* decline can be clearly seen at 92 cm which has been used to divide VIIa and VIIb. In VIIb *Betula*, *Quercus* and *Alnus* are the main trees.

The *Calluna* horizon has been drawn at 37 cm.

8.4. Interpretation

Stratigraphic Sequence and Bog Development (Table 10).

Organic deposition started during sub-zone VIb under extremely wet conditions. Remains of *Phragmites*, *Carex* spp. and *Drepanocladus fluitans* in the peat overlying a minero-

TABLE 10. Fox Earth Gill: Stratigraphic interpretation.

Zone	Stage		Community postulated	Evidence
VIIb	5	↑	Ombrogenous peat communities	Ombrogenous peat, Calluna, Eriophorum & monocot remains
VIIa	4	Rising water levels	Establishment of former rich fen & carr herb flora on the drier, less acid bog surrounds, probably near limestone outcrops	Peaks in ferns, Filipendula, Rumex, Melampyrum, Rubiaceae & Pteridium. Eriophorum remains. Phragmites rhizomes & Calluna twigs.
	3	Drying conditions	Betula carr ? perhaps with Alnus	Betula roots, Rosaceae pollen spores of ferns and Pteridium
VI	2 d	↑	Poor fen comms.	Phragmites rhizomes, Camptothecium nitens & Sphagna leaves. Cyperaceae pollen.
	c		Fen communities	Phragmites rhizomes, Drepanocladus fluitans leaves. Pollen of Gramineae, Rumex, Filipendula & Cruciferae.
	b		Sphagnum-sedge communities	Phragmites rhizomes, Drepanocladus & Sphagnum recurvum leaves.
	a	Fluctuating water levels	Rich fen comms.	Paludella squarrosa, Drepanocladus, Camptothecium & Sphagnum spp. leaves, Carex spp. remains. Pollen of Filipendula & Epilobium, fern spores.
	1		?Open areas of bare ground	Helianthemum pollen.
			Drier areas with a grass-sedge comm.	Pollen of Gramineae, Cyperaceae, Filipendula & Umbelliferae, Selaginella & fern spores.
			Open water	Phragmites rhizomes, Drepanocladus leaves. Pollen of Potamogeton sp. & M. alterniflorum.

organic layer, in which were remains of unidentified monocotyledons, Drepanocladus fluitans and Polytrichum spp. indicate this damp nature. Pollen of Potamogeton spp. and Myriophyllum alterniflorum suggest the presence of some open water. The drier areas of the bog surface were colonised by Gramineae, Cyperaceae, Filipendula and Umbelliferae, Selaginella selaginoides and Filicales (stage 1, Table 10).

Small amounts of Paludella squarrosa occur at 291 cm and a Sphagnum layer is present in the fen peat which, in addition to Paludella, contains Drepanocladus and Carex spp. remains. The variety of the Sphagna suggests that the site had few dry areas which, under fluctuating conditions (see below) were colonised by Cyperaceae, Helianthemum sp., Epilobium sp., Saxifraga stellaris and Filipendula. The indications are that this was the start of a period of fluctuating water levels (stage 2).

These fluctuating levels caused a succession of differing peat types:-

(i) Moss peat with Paludella, Camptothecium nitens and Drepanocladus (a).

(ii) Sphagnum peat with Drepanocladus, Phragmites and Sphagnum recurvum (b).

(iii) Moss peat with Drepanocladus and Phragmites (c).

(iv) Fen peat with Phragmites, Camptothecium and Sphagna (d).

The NAP curves similarly reflect this pattern. These show that the species of the initially disturbed conditions gave way to a poorer flora dominated by sedges as rising water levels caused the development of a Sphagnum peat (ii). This peat in turn dried and was overlain by a moss peat with grasses, Rumex (perhaps R. acetosella), Filipendula and Cruciferae spp. establishing themselves on the bog surface (iii). Increased water resulted in the extension of sedges and Phragmites (iv) and the destruction of this flora.

At the end of the Boreal period the substantial Betula root layer indicates that the bog became sufficiently desiccated to allow the establishment of Betula and perhaps Corylus and Alnus on its surface and surrounds along with Rosaceae spp. (perhaps Geum sp. or Malus sp.), Filicales and Pteridium (stage 3). A further fluctuation in the water table can be seen where the Phragmites dominated fen peat overlies this layer. The increasing acidity of the bog, due partly to the continued intense leaching of the fell tops, is reflected in the presence of Calluna twigs from this level (stage 4). The AP + SP/NAP ratio clearly shows this phase of desiccation and flooding. The ratio rises, due to increased Betula, Alnus and Corylus frequencies, during the levels occupied by the wood layer and declines after this layer. Conversely the Cyperaceae frequencies decline during the drying phase and rise during the fen peat stage.

Throughout the Atlantic period a high water table is reflected in the persistence of Phragmites. The occurrence of Eriophorum and Calluna remains and the predominance of Sphagnum recurvum and S. cuspidatum remains point to the lowered base status of the bog. Despite the presence of occasional Betula wood in the peat which indicates its continued local growth on the margins of the bog, it appears that the bogside tree cover which might have formerly existed

PLATE 12

Fox Earth Gill.

became destroyed during this period, Filicales, Filipendula, Rumex, Melampyrum, Rubiaceae and Pteridium establishing themselves on the damp surrounds, which could well have been less acid than the bog surface (stage 4).

At 90 cm where the boundary between the Atlantic and Sub Boreal periods has been drawn, ombrogenous peat started to form. The remains of the acid vegetation is reflected in the initially high Sphagnum frequencies but throughout this peat are remains of Calluna, Eriophorum, grasses and sedges, which today constitute most of the surrounding area of the site (stage 5).

Forest Development (Table 11)

1. Birch-hazel woods. (The late Boreal Period - subzone VIb).

During subzone VIb the AP + SP/NAP ratio is fairly high with large Corylus frequencies, which suggests the local growth of the shrub along with Salix and perhaps Betula on the damp ground. Betula appears the dominant tree at this time, although Quercus and Ulmus are apparently well established and Pinus frequencies are increasing slowly. It seems likely that a light Betula-Corylus scrub covered a large part of the fells with the thermophilous Quercus and Ulmus in areas of better soil, possibly in the vicinity of the limestone and sugar limestone outcrops, or in sheltered localities. The habit of these trees can only be surmised but it is not improbable that they were shrubby. Although the occurrence of Pinus pollen might be a reflection of its dominance during subzone VIb at lower altitudes (see Chapter 6), there is no reason to suppose it did not exist to a limited extent with

TABLE 11. Fox Earth Gill: Interpretation of woodland history.

Zone	Vegetation
Calluna horizon	Steady expansion of moorland[1].
VIIb	Re-establishment of Ulmus. Evidence of human alteration of the woodlands. Decreasing Quercus and Alnus, increased Betula.
VIIa	Ulmus decline. Start of ombrogenous peat growth. ? Small amount of human interference affecting Ulmus localities. Mixed oakwood. Quercus and Alnus dominate, their areas of distribution being adjacent to one another. During VIIa Alnus expanded at the expense of Quercus and Ulmus. Fraxinus becomes constantly represented in the pollen spectra. Decreased Betula-Corylus scrub at high altitude.
VI	? Open Pinus-Quercus woods. Pinus and Quercus co-dominant, both invade the drier limestone soils at the expense of Betula and Corylus. Extension of Alnus, Betula and Corylus extend to high altitudes. Local growth of Betula, Corylus and perhaps Ulmus. Betula-Corylus woods. Local growth of Corylus, Salix and Betula. ? Alnus on the damp ground, Quercus and Ulmus in sheltered localities and areas of favourable soils. Isolated Fraxinus.

[1]See chapter 3.2.

Quercus and Ulmus. The sporadic occurrence of Fraxinus pollen probably indicates its local presence on the numerous limestone outcrops or within the scrub areas. Alnus may have been present in damp localities, although the small amounts of pollen found might equally be the result of inblowing from lower altitudes.

2. The Pine Woods (subzone VIc).

The stratigraphic evidence (stage 2, table 10) indicates that during subzone VIc this site was subject to fluctuating water levels. The courses of the tree curves suggest that the cause of these changed bog conditions was not purely local, but also caused a reduction in the competitive ability of Betula in some way, increased Quercus and Pinus and the extension of Alnus from its former isolated sites or, alternatively, its establishment on the fell top. Although such fluctuating water levels might enable Quercus petraea to expand at the expense of Betula on the thin acid soils, a more likely explanation of the changes, which are reflected in the pollen spectra, is that initially rising water levels caused the decline in local tree growth, and at the same time permitted both Pinus and Quercus to invade the drier areas of limestone soils which possibly carried a light cover of Betula and Corylus. Ulmus does not increase because it had already reached its maximum extension under the prevailing conditions.

Subzone VIc is the period of the Pinus maximum at this site, although in fact Quercus and Pinus are co-dominants in the pollen spectra. (In view of the high pollen productivity of Pinus the dominant tree at this time may well have been Quercus). The AP totals, which suffer a decline at the start of this subzone due to local bog conditions (stage 2, table 10), regain their former (VIb) values due to the immigration of Pinus and the expansion of Quercus. Corylus however, does not increase until later which possibly reflects its growth on the bog surrounds being curtailed in some way. Open woodland appears prevalent with Pinus and Quercus dominant in the vicinity of the bog on the drier soils with some Corylus and Ulmus. Betula values are low but the tree undoubtedly existed at higher altitudes forming a scrub with Corylus, whilst the occasional presence of Betula wood in the peat suggests its local occurrence. Thus the Betula might be under-represented by its pollen due to the preponderance of other locally derived tree pollen, especially Pinus. The rise in Alnus frequencies above 242 cm is a reflection of the overall increase in moisture, indicated by the increased Phragmites remains, which caused an extension of habitats suitable for Alnus growth.

Fluctuating water levels appear to account for the sudden reduction in the AP + SP/NAP ratio at 212 cm. Quercus and Alnus frequencies decline whilst Pinus and Corylus frequencies rise to be followed by an increase in Cyperaceae values. This is a pattern which might be caused by small changes in the water level. Increased moisture allowed Pinus to extend its distribution at the expense of Quercus and Corylus and Alnus became established near the bog surrounds or in similar localities. This is indicated by the pollen spectra of the layers immediately beneath the wood layer. These same conditions might also allow sedges to increase.

The declining Pinus frequencies at 195 cm along with increasing Quercus and Ulmus frequencies, suggest that once again the changes during the late Boreal period, reflected in changing bog conditions (stage 3), were fairly widespread. The increased Alnus frequencies in no way contradicts the evidence of fluctuating water levels because these values are almost certainly due to its local presence in favourable situations, although there is no evidence for its growth at this site. The increased dryness, postulated for the occurrence of the wood layer in the bog, caused Pinus, which had invaded the driest areas during a damper phase (see above), to decline and allowed both Quercus and Ulmus to increase into some, if not all of the former Pinus localities. The rise in the Ulmus values before Quercus frequencies might reflect the availability of the base rich soils of the former Pinus localities for colonisation at this time. These soils gradually became leached in the succeeding damper phase when the bog surface became flooded (stage 4), and Quercus expanded at the expense of Ulmus. Alnus during this time might have been influenced by similar factors and exhibits a pattern similar to that seen earlier (242-212 cm). Drying conditions allowed it to become locally established in damp hollows on the margins of any organic deposits which might have been growing in localities such as Fox Earth. Increasing moisture caused this local growth to decline whilst allowing its extension into areas formerly too dry for its growth, thereby increasing its distribution. It is pertinent to note that the Cyperaceae frequencies, which have been used elsewhere to denote the changing water levels in the bog, have an inverse relationship with the Alnus frequencies.

3. The Mixed Oakwood (The Atlantic Period - zone VIIa).

In the Atlantic period the Pinus frequencies continue their decline to very low values which began during the latter stages of the Boreal period, whilst Quercus and Alnus frequencies reach their maximum values. The Ulmus curve shows a continuous decline from its peak in subzone VIc. The small flucutation in both Quercus and Alnus curves appear to be related, which suggests that rising water levels, after causing an increase in Quercus at the expense of Ulmus, caused widespread increases in Alnus, by increasing the localities which would favour the growth of Alnus at the expense of Quercus and Ulmus.

From this period Fraxinus pollen is constantly found in the spectra. The status of this tree is not clear from the pollen diagram. If the decline in Ulmus values and consequent increase in Quercus frequencies, followed by increased Alnus and Corylus frequencies, can be attributed to rising water levels causing accelerated soil leaching therefore degradation, the soils of the fell tops would probably be too poor for Fraxinus, which is as base demanding as Ulmus. Therefore, it is doubtful whether the increase in Fraxinus pollen can be due to Fraxinus invading former Ulmus localities. These localities would probably favour Quercus and Alnus under the prevailing conditions (above). It would appear more likely that Fraxinus invaded former Pinus localities, which appear to have been (2 above) the areas of drier and probably shallower limestone soils.

The decreased Cyperaceae values in the pollen diagram at these levels (90-160 cm) might appear to represent drier conditions on the bog surface and surrounds. However, the increased Gramineae and Calluna frequencies allied to the increased Alnus, Corylus and Quercus values, indicate the period when, under conditions of increased moisture, soil deterioration became widespread and blanket peat began to form in many areas. This process is partly reflected in the decreased Betula frequencies which may indicate blanket peat formation at higher altitudes, in addition to a reduction in the local growth of Betula, Filipendula, Rumex and Filicales, which was probably caused by the increasing acidity of the bog and surrounds.

The steady nature of the AP + SP/NAP ratio during this period, when blanket peat was forming in many parts of the northern Pennines (see Chapter 3.1), suggests that most of the pollen in the spectra reflects fairly local conditions. Throughout the Atlantic period the tree and shrub cover does not appear affected by peat formation or soil deterioration, which points to the presence of areas of permeable soils on or near the drift free limestone outcrops on which trees could survive. Thus, a parkland vegetation is envisaged in zone VIIa, clumps of mixed oakwoods in areas of fairly base rich but rapidly leaching soils, local alderwoods in small basins and areas of Betula-Corylus scrub. All of these were being gradually reduced by encroaching ombrogenous peat.

The occurrence of unidentified charcoal at 122 cm coincides with a peak in Pteridium frequencies and the occurrence of Plantago lanceolata, Umbelliferae and Melampyrum pollen. Although there is only slight evidence in the AP/NAP ratio for decreased trees, Ulmus values temporarily decline and Filipendula frequencies decrease. These small changes in the pollen spectra might have been caused by man, who cleared the small pockets of damp base rich soil where Ulmus grew with Filipendula. Such an explanation for one fluctuation in the pollen spectra is obviously tentative and raises the question of whether other undetected changes might not have resulted, or at least aided, in the decrease of habitats suitable for Ulmus. Burning of small areas could increase the process of soil degradation by removing the vegetation cover and also cause some paludification of the surface.

4. Deforestation (Post Atlantic times).

The pollen spectra indicates major changes in the vegetation at 92 cm. The Ulmus curve, which had been declining since the late Boreal reaches its minimum values and both the Quercus and Alnus curves decrease. The Calluna curve sharply rises and there are increases in the frequencies of Plantago lanceolata, Rumex and Pteridium.

These changes point to the continued growth and extension of blanket peat and is reflected at this site by the start of ombrogenous peat growth (stage 5). There is no change in the AP/NAP ratio however, which supports the theory that trees persisted near this site long after blanket peat was forming in many parts of the Reserve. The reason for this must be the presence of the limestone outcrops, which would provide suitable peat free areas for the maintenance of a limited tree cover, although the species might be changed. The increased Betula values might reflect this tree's ability to colonise and exist in acid conditions and would almost certainly benefit from the decreased Quercus competition in the limestone areas.

It has already been tentatively suggested that man was present on these uplands in Atlantic times, although there is only evidence for limited destruction of the woodland vegetation. During Sub Boreal times the effect of man is more clearly seen. The occurrence of Betula charcoal at 72 cm, along with rises in Betula frequencies at the expense of Quercus and Alnus, points to human interference. At the same level Eriophorum (E. vaginatum) peat becomes predominant, which indicates highly acid conditions. The presence of this peat directly above the charcoal might be purely fortuitous. Without further evidence it can only be suggested that man's activities, which might not have been limited to areas where blanket peat was absent, helped in the general degradation of the vegetation, especially in the limited areas of woodland. In this upland environment this activity was probably orientated towards grazing or hunting practices. Fire would be used to improve pasture or to drive game and animals could be pastured on the fells, especially if the blanket peat was seasonally dry, as is likely but for which there is no evidence.

A decline in the AP/NAP ratio at 62 cm is due principally to temporary decreased Betula and Fraxinus frequencies, although Quercus, Alnus and Corylus values also decrease. This temporary decline may merely be a transient natural feature in the generally declining tree cover due to the encroachment of blanket peat, but small values of Plantago lanceolata, Rumex and Pteridium point to the possibility of man's continued presence.

As at Dufton (chapter 6) the re-establishment of Ulmus can be seen. The rising Ulmus values complement the falling Fraxinus values, which may indicate the natural succession on the base rich soils, especially if Fraxinus invaded these limestone soils after the decline of Pinus in Atlantic times. There is the possibility however, that this re-establishment merely reflects the Ulmus re-establishment at lower altitudes.

Throughout the Sub Boreal period the rising Calluna curve points to the steady expansion of the moorland. This curve reaches its maximum at the Calluna horizon (37 cm). Coincidental with this horizon and the presence of abundant Calluna twigs in the peat, is a clearance phase with a sharp decrease in the AP/NAP ratio. This decreased ratio is marked by declines in Alnus, Corylus and Ulmus frequencies, followed by Betula and Quercus, which indicates increased peat growth on the Reserve, although at this site the bog appears to have dried out slightly. This further extension of the peat area resulted in the elimination of most trees from the fell tops. The Calluna charcoal in the surface root mat is evidence of continued human activity on the Reserve in the form of burning of the moorland communities to provide improved grouse herbage.

SUMMARY

Deposition started in a depression during the latter part of the Boreal period. Phragmites fen predominated throughout the Boreal and Atlantic periods, although evidence points to considerable fluctuations in water levels. During subzone VIc a variety of communities caused by these fluctuations indicate substantial environmental changes, culminating in the establishment of a Betula carr on the bog surface at the

start of the Atlantic period. This wood subsequently became flooded and ombrogenous peat started to form at the Atlantic/ Sub Boreal boundary.

Extensive Betula-Corylus woods were present on the fell top in subzone VIb, although Quercus and Ulmus appear well established and Pinus was possibly immigrating to these altitudes from the lower slopes and the valley floor (see Chapter 5). Pinus became co-dominant with Quercus in subzone VIc, whilst Ulmus occurred on the richer soils. Betula-Corylus scrub still persisted probably over large areas. Decreasing Pinus during the late Boreal allowed substantial increases in Alnus, Quercus and Ulmus and during VIIa mixed oakwoods were predominant in patches, whilst blanket peat curtailed extensive areas of scrubland. Evidence for early man's influence can be seen in VIIa but this becomes more definite in VIIb when interference appears more or less continuous, almost certainly aiding the steady expansion of the moorland communities. This extension of acidophilous communities caused the gradual decline of trees on the richer soils and by the Calluna horizon evidence points to the fell tops being treeless.

Chapter 9. MIRE HOLES (profile R1)

Grid reference: NY 849267.
Altitude: 1850 ft (562 m).
Sampled: Macaulay-type peat sampler.
Length: 220 cm.
Diagrams: Figs. ~~44-46~~. 38-40
Data sheet: 7.

9.1. Site

A sample was taken for analysis from an area of actively growing blanket peat. Approximately 0.5 km square of extremely wet peat dominated by Eriophorum vaginatum, Calluna vulgaris and Sphagnum sp. (S. cuspidatum, S. rubellum, S. papillosum) occupies a low watershed between two small streams. At least two springs drain from the bog, one in the east and one in the west. Growing on the site, which is prevented from being drained or burnt by a Nature Reserve Agreement, in addition to the above species, were: Erica tetralix, Trichophorum caespitosum, Empetrum nigrum, Eriophorum angustifolium, Drosera rotundifolia, Narthecium ossifragum, Oxycoccus palustris, Rhytidiadelphus sp., Dicranum sp., and Cladonia spp. Rubus chamaemorus was present where the drainage was free, around the shake hole (swallow hole) in the central part of the bog.

9.2. Stratigraphy

0-15 cm

Mid brown Sphagnum peat with Calluna roots. Eriophorum fibres throughout. Sphagnum magellanicum (d) at the surface.

15-25 cm

Mid brown monocot peat with Calluna twigs and roots and Eriophorum fibres. Aulocomium palustre leaves and Dicranum scoparium leaves at 20 cm.

25-85 cm

Sphagnum peat with abundant monocot remains. Eriophorum fibres throughout, E. vaginatum 'spindles' at 30, 40, 50, 80 cm. Sphagna include:

30 cm Sphagnum papillosum.
40 cm Sphagnum magellanicum and S. cuspidatum.

50 cm Sphagnum cuspidatum (d) and S. tenellum.
70 cm Sphagnum papillosum, S. cuspidatum, S. rubellum and S. magellanicum.
80 cm Sphagnum cuspidatum.

85-95 cm

Monocot peat with few Eriophorum fibres. Calluna charcoal (stems and fruit) at 90 cm.

95-105 cm

Sphagnum peat with abundant monocot remains. Sphagnum papillosum (d), S. magellanicum, S. cuspidatum and Calluna charcoal at 100 cm.

105-220 cm

Monocot peat. Eriophorum fibres to 210 cm.
110 cm Poorly preserved Sphagnum cuspidatum and S. rubellum.
130 cm Eriophorum vaginatum 'spindles'.
140 cm Sphagnum papillosum, S. tenellum and S. cuspidatum.
150 cm Sphagnum tenellum, S. cuspidatum, Calluna charcoal, Carex sp. nutlet and Polytrichum sp. stems.

Sphagna remains absent below 150 cm. Calluna charcoal at 160, 170 cm, Pohlia nutans leaf at 180 cm. Below 200 cm quartz fragments become abundant. Polytrichum sp. stems at 210 cm. Calluna charcoal at 202, 204, 206, 208, 210, 220 cm, along with Juncus cf. effusus seeds. Sphagnum recurvum at 204 cm; Carex sp. nutlet at 208 cm, Rosaceae seed at 220 cm.

220 cm

Impenetrable obstacle.

9.3. Pollen Analysis

Diagram. Analytical samples were taken as follows:

10 cm intervals 10-180 cm, 210-220 cm.

5 cm intervals 180-200 cm.

2 cm intervals 200-210 cm.

Zonation and Description

A well marked decline in the Ulmus frequencies can be seen at 195 cm marking the VIIa/VIIb boundary. In VIIa the mixed oak woodland species dominate with grasses and sedges the main NAP. The Calluna horizon has been drawn at 90 cm, which marks the maximum values of Calluna. This horizon also marks the start of great increases in Plantago lanceolata, Rumex and Pteridium.

PLATE 13

Mire Holes in the middle distance, micro-pingoes caused by frost heaving in the foreground.

9.4. Interpretation (Table 12)

1. The Mixed Oak Woodland (The Atlantic Period - zone VIIa).

A peat dominated by monocot remains with Carex spp. and Polytrichum spp. remains started growing between two spring heads during the Atlantic period. The frequencies of Gramineae, Cyperaceae, Rosaceae, Potentilla, Rumex, Filipendula and Succisa pollen and Filicales and Sphagnum spores indicate that this was a very damp unstable (i.e. liable to erosion, most likely on a small scale), base-rich habitat at this time, as might be expected from its nature and situation on Lower Limestone Group rocks (stage 1, table 12).

The amounts of Corylus pollen point to its local presence whilst the tree pollen curves indicate the occurrence of a mixed oakwood, which was fairly dense (see AP + SP/NAP ratio) on the damp base-rich soils of the spring surrounds away from the unstable spring heads. A similar type of woodland might also be present on the numerous limestone outcrops, which probably existed on the fell at this time, although these were becoming increasingly limited by the encroachment of blanket peat. Quercus, Ulmus and Alnus pollen constitute the major component of the pollen spectra, although Tilia and Fraxinus pollen is present and Pinus pollen has a small but continuous occurrence. Corylus no doubt existed as an understorey to this canopy of Quercus, Ulmus and Alnus and also existed with Betula between the areas of richer woodland, blanket peat and unstable habitats, not capable of supporting either woodland or blanket peat, perhaps to the summit of Mickle Fell.

The high Gramineae and Cyperaceae frequencies, in addition to reflecting the grassy nature of the local herb flora, may also demonstrate the fairly open nature of the vegetation at this time between the dense patches of woodland.

The presence of Calluna charcoal and quartz fragments throughout the Atlantic period is a marked feature of the peat at this site. This is the product of burning, which appears to have had little immediate effect on the local vegetation. As the charcoal is in the basal layers of the peat, it may have existed prior to the start of peat growth and become incorporated later into the organic deposits along with the quartz fragments; therefore, the burning may have had little effect on the vegetation whose composition is reflected in the pollen spectra. The results of this apparently continual process are more noticeable higher up the profile, although it might be suggested that burning might initially have induced peat growth at this site by destroying the vegetation cover, thus promoting more rapid leaching of the soil and changing the water balance (see Chapter 12.3) in a similar manner to the inception of peat growth at Cronkley Pastures (Chapter 7).

2. Human interference (Post Atlantic times).

The quartz fragments which were present in the basal layers of the peat, disappear and Eriophorum fibres appear at 200 cm pointing to the build-up of peat around the springs resulting in more oligotrophic conditions than formerly (stage 2). The unstable base-rich habitats around the springs therefore, became more stable with a covering of acid peat and there was a consequential reduction in the variety of NAP which were present in VIIa. In the pollen spectra the sharp rise in the Calluna frequencies partly reflects this process.

TABLE 12. Mire Holes: Pollen Diagram Interpretation.

Zone	Stage		Bog surface	Bog surrounds	Evidence
	4			Widespread reduction of woodland areas due to blanket peat extension	
Calluna horizon					
VIIb	3	d		Limited woodland regeneration	
		c	Burning	Some burning of the local woodlands	Charcoal
		b	Oxyphilous communities, mainly Sphagnum dominated	Extension of ombrogenous peat at the expense of local woodlands and the Betula-Corylus scrub	Ombrogenous peat
		a	Drier bog communities, some burning of the surface		Pteridium and Filicales spores. Saxifraga stellaris & Ranunculus pollen. Reduction in Cyperaceae pollen Calluna charcoal
	2		Acidification of the spring head communities. Buildup of acid peat. More stable habitat	Decline of Ulmus by ?selective clearance. Extension of Alnus and Corylus	Eriophorum fibres, increase in Calluna pollen. Reduction in NAP types
VIIa	1		Spring head comms. Unstable base-rich habitat. ?Flush comms. ?Some burning of veg.	Mixed oakwoods with Corylus on the spring surrounds. Similar local comms. on the numerous lmst. outcrops. Betula-Corylus scrub over extensive areas	Carex spp. & Polytrichum spp. remains. Rosaceae, Potentilla, Rumex, Filipendula & Succisa pollen. Calluna charcoal.

At the beginning of the Sub Boreal period Quercus, Alnus and Fraxinus frequencies increase at the expense of Ulmus. The sharp nature of the decline in Ulmus frequencies is not consistent with the idea of gradual soil deterioration allowing Quercus to expand at the expense of Ulmus, neither is it consistent with increasing water levels allowing an extension of Alnus, unless here Ulmus was so critically sensitive that changed environmental conditions drastically and immediately affected Ulmus (see Smith 1965: 340). From evidence at this site the decline in the Ulmus frequencies could have been caused by the fairly widespread clearance of local woodland from the deeper loamy soils where Ulmus grew. This, allied to the high precipitation, for which evidence is limited at this site, resulted in the initiation of peat growth at this site and the start of soil deterioration in the immediate vicinity of the bog. Thus, there was a decrease in habitats suitable for Ulmus and both Quercus and perhaps Fraxinus were able to extend into its former localities, although Fraxinus might have become established on the drier, more calcareous, localities where Pinus previously existed (see Chapter 8). Alnus increased into damp situations, around springs for example, perhaps with Corylus in places.

The great increase in the Calluna frequencies point to the extension of blanket peat during the Sub Boreal period. If part of this rise reflects local conditions, it might be suggested that the clearance of Ulmus was purely local especially since the values it attains after its decline appear to reflect its presence in remaining suitable localities. Thus, two processes may have affected the vegetation at the start of zone VIIb, although there is only inferential evidence:

a. The selective clearance of Ulmus, initiating local bog growth and resulting in increased local Quercus, Alnus and Ulmus.

b. The continued soil deterioration over a larger area resulting in the spread of Calluna perhaps under the Betula-Corylus scrub or the oakwoods, in addition to the increased moorland (i.e. moorland as defined in Chapter 3.2).

After the initial rise in the Quercus frequencies (195-190 cm) both Betula and Corylus frequencies increase, suggesting continuing soil degradation proceeding to affect the areas where Quercus and perhaps Calluna already existed on poor soils.

Calluna charcoal again occurs at 170-150 cm in a peat which is still dominated by monocot remains. At 160 cm the AP + SP/NAP ratio declines and Plantago lanceolata, Plantago major/media and Pteridium aquilinum all have temporary peaks. One explanation of this phenomenon could be that the bog surface and surrounds became drier, reflected by a fall in the Cyperaceae frequencies, and allowed the above species along with Saxifraga stellaris, Ranunculus spp. and Filicales to become established on the bog surface and surrounds (stage 3). Above this however, Sphagnum remains are frequent in the peat and Sphagnum frequencies rise which would appear to contradict this explanation (stage 3(b)). Also, tree curves are temporarily affected and this, along with the presence of charcoal, suggests human interference in the limited local woodland.

Quercus and Corylus frequencies decline whilst both

Fraxinus and Calluna frequencies rise. If this process again reflects local conditions, as is suggested, then this pattern indicates that some clearance of the Quercus dominated soils took place, away from the very damp areas where Alnus might be dominant and away from the drier areas where Fraxinus was present (stage 3(c)). From the pollen spectra this local clearance appears to have enabled Plantago spp. and Pteridium to become established and also Helianthemum sp. on the bare ground created by the burning.

Following this clearance phase the local woodland regenerated, although the Quercus frequencies rise slowly and never regain their former values (stage 3(d)). Although there is no evidence to suggest any reduction in the postulated widespread Betula-Corylus scrub, there must have been some reduction in the distribution due to blanket peat growth. Alnus and Fraxinus frequencies increase initially after the clearance indicating that both species were able to take advantage of the decreased Quercus competition and colonise the cleared areas more quickly than Quercus. This is consistent with the idea that the Quercus dominated vegetation did exist on intermediate soils between the Alnus dominated and Fraxinus dominated soils as suggested above.

These fluctuations however, are secondary to the general trend of decreasing tree cover as portrayed by the declining AP/NAP ratio. By the end of zone VIIb this ratio indicates that few trees existed on the fell top, although the increased Quercus and Betula values at 130-120 cm suggest that drier conditions might have allowed these species to increase at the expense of Alnus and Corylus in a few isolated localities.

This same pattern can be seen in the *Calluna* curve, which also rises (stage 3(d)).

The declining AP + SP/NAP ratio, which started during Atlantic times, becomes more pronounced, after the *Calluna* horizon when all trees and shrubs are affected. The increased frequencies of Gramineae, Cyperaceae and Ruderal (especially *Plantago lanceolata*, *Rumex* and Compositae) pollen and *Pteridium* spores along with consistently high values for *Calluna*, indicates the generally deforested conditions on the fell with the gradual extension of blanket peat.

The cause of the extension of blanket peat during post Sub Boreal times is generally considered to be climatic (Godwin, 1956: 58). At this site there is also evidence for anthropogenic activity, which may have affected this process. *Calluna* charcoal is present indicating local burning at least, and whilst the AP/NAP ratio appears to indicate more or less deforested conditions, the response of the tree curve to this interference suggests localised patches of trees. Another explanation for this pattern might be that burning was a local phenomenon but that the tree curves reflect the climatic deterioration at lower altitudes. The latter explanation would appear more likely, although isolated trees have been suggested at Fox Earth (Chapter 8) at this time. The *Quercus* values are most affected by this climatic deterioration, lending support to the view put forward in Chapter 7, that oak was the last tree to be affected by the soil degradation on the valley slopes.

The increased variety of NAP types may be attributed to this local burning. If the local extension of ombrogenous peat was retarded by firing and the base status of the peat temporarily raised or the peat eroded, this increased variety of NAP might occur in addition to the decline in *Calluna* values. Conversely a reverse trend, which can be seen above 70 cm, might reflect continued moorland extension. The steady tree decline indicates that the soils and possibly climate were adverse for tree growth during this period.

The only change of note in the pollen frequencies in the topmost part of the diagram is the decline in *Calluna* values and the rise in the Gramineae curves. This points to the development of grassland near the bog, although *Calluna* dominated the vegetation.

SUMMARY

Peat growth started at Mire Holes around a springhead during the Atlantic period, and there is some evidence to suggest that this was associated with firing of the vegetation at this time, although the limited patches of mixed oakwoods do not appear immediately affected. The change in the base status of bog may be reflected in the *Ulmus* decline, but is symptomatic of the process of blanket peat growth in the Reserve. There is ample evidence for continued human activity in the very limited local woods of *Quercus*, *Betula*, *Alnus* and *Corylus*, which eventually caused the extension of blanket peat and may have led to the development of the grassland areas which can be seen at the top of the diagram.

Chapter 10. LONG CRAG (profile L1)

Grid reference:	NY 835255.
Altitude:	2200 ft (669 m).
Sampled:	Monolith tin.
Length:	126 cm.
Diagrams:	Figs. 47-49.
Data Sheet:	8.

10.1. Site

Long Crag and Arngill Head Brocks mark the watershed between the River Lune and the River Tees drainage basins, and is the most easterly portion of land over 2000 ft (608 m) south of the River Tees (fig. 25). The area from which the samples were taken is an erosion complex, approximately 500 m^2, where isolated peat haggs and bare limestone boulders form the surface. The samples for analysis were taken from a peat hagg where the following flora were found: Eriophorum vaginatum (d), E. angustifolium, Calluna vulgaris (d), Vaccinium vitis-idaea, Empetrum nigrum, Rubus chamaemorus (r), Dicranum sp. and Cladonia spp. Where the peat had been eroded the sub-peat soil was exposed. A profile examined showed the following:

0-10 cm	Bleached limestone fragments.
10-30 cm	Yellow/ochre mottled clay with Fe. staining.
30 cm	Grey clay.

This has the appearance of a gleyed podsol resting on a solifluxion deposit. The erosion complex was slowly being recolonised by: Calluna vulgaris (d), Vaccinium vitis-idaea, Festuca sp., Poa sp., Empetrum nigrum, Juncus squarrosus, Trichophorum caespitosum, Nardus stricta (r), Eriophorum vaginatum (r), Polytrichum commune, P. juniperinum and Cladonia spp. Where the peat was newly redeposited Eriophorum angustifolium became abundant.

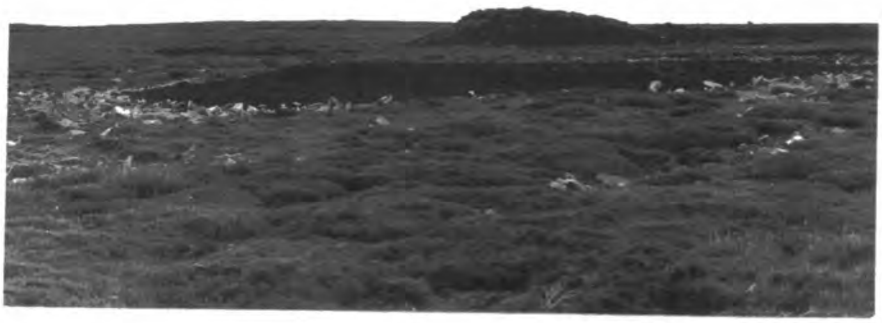


PLATE 14

Long Crag and the remnants of peat erosion at 2200 ft (669 m).

10.2. Stratigraphy

The stratigraphy recorded during sampling was:

0-20 cm

Dark brown friable fresh rootlet peat with monocot remains and Calluna twigs < 3 mm. Vaccinium leaf at 7 cm; Calluna charcoal at 10 cm. Sphagnum capsules throughout with S. magellanicum at the surface. Quartz grains at the surface.

20-41 cm

Dark brown monocot peat with many fine roots and occasional Eriophorum fibre. Often badly preserved remains. Molinia and Sphagnum recurvum at 25 cm; Molinia, Sphagnum recurvum and S. subsecundum agg. at 30 cm; Sphagnum recurvum and S. subsecundum agg. at 40 cm.

41-43 cm

Sphagnum band.

43-49 cm

Dark brown monocot peat similar to above. Calluna charcoal, Eriophorum vaginatum 'spindles' and poorly preserved Sphagnum cuspidatum and S. recurvum at 45 cm.

49-57 cm

Eriophorum peat with monocot remains and occasional Calluna twig. Poorly preserved Sphagnum recurvum and S. acutifolia group at 50 cm.

57-61 cm

Sphagnum peat with Calluna remains. Sphagnum squarrosum, S. recurvum and S. teres at 60 cm.

61-65 cm

Dark brown Eriophorum peat. E. vaginatum 'spindles' with occasional Calluna twig and fruiting head. Monocot remains and Sphagnum capsules.

65-68 cm

Sphagnum peat.

68-73 cm

Eriophorum peat.

73-92 cm

Sphagnum peat. Calluna twigs 74-76 cm; Calluna charcoal at 90 cm.

92-123 cm

Well humified monocot peat with few Calluna twigs and Eriophorum fibres. Quartz grains at 90, 120 cm; Eriophorum vaginatum 'spindles' at 95 cm; Calluna charcoal at 105, 115 cm; Juncus cf. effusus seeds at 120 cm.

123-126 cm

Minero-organic layer. A few monocot remains with some quartz grains.

10.3. Pollen Analysis

Diagram. Samples were taken for analysis as follows:

10 cm intervals 0-20 cm, 50-90 cm.

5 cm intervals 20-50 cm, 90-125 cm.

Zonation and Description

The VIIa/VIIb boundary has been drawn at 90 cm, where *Ulmus* frequencies markedly decline and there is a change in peat type. Typical Atlantic period spectra are present during VIIa with *Betula*, *Quercus*, *Ulmus*, *Alnus* and *Corylus* pollen in considerable amounts. After the *Ulmus* decrease the most notable features are the fluctuations in the tree pollen curves and the rapid rise in the *Calluna* frequencies.

The *Calluna* horizon has been drawn at 50 cm before *Calluna* reaches its maximum extension and there is a stratigraphic change.

10.4. Interpretation (Table 13).

1. The mixed oakwoods.

Organic deposition, consisting of a monocot peat, started at this site in the Atlantic period near a mixed oak woodland, in which *Quercus*, *Betula*, *Ulmus*, *Alnus* and *Corylus* were predominant. The herb flora was mainly composed of grasses and sedges, although many genera unequivocably favouring damp habitats also occurred, such as: *Succisa*, *Mercurialis*, *Valeriana*, *Filipendula*, and genera of the Rosaceae and Caryophyllaceae families (e.g. *Geum*, *Alchemilla*, *Sanguisorba*, *Malus*, *Silene*, *Lychnis* and *Stellaria* - identification was to the family level only).

The slowly declining *Ulmus* and *Corylus* curves suggests increasing moisture, reflected in a temporary peak of *Filipendula*, or soil deterioration. The presence of Calluna charcoal at 105 and 110 cm, prior to the start of the rise in Filipendula frequencies and a decline in the Gramineae frequencies, points to human activity. This charcoal occurs at a point where the Ulmus values are at a maximum and the process of firing appears mainly to affect this species and Corylus, although both Quercus and Alnus show temporarily reduced values. This suggests that Ulmus and Corylus suffered because they were growing on the richer soils although the process was severe enough to affect the trees on the poorer and damper soils. The values for Betula are higher than Ulmus which points to its existence on these upper slopes possibly with Corylus on the poorest soils, which may have had a thin peat or an acid mor cover. The small declines exhibited by both curves might reflect the start of ombrogenous peat growth.

2. Human Interference. (Post Atlantic times)

At the decline in the Ulmus frequencies the monocot peat gives way to a Sphagnum peat, which in turn is overlain by Eriophorum peat. At the VIIa/VIIb boundary both Calluna charcoal and quartz fragments are found. There is no stratigraphic evidence to suggest that there is a hiatus in the deposit, so that both the quartz and charcoal may be causally related. Burning might cause the production of bare ground from whence the quartz might be blown. Thus there appears evidence for changed water levels (the formation of ombrogenous peat) and/or soil degradation and human activity at this time.

TABLE 13. Long Crag: Pollen Diagram Interpretation.

VIIa

Damp mixed oak woodland in local patches

Extensive *Betula-Corylus* scrub being reduced by blanket peat

Burning (reduction of *Ulmus*) →

VIIb Extremely local woodland patches with *Quercus* and *Alnus* dominant

Burning/changed water levels causing widespread soil deterioration and acidification of the former vegetation communities →

Continued burning →

***Calluna* horizon**

Blanket peat domination except in areas where
(a) base rich soils predominate;
(b) steep slopes predominate;
(c) erosion has removed the peat cover.

After the decline in these Ulmus frequencies, values for the tree still remain high enough to suggest that it remained present in favourable localities. Both Quercus and Alnus reach their maximum values, perhaps aided by interference and soil deterioration, and Calluna becomes strongly represented with declining Gramineae and Cyperaceae frequencies. This probably reflects the increasing growth of blanket peat which at this time was probably extensive (nowhere in the Reserve was the blanket peat found to have a post-VIIa inception), and the increasing podsolisation of the soils which, as suggested above, might have been helped by human actions. The net result would be an increase in Calluna, which could have become the dominant ground cover underneath any of the local patches of woodland. The presence of charcoal fragment in the peat does not necessarily indicate actual burning of the peat surface in this locality, especially since there is no reason to suppose the charcoal, which is consistently found in the blanket peats, was synchronously deposited. The presence of both these fragments and quartz grains, which are found stratified in the peat, may have been deposited by the wind. If a fairly extensive Betula-Corylus scrub cover with localised patches of trees is envisaged then burning would inevitably cause a reduction in the AP/NAP ratio. This does not occur, there is apparently no decline in the tree cover, which suggests that at this altitude at least trees were extremely localised and burning did not affect these, rather burning affected already open areas.

The process of burning thereby aiding podsolisation and increasing Calluna domination in the pollen spectra which indicates increasing blanket peat growth, may be independent of each other. Increasing Alnus frequencies suggest some change in the moisture content. In the light of the firing not affecting Alnus, this suggests that this change was independent of anthropogenic activity. Such an increased moixture content might account for the declining Betula and Corylus frequencies, the scrub areas becoming overwhelmed by blanket peat.

Plantago lanceolata appears for the first time after the decline in Ulmus frequencies and its peak at 73 cm coincides with a Calluna peak, whilst Gramineae frequencies slowly rise, as do Pteridium frequencies. This pattern may well be caused by human activity.

At the Calluna horizon (50 cm) a monocot peat which contains Nardus remains, overlies the Eriophorum peat. More Calluna charcoal occurs at 45 cm with increased Calluna, Ruderal and Pteridium frequencies. This promotion of the growth of Calluna can be seen earlier when Ulmus was mainly affected, but here the difference is that a larger proportion of the trees appear affected, which might point to the scarcity of trees in the immediate neighbourhood (i.e. the dominance of blanket peat). After this charcoal layer, which possibly reflects the burning of woodland at lower altitudes, all trees start to decrease.

The fluctuations in the curves for the topmost part of the diagram denote the extension of blanket peat, although the AP/NAP ratio does not show the extremely low values which are found in other diagrams (chapters 6, 8, 9), probably because of wind enlarging the possible source area for grains after treeless conditions became predominant. One feature of note however, is the rise in Gramineae frequencies and the fall in Cyperaceae values, which was also found at Mire Holes.

SUMMARY

Blanket peat started to grow in Atlantic times, perhaps as a result of burning, which principally appears to have affected *Ulmus* and *Corylus*. During the Sub Boreal period further severe burning of a predominantly open vegetation accelerated the process of podsolisation, and *Calluna* became dominant with increasing blanket peat. The recent development of grasslands can be seen.

Chapter 11. BASAL SAMPLES

All basal profiles were sampled by means of a monolith tin.

11.1. Black Hill (profile B1)

Here a fairly deep peat skin overlies the irregular surface of the Whin Sill, which forms a structural bench overlooking the confluence of the River Tees and Maize Beck. A *Juncus* infested grassland covers the low watershed between two springs, whose streams flow north westwards and north eastwards. The area is eroded, especially in the immediate vicinity of the streams and small stools of birch are fairly abundant in the basal layers of the peat.

The following stratigraphy was observed:

123-129 cm
Well humified monocot peat. *Carex* nutlets, *Juncus* (cf. *effusus*) seeds and *Sphagnum* capsules.

129-133 cm
Wood fragment. *Betula* remains in a monocot peat, similar to above. *Eriophorum vaginatum* 'spindle' at 129 cm.

133-140 cm
Monocot peat with abundant *Betula* wood, few *Eriophorum* fibres at 134 cm.

140-153 cm
Humified monocot peat. *Phragmites* stem at 144 cm.

At the base of the peat immediately above the peat-Whin Sill interface, occurs a greenish-black highly amorphous peat. No pollen was found in this layer, which was mainly confined to the micro-depression in the Whin surface.

The high *Pinus* frequencies which occur in the late Boreal (zone VI) period at Dufton Moss (chapter 6) and Fox Earth (Chapter 8), are clearly shown. The low values of *Quercus* and *Alnus* further suggests a Boreal inception of peat growth, but there are anomalous features:

a. The generally low frequencies of *Quercus* compared with those of Fox Earth (1750 ft - 531 m) during zone VI.

b. The decline of *Pinus* and the rise of *Alnus* frequencies, which have been taken to indicate the Boreal-Atlantic transition (Chapters 6 and 8), occurs before *Quercus* values exceed those of *Ulmus*, which represent the boundary between subzones VIa/VIb.

Both of these features are explicable only if *Quercus* was not present during Boreal times near this site, the vegetation being composed of *Pinus*, *Betula*, *Ulmus* and *Corylus*. *Ulmus* would probably occupy the deeper soils in the main Tees valley, whilst *Pinus*, *Betula* and *Corylus* occupied the hillside.

There can be no real doubt that this profile shows a break in deposition. A highly humified peat with occasional *Phragmites* stems is overlain by a monocot peat at 140 cm containing *Betula* wood and *Eriophorum* fibres. This indicates a dry phase enabling *Betula* to become established on the bog surface reducing the Umbelliferae, *Filipendula* and fern ground cover, and allowing more acidophilous vegetation to become dominant.

This dry phase corresponds to the Boreal-Atlantic transition so that the very sharp changes in the *Pinus* and *Quercus* curves, might be a reflection of dessication during the Atlantic period. A well defined decline in the *Ulmus* frequencies occurs at 129 cm, so that the whole Atlantic period is apparently shown by 10 cm growth of peat. This means that either the entire period was dry or that initially the period was dry and evidence seems to point to the latter

TABLE 14. Details of Basal Peat Samples.

Name	Grid Reference	Altitude	Diagrams	Data Sheet	Peat Start	Ombrogenous Peat Start	Initial Common
Black Hill (B1)	NY815280	1550 ft (471 m)	figs. 44, 46A	9 100 cm = 0	VI	? VIIa/VIIb	Fen (Phragmites?)
Cronkley Fell (CF2B)	NY843287	1750 ft (531 m)	figs. 45, 46B	10 100 cm = 0	VI	? VI	Grass/sedge (burning)
Greenmines (G1)	NY 808265	1950 ft (592 m)	figs. 47, 49A	11 50 cm = 0	VIIa	VIIa	Grass/sedge
Black Band (B2)	NY809269	2010 ft (611 m)	figs. 48, 49B	12 50 cm = 0	?VIIb	? VIIb	Grass/sedge
Bald Crag (B3)	NY 814261	2010 ft (611 m)	-	Table 15	-	-	-

probability, particularly as the local *Betula* growth is curtailed during VIIa, possibly indicating rising water levels.

From this site the following conclusions appear valid:

a. Peat growth started during the late Boreal period.

b. At the end of the Boreal occurred a dry phase (this may account for the relatively low *Alnus* values during zone VIIa).

c. Throughout the Boreal and Atlantic periods tree cover was not dense at the site.

11.2. Cronkley Fell (profile CF2B)

A peat face was examined at the lakeside on the top of Cronkley Fell. The surface vegetation was dominated by *Calluna* and the peat had the following stratigraphy:

120-145 cm

Eriophorum peat. *E. vaginatum* 'spindles' frequent with monocot remains. *Calluna* twigs and charcoal at 120 cm, *Calluna* twigs at 140 cm.

145-176 cm

Monocot peat, few other remains. Occasional *Eriophorum* fibre. *Calluna* charcoal at 150 cm and 160 cm.

176-182 cm

Wood peat (*Betula*) with monocot remains and *Eriophorum* fibres. *Calluna* charcoal at 181 cm.

182-184 cm

Monocot peat.

184 cm

Irregular surface of Whin Sill.

The base of the deposit, containing a well defined wood layer, has been assigned to zone VI and a clear VI/VIIa boundary can be seen. In zone VI fairly dense *Corylus* woods appear prevalent with local *Betula* and some *Pinus*, *Quercus*, *Ulmus* and *Alnus*. The *Calluna* charcoal at the base poses the questions whether the burning was natural or not, and whether this burning might have caused peat growth. The further presence of Calluna charcoal at 160 cm and 150 cm, which coincides with the start of the Atlantic period and the start of the decline in Ulmus frequencies, might point to human interference which may have helped changes in the base status of the peat, which is reflected in the growth of the Eriophorum peat.

11.3. Greenmines (profile G1)

This site is near an old mine working. The peat sample was taken from a peat face where erosion was fairly widespread. The stratigraphy showed:

92-110 cm
Well humified Eriophorum peat, increasing monocot amount with depth. Sphagnum capsules, Juncus sp. seeds and Calluna twigs at 105 cm. Occasional quartz grain throughout and occasional Betula fragment.

110-115 cm
Minero-organic layer. Quartz mixed with monocot peat. Few remains include: Sphagnum capsule, Juncus sp. seeds, Eriophorum fibres and humified Calluna twigs.

115 cm
Inorganic sediment with some unweathered parent material. Only remains, few monocot and Juncus sp. seeds.

The diagram has been tentatively divided into zones VIIa and VIIb at 110 cm. The main features are:

a. The high Pinus frequencies in the basal sample.

b. The declining Alnus and Corylus frequencies and the rising Calluna values.

c. The stratigraphic change at the proposed VIIa/VIIb boundary.

Both the high Pinus frequencies and the values for Fraxinus appear consistent with the view of both growing on the drier limestone soils. The Alnus and Corylus values declining in the face of increased Calluna values, suggests an extension of blanket peat which appears to have started as a humus at this site. The ombrogenous Eriophorum peat perhaps started in response to continued high precipitation.

11.4. Black Band (profile B2)

A sample was taken from a peat hagg at the foot of the north slope of Mickle Fell. Here the stratigraphy was:

82-113 cm
Well humified monocot peat. Betula at 100 cm. Frequent remains of Carex sp. and Equisetum.

In the absence of any stratigraphic features or pollen analytical features, the entire diagram is designated as zone VIIb.

11.5. Bald Crag (profile B3)

An extremely eroded area of peat was examined and samples taken from a peat hagg to analyse a structural feature in the peat, which had the appearance of a recurrence surface. Only four samples were taken. The stratigraphy was:

25-42 cm
Relatively unhumified Sphagnum peat. Calluna twigs at 35 cm.

42-56 cm
Monocot peat with Calluna and Eriophorum remains. Eriophorum (d) below 49 cm.

The pollen record shows typical zone VIIb spectra with high Quercus, Betula and Alnus values and low Ulmus frequencies with the occurrence of Fagus pollen. The declines in the Alnus, Corylus and Calluna curves coincide with the marked stratigraphic change and rises in Betula, Gramineae and Cyperaceae frequencies. This points to increased moisture causing renewed growth of an area of blanket peat.

TABLE 15. Bald Crag Pollen Data: actual pollen counts (chapter 11.5)

	Depth (cm)			
	35	40	44	49
Betula	126	124	50	51
Pinus	1	0	1	5
Quercus	53	35	49	41
Ulmus	7	4	10	13
Tilia	1	0	0	1
Fagus	1	3	x	0
Fraxinus	8	17	7	8
Alnus	52	51	102	124
Salix	2	7	2	1
Coryloid	107	65	160	223
Ericales	59	133	305	403
Gramineae	76	98	50	47
Cerealia	1	1	0	0
Cyperaceae	84	90	45	81
P. lanceolata	10	17	8	16
P. major/media	1	0	0	0
Rumex	9	5	3	3
Chenopodiaceae	1	0	1	2
Artemisia	1	2	0	0
Umbelliferae	2	2	1	0
Comp. Tubuliflorae	0	1	0	1
Comp. Liguliflorae	0	1	0	0
Rosaceae	4	2		1
Potentilla	1	3	1	0
Rubiaceae	1	1	0	0
Cruciferae	2	1	1	1
Mercurialis	1	0	0	0
Ranunculus	2	1	2	0
Filipendula	3	19	2	0
Polypodium	1	0	1	3
Filicales	7	2	5	10
Pteridium	5	5	23	14
Sphagnum	32	1298	39	200

11.6. Mickle Fell (profile K1)

Grid reference: NY 810249.
Altitude: 2450 ft (745 m).
Length: 92 cm.
Diagrams: Figs. 50-52.
Data Sheet: 13.

An erosion face on the northern slopes of the fell was taken as representative of the blanket peats at this altitude. The cover of blanket peat is variable, usually less than 1 metre thick and occurs in patches, a feature which Hornung (pers. comm.) attributes to erosion. Shimwell (1968) pointed to the influence of superficial deposits (probably solifluxion detritus) in forming a brown calcareous soil in parts and carrying Festuco-Poetum communities (chapter 3.2), which markedly contrasts with the Eriophoretum-Caricetum communities of the thin blanket peat. The following species were recorded at the place of sampling: Eriophorum angustifolium, E. vaginatum, Carex bigelowii, Vaccinium myrtillus, V. vitis-idaea, Rubus chamaemorus, Empetrum nigrum, Juncus squarrosus, Sphagnum rubellum, S. recurvum, Polytrichum strictum, Hypnum cupressiforme, Dicranum scoparium, Rhytidiadelphus loreus, and Cladonia uncialis. On other parts of the summit on the blanket peat, Festuco rubra and Deschampsia flexuosa are more abundant, especially on the more southern aspects. Shimwell (pers. comm.) suggests these areas might indicate a more degraded 'grassland' due to the extensive sheep grazing, although they may form transition communities between the Festuco-Poetum communities and the Eriophoretum-Caricetum communities.

The following stratigraphy was recorded:

0-5 cm

Dark brown monocot peat. Polytrichum strictum remains at the surface. Calluna twigs and Carex sp. nutlets present.

5-80 cm

Mid-brown Sphagnum peat with monocot remains and Eriophorum fibres throughout.

5 cm	Sphagnum magellanicum (d), S. tenellum and S. subsecundum.
10 cm	Sphagnum recurvum (d), S. rubellum and S. palustre.
15 cm	Eriophorum vaginatum 'spindles', well preserved Sphagnum recurvum, S. cuspidatum and S. plumulosum.
20 cm	Eriophorum vaginatum 'spindles', Juncus cf effusus seeds and Sphagnum papillosum.
25 cm	Sphagnum papillosum and S. cuspidatum.
30 cm	Sphagnum recurvum and S. cuspidatum.
35 cm	Sphagnum recurvum, S. plumulosum, S. cuspidatum and Polytrichum commune.
40 cm	Sphagnum recurvum (d) and Polytrichum commune.
50 cm	Calluna twigs, Sphagnum recurvum and S. plumulosum. Humification change at 51 cm, more humified below.
60 cm	Sphagnum recurvum (d), S. cuspidatum, S. tenellum and S. plumulosum.
70 cm	Calluna twigs, Sphagnum cuspidatum and S. rubellum. Monocot remains increase downwards, Sphagna show the reverse trend, being almost absent at 75 cm. Occasional quartz grain at 75 cm.

80-89 cm

Well humified dark brown monocot peat. Eriophorum vaginatum 'spindles' at 85 cm with small Calluna stems.

89-92 cm

Organo-mineral deposit, quartz and monocot remains.

A clear Ulmus decline can be seen at 70 cm which delimits VIIa/VIIb. No Calluna horizon is distinguishable as the frequencies for Calluna are consistently high.

This profile has been included within the chapter on basal profiles simply because it is not known how much reliance can be placed on the pollen curves reflecting relatively local changes, especially in view of its altitude and aspect.

The main features of the diagram are:-

a. The Atlantic inception of peat growth.

b. The fairly high AP + SP/NAP ratio during VIIa.

c. The high Calluna values in VIIa.

d. A re-establishment of Ulmus after its decline.

e. The relative scarcity of Fraxinus during zone VIIb compared with Fox Earth and Mire Holes.

f. The sharp decline of Alnus at the secondary Ulmus decline and the increase in ruderals, Pteridium and Gramineae frequencies.

SECTION C.

DISCUSSION AND CONCLUSIONS.

Chapter 12. DISCUSSION

In the General Introduction the reasons for the Post Glacial survival of the rare plants for which Teesdale is famous were propounded. Although little direct evidence for these rare species (e.g. macro-remains, leaves etc., or pollen grains) has been found in the palaeoecological investigations, the evidence presented by these investigations allows a statement to be made on the Post Glacial vegetation development of Cronkley and Mickle Fells and the Upper Tees valley around 1300 ft (395 m). The processes which modified vegetation in the Post Glacial period (i.e. the spread of forests, the development of ombrogenous peat and podsolisation) are of obvious importance in the development of the present distribution of vegetation, and therefore discussion is properly along these lines. In the following chapter the spread of the woodlands in the Boreal and Atlantic periods is discussed, the formation and extension of blanket peat is postulated and evidence for human activity is discussed in the light of the known, albeit fragmentary, prehistory and early history of the valley, described in chapter 3.3.

The discussion suffers from three main disadvantages, firstly, the lack of radiocarbon dates, which would enable features of the diagrams to be directly comparable with those of diagrams from other areas, secondly, the lack of prehistoric remains in the area (see chapter 3.3), and thirdly, the lack of documentary evidence. Both prehistoric remains and documentary evidence would complement the following speculations on the early history.

12.1. The Boreal Period

This so called early warm period (see Godwin 1956: 326) was characterised by forest expansion and migration under increasing temperatures. Although it is 'not clear what the forest composition was ' (see Pennington 1964: 49) in general the successive features of the period were: the strong expansion of hazel, the extension of pine into the Pre-Boreal birch dominated woodland and the onset of the displacement of pine by oak and elm. Throughout zones V and VI pollen diagrams from varying localities show great diversity, which Pennington (1965) attributed to soil differences. This diversity has led Smith (1965) to conclude that neither the distribution of the various species, nor their succession in response to the increasing temperatures, was simple.

Zone V, dated as 7600 BC-7000 BC (Godwin 1960)[2], was relatively short and Bartley (1966) suggested that in Northumberland this was a transition period between the establishment of the birchwoods and the immigration of hazel. At Moor House in Teesdale, Johnson (1963) concluded that trees started to grow in favourable localities during zone V. Zone VI, dated as 7000 BC-5500 BC (Godwin 1960), was the main period of the immigration of forest species in the Pennines and by the Boreal-Atlantic transition scattered woodland existed up to 2500 ft (760 m) (Godwin and Clapham 1951; Johnson 1963), whilst in the Lake District oak, birch, elm and hazel were present up to 1700 ft (517 m) (Pennington 1964).

In Upper Teesdale organic deposition started in persistently waterlogged habitats such as depressions, typified by Dufton Moss and Fox Earth, or on hillside structural benches, typified by Black Hill (see also Johnson 1963: 144), where Phragmites reed swamp became prevalent during zone V. If fig. 29 may be regarded as indicative of zone V vegetation (chapter 6.4, table 8) open birch woods were predominant in the valley around 1200 ft (365 m) with immigrating hazel and pine. This is consistent with the pictures found elsewhere in northern England. Although there is no direct evidence for the same vegetation on the tops of Cronkley and Mickle Fells corroboratory evidence is provided by Johnson (1963), who concluded that birch, with willow and juniper, formed a light forest up to about 2500 ft (760 m) on the Moor House N.N.R. On the slopes and summits of the Cross Fell area the early presence of oak, elm and pine pollen has been attributed to long distance transport rather than the actual growth of these species (Godwin and Clapham, 1951).

The main features of the Boreal period, as shown in the deposits of this age which were examined (i.e. figs. 25-29, 35-37), were:

a. A hazel maximum in subzone VIa at Dufton (fig. 25).

b. The strong expansion of pine during subzone VIa with a subsequent gradual decline in the composite subzone VIb + c at Dufton (fig. 25) and during subzone VIc with a subsequent decline at the Boreal-Atlantic transition at Fox Earth (fig. 36).

c. Rising but fluctuating water levels during the late Boreal.

d. Increasing thermophilous oak and elm representation in the pollen spectra during the late Boreal (Dufton subzone VIb + c, Fox Earth subzone VIc.)

Hazel.

From the limited evidence presented in section B, it is apparent that hazel immigrated into open birch woods in the Upper Tees valley during zone V, and by the start of zone VI had achieved its maximum Post Glacial values. There is no evidence to suggest that during its expansion it prevented birch regeneration, as Iversen (1960) concluded, rather that it formed extensive woods with birch (fig. 29 and table 8). This early zone VI maximum of hazel has also been found at lower and higher altitudes in Teesdale than the altitude of Dufton. Pollen diagrams from Romaldkirk (660 ft: 200 m) (Bellamy et al., 1966), Moor House (1800 ft: 547 m, 2250 ft: 684 m) (Johnson, 1963) and Cross Fell (2250 ft: 684 m) (Godwin and Clapham, 1951) all show a similar pattern of hazel immigration so that it may be assumed, in the absence of direct pollen analytical evidence, that hazel extended to considerable altitudes on Cronkley and Mickle Fells during its maximum although, as Seddon (1962) pointed out in Snowdonia, there might have been some altitudinal limit.

This early hazel maximum has been generally related to maritime conditions with mild climatic gradients (Godwin, 1940, 1956; Moore and Chater, 1968) and favourable soils. The hazel is presumed to have outstripped the more thermophilous oak and elm on the mull or fresh calcareous soils, where there was little competition from birch. Evidence from Dufton tentatively supports this. During the early part of zone VI in Teesdale there would probably be an abundance of fresh calcareous soils. The calcareous boulder clay (see chapter 2) would perhaps be unconsolidated because only during the latter part of the zone V do the final stages of Post Glacial solifluxion occur (see Godwin and Clapham, 1951)[3]. Furthermore, recent work suggests that a hiatus occurred in inorganic deposition between zones III and V on Widdybank Fell (Hewetson unpub.), probably due to pre Boreal solifluxion, which points to the unstable conditions favourable for the production of fresh soils and thus allowing the rapid expansion of hazel. From the evidence at Dufton (fig. 29) hazel immigration may have been aided by the firing of the vegetation, which could have accentuated already unstable conditions. The exact status of the shrub cannot be determined from the diagram and although Pennington (1964: 49) suggested that pure hazel woods might have existed in certain localities, it probably existed with birch in a large number of places (table 8).

An early (zone VI) hazel maximum has been found throughout northern England, from the Northumberland coast (Bartley, 1966) to the eastern flanks of the Pennines (Blackburn, 1953), from south Lancashire (Oldfield, 1960) to the Lake District (Pennington, 1964; Walker, 1965) and also from the southern Pennines (Pigott and Pigott, 1963). It is such a consistent feature in many diagrams that Walker (1955) used its rising frequencies to demarcate the V/VI boundary. However, despite this general picture local variations have been found in northern England. In Cumberland the maximum hazel frequencies persist throughout zone VI (Walker and Lambert, 1965), whilst in Northumberland Pearson (1960) described a zone V maximum which he attributed to the presence of local gulleys offering suitable habitats for the early increase of hazel. Perhaps the most striking disparity between the hazel records of neighbouring sites occurs at Burtree Lane and Neasham, both in the lower Tees basin. At Burtree Lane a more 'normal' early zone VI hazel maximum is found (Bellamy et al., 1966) but at Neasham, eight miles to the south-east, hazel frequencies never reach more than 10% of the tree pollen (Blackburn, 1952). Therefore, sudden areal changes in the vegetation, as portrayed in the pollen spectra, are not uncommon during zone VI and while the evidence presented in Section B suggests a vegetation which is similar to the vegetation found elsewhere in northern England at this time, the complete picture may, not be as simple.

Pine.

Pine expanded into the early zone VI birch-hazel woods of the Upper Tees valley. Although the tree was present earlier (i.e. in zone V) it established itself, along with limited amounts of oak and elm, under an ameliorating climate and rising water levels, and became a major constituent in the valley woodlands late in subzone VIa (fig. 25, table 8). In these woodlands it expanded at the expense of hazel and despite its early expansion being precarious (see chapter 6.4) formed closed birch-pine woods, possibly with a hazel understorey. After its maximum extension in VIa the species declined throughout the composite subzone VIb + c in the valley woodland as it was competed out by increasing oak and elm and migrated into high altitudes.[+] This process of pine migrating onto the fell top can clearly be seen at Fox Earth Gill, where it became established in subzone VIc (fig. 35, table 11). Once there it expanded at the expense of birch and hazel into areas where oak and elm were already present. However, neither oak nor elm are affected by this process which suggests that pine and oak and elm occupied different areas, probably influenced by edaphic differences.

The late Boreal marks the time of the greatest variety of trees in the woodlands of the area, both in the valley and on Cronkley Fell, and possibly marks the time of the greatest competition for available space. The unstable environmental conditions, which are evident at this time, probably affected the disposition of the vegetation, although how it is not certain. Both at Dufton (table 7) and Fox Earth (table 10) the varying peat types indicate fluctuating water levels with a slowly changing base status, whilst the increasing deciduous component of the woodland, particularly in the valley, perhaps reflects increasing temperatures. On Cronkley Fell, where pine and oak dominated the vegetation in certain localities during subzone VIc (Table 11), both appear to invade the drier limestone soils under conditions of increased moisture, at the expense of birch and hazel (chapter 8.4). Thus, at the end of the Boreal period the following vegetation zones existed in Upper Teesdale.

a. A mixed oak woodland (see 2 below) in the valley.

b. A birch-hazel scrub on the fell top up to the altitudinal limit of tree growth. Johnson (1963) put this at 2500 ft (760 m) although no evidence has been found to confirm or refute it.

c. An intermediate zone where oak, elm,pine and alder existed. The distribution of these appears to be governed, not by altitude, but by the presence of suitable soils.

d. Swampy hollows dominated by reedswamps which occurred in all of the above zones.

It is usual to interpret the pine maximum as a response to dry 'continental' conditions (Godwin, 1956; Oldfield, 1965). In the Reserve however, there is abundant evidence to suggest slowly rising but fluctuating water levels. These are most apparent at Fox Earth (fig. 35, table 10). As Oldfield (1965) pointed out the distribution of present British pinewoods does not bear out this theory of continentality and both he and Birks (1964) noted rising water levels coincident with a subzone VIc maximum of pine in Cheshire and Lancashire, which followed a period of reduced water levels. Although it may be argued that Fox Earth and Dufton (fig. 25), which both show increasing water levels throughout the Boreal period, might reflect only local conditions, Johnson (1963: 144) also noted the same process in the Upper Valley Bog at Moor House, where an organic detritus mud gave way to a *Carex*-*Phragmites* peat. This suggests that rising water levels were of a fairly widespread nature at the end of the Boreal period in northern England, although further confirmatory evidence is required.

The pattern of the immigration of pine into higher altitudes on the Reserve in subzone VIc is at the expense of birch and hazel, although as pointed out (table 11 above) oak and elm were both already well established in localities on Cronkley Fell at least to an altitude of 1700 ft (517 m). Because of this pine appears to become a calcicole, an occurrence which is analoguous with present-day pine communities in the Champagne (Salisbury, 1920: 207; see also McVean, 1963, Oldfield, 1965). The same pattern of pine extending at the expense of birch and hazel can be seen at Thrang Moss (Oldfield, 1965). Whilst Oldfield made no suggestion of a mechanism for pine immigrating into an apparently well established deciduous woodland in north-west England, evidence from Dufton and Fox Earth suggests that rising water levels enabled pine to compete successfully with birch and hazel on the drier soils rather than competing against the well established oak and elm. Evidence from Lowland Lonsdale is not entirely inconsistent with this hypothesis which thus avoids the question of any biotype of pine existing during the Boreal period which has been suggested by Oldfield (1965) to explain the expansion of pine at this time. Under conditions of increased moisture pine might have the competitive ability to expand at the expense of the Pre Boreal and Boreal birchwoods (see McVean, 1963). Evidence which supports this occurs near the VI/VII boundary at Fox Earth (fig. 35), where the bog surface appears to dry out and the pine frequencies start to fall. This suggests a reversal of the process which occurred early in subzone VIc (i.e. a fall in water levels resulting in the decline of pine on Cronkley Fell).

The tentative date for the fall in the pine frequencies on Widdybank Fell, 4200 $\pm$ 160 BC (Hewetson unpub.) is consistent with the date shown by Oldfield for the same phenomenon at Silverdale Moss in Lancashire, and although the vegetational histories of Cronkley and Widdybank Fells may be dissimilar in certain respects, the general agreement for a subzone VIc pine maximum at altitudes of around 1700 ft (517 m) on both fells might suggest a similar date for the pine maximum on Cronkley Fell. This date is approximately 700-1500 years later than the same period in southern England, and would seem to point to a northward expansion of pine during the Boreal period. This expansion is clearly reflected in the altitudinal migration of the pine maximum in Teesdale[4].

Burtree Lane	(250 ft 77 m)	V-VI	(Bellamy *et al*., 1966).
Romaldkirk	(660 ft 200 m)		(Bellamy *et al*., 1966).
Dufton	(1200 ft 368 m)	VIa	(chapter 6 above).
Fox Earth	(1750 ft 531 m)	VIc	(chapter 8 above).
Valley Bog	(1800 ft 547 m)	VIc	(Johnson, 1963).
Hard Hill	(2250 ft 684 m)	VI	(Johnson, 1963).

At Moor House a pine maximum has also been noted in subzone VIc (see above) both at 1800 ft (547 m) and 2250 ft (684 m) (Johnson, 1963), although the presence of the tree at 2250 ft (684 m) is doubted because of the low values which the pine curve shows; above 1800 ft (547 m) on the Pennine Escarpment the pine maximum has been attributed to long distance pollen transport reflecting the pine dominance found at lower altitudes (Godwin and Clapham, 1951). This late maximum of pine is common in the north of England (Godwin, 1956: 280) whilst Hyde (1940), Godwin (1955), Seddon (1962) and Moore & Chater (1968), all noted the same phenomenon in the mountains of Wales. This contrasts with the early VI pine maximum in southern and eastern England.

Just as the nature of the hazel curves from various pollen diagrams indicate that there is no simple regional picture of the Boreal vegetation, similar indications are afforded by differences in the nature of the pine curve from various localities. Abundant evidence from a variety of sites suggests that local differences in topography, and hence soil and drainage, made the above picture more complex. For example, in the Tees drainage basin at Romaldkirk, no pine maximum can be seen whilst a zone VI maximum occurs at Burtree Lane (see above). The consistently high AP:NAP ratio and high oak and elm values at Romaldkirk perhaps point to pine not being able to establish itself at this site because it was unable to compete with oak and elm, whilst at Burtree Lane it became established where there was a less dense tree cover. Deviations from a simple immigration of pine which species took over from birch and hazel have been noted by many workers (e.g. Walker, 1966; Walker and Lambert, 1955; Pearson, 1960; Pennington, 1964; Moore and Chater, 1968) who all suggest local factors to account for the various features in the Boreal pollen curves. From an examination of the available data however, it is clear that on the eastern side of the Pennines at least pine became more important as a constituent member of the late Boreal woods in upland areas than in lowland areas (Blackburn, 1953; Bartley, 1966; Turner unpub.), although many local variations can be found.

From the above discussion of the late Boreal period it is clear that differences between the pollen curves is dependent to a large extent on local factors. Throughout the period rising water levels and temperatures enabled hazel, pine, oak and elm to expand but the exact manner of their expansion appears to have been due to the presence or absence of favourable soils. Thus, elm and oak expanded into the early Post Glacial birch-hazel woods at high altitudes and certain valley locations (e.g. Romaldkirk) where suitable soils were present, before the establishment of pine (see Iversen, 1960).

12.2. The Atlantic Period

The Atlantic period, which lasted from 5500 BC-3000 BC (Godwin, 1960), and late zone VI, are generally known as the time of the Climatic Optimum (Godwin, 1956: 330), although Faegri (1940, 1944) regarded the Sub Boreal as such and Conway (1954) considered the term inapplicable to those areas where a notable feature of the development of the vegetation at this time was the replacement of woodland by ombrogenous peat (e.g. upland areas). Iversen (1944) concluded that during this period in Denmark the July mean temperatures were 1.5 °C higher than they are today, whilst Degerbøl and Krog (1951) showed that summer temperatures were 2 °C higher in zones VIIa and VIIb than at present. The reason for these maximum Post Glacial temperatures has been attributed to a northerly shift of the depression track crossing the Atlantic (Lamb, 1965).

This was the time of the maximum expansion of forest trees (Godwin, 1956: 330; Moore, 1966), when the woodlands, instead of being subjected to continual reassortment as they were in the Boreal period (see 1 above) became more stable (Walker, 1965). In addition to this stability of the natural dominants of the vegetation the Atlantic period was characterised by the rise of alder as a major component of the woodland, the inception of ombrogenous blanket peat over wide areas and the expansion of lime, which is the most exacting of our forest trees in terms of its climatic requirements, even in northern and western England (Blackburn, 1953; Walker, 1955; 1956; Godwin, Walker and Willis, 1956; Pennington, 1957; Smith, 1958, 1959). Although the maximum extension of the predominantly deciduous woodlands during the Atlantic period, was variable from locality to locality, Godwin (1955), Donner (1962) and Pennington (1964, 1969) all suggested that woodland was present on well drained mountain slopes up to 2500 ft (760 m).

From the evidence presented in Section B it is possible to divide the sites examined into three categories, firstly, those on the fell top which show evidence of the initiation of blanket peat during the Atlantic period, secondly, the valley floor site (Dufton Moss) which shows a well developed dense mixed oakwood at this time, and thirdly, a valley slope site where organic deposition started after the Atlantic period.

One of the major features of the diagrams from Dufton Moss (chapter 6, figs. 25-29) and Fox Earth (chapter 8, figs. 35-37) is the gradual rise in the alder curve which coincides with the decline in the pine frequencies. This feature has been used to denote the boundary between zones VI and VII. In other diagrams, which start during the Atlantic period, alder values are already high.

Alder.

Before the expansion in the Atlantic period alder was present in limited amounts both in the valley and on the fell top (figs. 25 and 35, tables 8 and 11) probably in localities with a high ground water content. This feature of early alder establishment has also been found in other parts of Teesdale (Johnson, 1963; Bellamy et al., 1966) and elsewhere in northern and western parts of the British Isles in the Boreal period (Jessen, 1949; Mitchell, 1951; Fraser and Godwin, 1955; Durno, 1956; Donner, 1957; Franks and

Pennington, 1961). Therefore, it is likely that alder was established in certain localities on the Reserve prior to the Boreal Atlantic transition and expanded from these isolated localities in zone VIIa.

Firbas (1949) ascribed this expansion to the following factors, firstly, increased temperatures which raised the tree limit on mountains, secondly, increased rainfall and decreased evaporation thereby increasing surface soil moisture, and thirdly, rising sea levels. Whilst McVean (1956) pointed out that autecological studies had largely verified that alder did expand under these changed circumstances, he showed that any destruction of, or interference with, the existing vegetation by climatic or biotic agencies would also aid in the expansion of the species. Against these theories however, he pointed out that all these climatic factors have a bearing on seedling establishment, therefore altered temperature and rainfall conditions were not likely to result in alder expansion. Similarly, any extension of the altitudinal limits were likely to favour all species not merely alder. Not all aspects of the Atlantic climate were favourable to the propagation of alder, the occurrence of late frosts after seed germination, the incidence of strong winds during flowering and the encouragement of leaching, podsolisation and the formation of raised bogs and blanket peats were all inimical to its growth (McVean, 1956). Therefore, McVean concluded that the expansion of alder appeared to 'be the result of a balance of conflicting tendencies, the various factors (biotic and climatic) replacing one another in importance with time on one site or from west to east at any other one time'.

In figs. 25 and 35 the pollen spectra show that oak and elm expanded in the Atlantic period prior to the main expansion of alder. This pattern might point to increased temperatures before alder became widespread. At Fox Earth (fig. 35) ombrogenous peat started to form on zone VIIa and at Dufton during the same period birch and heather frequencies rise whilst elm values decline. This suggests some edaphic and/or climatic agency other than increased temperatures. The possible mechanism of blanket peat formation will be discussed below but there is sufficient pollen and stratigraphic evidence to postulate that an increase precipitation: evaporation ratio, which helped in the initiation of blanket peat on Cronkley Fell, might have permitted alder to expand from its limited localities during the Atlantic period. Any destruction of the Boreal vegetation (see 1 above) might also allow alder to expand.

Increased precipitation is suggested at Fox Earth by the flooding of a substantial birch layer (fig. 35) so that on the fell top alder might have expanded in the increased wet peaty areas (see also Moore, 1966) in certain localities which also might have contained organic deposits. The restriction of the tree to certain localities on Cronkley Fell seems apparent by the nature of the pollen curves because the widespread growth of blanket peat, which is a consistent feature of the sites examined, did not affect either the rate of increase or the high frequencies which the species attains.

The destruction of the Boreal vegetation which McVean (1956) has suggested aided in the expansion of alder, may have been due to biotic or climatic factors. The presence of

Mesolithic man will be discussed later (see 4 below). Although it is acknowledged that climate allows one type of vegetation to succeed another, it is doubtful whether changes in climatic conditions can destroy vegetation (see 3 below). It has already been suggested (see 1 above) that pine was present on Cronkley Fell at 1700 ft (517 m) during the Boreal period. McVean (1963), writing on the decline of the pinewoods in the eastern Highlands during the seventeenth and eighteenth centuries, suggested that the destruction of the woods ~~were~~ was inevitable because of the deep leaching of the mineral soil following an increase in the raw humus forming species; mor humus replaced mull humus and Sphagnum spread with a concomitant decrease in soil aeration. These changing conditions he attributed to the oceanic climate. A similar set of conditions might have affected the limited areas of Boreal pine-oak woods on Cronkley Fell.

Although alder frequencies rise as pine frequencies decline evidence from the pollen spectra in figs. 25 and 35 indicate that the nature of the alder expansion in the valley and on the fell top was dissimilar as were the species alder replaced. In the valley the pollen spectra in fig. 25 indicate that pine declined throughout subzone VIb + c and oak and elm replaced it. Only after the maximum extension of oak and elm does alder strongly expand, mainly at the expense of hazel, oak, elm and perhaps pine in the few localities in which pine remained. On the fell top a pattern of alder replacing pine is more clearly shown (fig. 35), although here again oak and elm are well established. In view of the distribution of pine which is postulated during the late Boreal period to be on the drier soils (see 1 above) a simple alder-pine replacement is inconceivable. Thus a more complex process appears to have taken place, involving fluctuations in oak and elm, a process which Smith (1965) first suggested.

Under conditions of an increased precipitation and changed soil conditions alder therefore expanded during the Atlantic period; however, there is no reason to suggest that this should have been a simple process neither is there any reason to suppose the processes portrayed by the pollen spectra at any one locality reflects the complete pattern. Available evidence from the Upper Teesdale N.N.R. suggests that the replacement of pine by the deciduous elements of the vegetation was a complex process. Oak and elm initially increased as a result of the decline in pine and is the natural succession under an ameliorating climate. Alder expanded as a result of the changed climatic and soil conditions suggested above. Thus, on the fell top oak and elm might have expanded into the drier limestone soil areas where pine formerly existed (see 1 above) but would suffer contraction from the expansion of alder where the soils were deeper and/or liable to great moisture conditions. (Although these appear to be the main features of the vegetation change during zone VIIa, for which there is evidence, attention is drawn to McVean's (1956) conclusions concerning the expansion of alder).

The nature of the Atlantic woodland.

Two vegetation zones are represented in the diagrams. In the valley a fairly high AP + SP/NAP ratio indicates that woodland of oak, elm, birch, alder and hazel was prevalent. The exact nature of this is uncertain because of the limited amount of evidence (i.e. one site, Dufton). Alder increased throughout the Atlantic period, elm declined and both birch and heather expanded. This suggests that despite the overall composition of the woodland changing little, components within this woodland varied quite considerably (see also Peace, 1961).

Cronkley Fell probably carried the following vegetation (table 16):

a. Limited areas of mixed oakwood with oak, elm, birch, ash and hazel. These areas were localised around drift free limestone outcrops (see chapters 8-10).

b. Damp hollows containing alder, hazel and birch, possibly on the sides of basin peats such as Fox Earth (see chapter 8).

c. Patches of the once more extensive birch-hazel scrub.

d. Areas of thin blanket peat, encroaching on the birch-hazel scrub.

e. Areas of unstable habitats such as springheads and screes which initially remained free from blanket peat (see chapter 9).

The presence of patches of oak dominated woodland on the fell top, at altitudes in excess of 1700 ft (517 m), was almost certainly due to the limited amounts of suitable soils capable of supporting base demanding species such as elm and ash. Their limited extent is indicated by the fact that no site does the ombrogenous peat growth of the Atlantic period cause a decline in the AP:NAP ratio (figs. 35 and 39). This feature, of edaphic rather than altitudinal factors affecting the distribution of oak and elm which has also been described by Pearson (1960), Pennington (1964) and Walker (1965), means that the tree line on Cronkley and Mickle Fells during the maximum forest extension, cannot be delimited with certainty. Areas of birch scrub might easily have covered extensive tracts of these fells only to be reduced by the blanket peat. The pollen diagrams from Long Crag (figs. 41-43) and Mickle Fell (figs. 50-52) do not afford much indication. If the pollen spectra at these two sites reflect local conditions then mixed oakwoods might have existed in patches to 2500 ft (760 m), to the summit of Mickle Fell, as suggested by Donner (1962) on Ben Lawers, Pennington (1964) at Red Tarn, Helvellyn and Godwin (1955) at Cwm Idwal, Snowdonia. There is always a possibility however, of long distance transport in considerable amounts. (In this connection Dr. D. W. Shimwell and I found a mature beech leaf at approximately 2000 ft (608 m) on the slopes of Mickle Fell during the summer of 1968).

At Dufton Moss a closed woodland is apparent. The nearest site altitudinally to Dufton, which shows deposition in the Atlantic period, is the anomalous Black Hill (chapter 11.1) which apparently indicates a period of dessication early in zone VIIa. Cronkley Fell base (chapter 11.2) shows pollen analytical features similar to those at Fox Earth (i.e. the fell top rather than the valley). It is tentatively suggested therefore, that the limit of the closed woodland was below 1700 ft (517 m), although patches, perhaps extensive

TABLE 16. Schematic relationship of the postulated woodland and blanket bog on Cronkley and Mickle Fells during the Atlantic period.

Mixed oakwood: oak, elm, birch and hazel on the limestone margins.	human activity (4 below) ? natural encroachment (3 below)	BLANKET BOG
Alderwood in areas of high water levels, perhaps on a peaty substrate with birch (see McVean 1956).	natural encroachment increased water levels	BLANKET BOG
Oak-birch scrub on the margins of the mixed oakwoods where soils become more acid, perhaps because of the influence of non-calcareous drift.	human activity natural encroachment	BLANKET BOG
Birch and birch-hazel scrub on the poorest and thinnest soils at the maximum limit of tree growth.	natural encroachment	BLANKET BOG

(A discussion on the species of <u>Quercus</u> which were present is in Appendix A).

in places, existed to greater altitudes in areas of favourable soils.

Perhaps something of the nature of the fell top Atlantic oakwoods can be imagined by examining contemporary high level natural oakwoods of the Lake District and Pennines. Yapp (1953) and Pearsall (1950) described woodlands which occurred on soils of high base status up to 1500 ft (456 m). These woodlands largely comprise of oak (mainly Q. petraea), with alder in many damp areas, and often have a fringing birch scrub above. The ground flora of the highest oakwoods are not greatly different from that of the open hillside so that a whole range of woodland types, which may justifiably be termed deciduous woodland, exist at present to considerable altitudes. A similar wide range of woodland types might have existed during the Atlantic period on Cronkley and Mickle Fells, whose nature and disposition, under the most favourable climatic conditions for woodland development, would depend on the prevalent soil conditions of the period. Thus, alderwoods might exist in damp peaty depressions (see above), oak-elm-birch-hazel woods on the base rich soils adjacent to the limestone outcrops and oak-birch scrub with a moorland ground cover on the poorer soils, which had floristic similarities to the encroaching blanket peat (see Tansley, 1939: 35, Quercetum ericetosum). Because of the nature of the pollen spectra it has been suggested (section B) (and above), that much of these woodland types were of local occurrence, areas of birch-hazel scrub and blanket peat being of more widespread occurrence.

The pollen record for ash in the Atlantic period is puzzling. Ash is not a characteristic of the mixed oakwood although it is very tolerant to shading by deciduous trees (Tansley, 1939). It often exhibits calcicolous tendencies (Salisbury, 1920), and is an important pioneer species in the following situations where it forms stands rather than isolated trees (Wardle, 1961): moist well drained soils, well drained calcareous brown earth, dry rendzinas, unstable slopes, limestone pavements, and waterlogged and open habitats. Although it has been suggested (chapter 8) that the drier limestone soils might provide suitable localities for the species, the presence of other habitats has also been demonstrated. Its relative absence from the pollen spectra at Mickle Fell suggests some altitudinal limit.

A feature which has been omitted so far is the relative scarcity of lime, which characteristically expands in diagrams from other areas during the Atlantic period. This expansion is almost totally absent from diagrams from the Reserve as it is from Moor House (Johnson, 1963) although its presence is recorded. A likely explanation is that lime was never able to become established, although, at least in the Tees valley, temperatures were not inhibitory (see Simmons, 1969).

12.3. Blanket peat development

The majority of the Reserve above 1500 ft (456 m) is covered by blanket peat of varying thickness, although flush peats are common and basin peats are found at the base of Cronkley Scar (chapter 7). This extensive mantle of peat masks the topmost inorganic layers of the land surface so that variations in peat thicknesses may partly be attributed to the surface form and partly to the nature of the peat, the mode of formation and the date of cessation of peat growth.

Although most of the blanket peat is composed entirely of ombrogenous peat, in parts it is underlain by a fen peat. This feature is found in surface depressions and on structural benches (see 2 above), where a continuously high water table resulted in the formation of reedswamps and fen peat started to form some time before the more widespread development of ombrogenous blanket peat. Where fen peat is present organic deposition started during the Boreal period, whilst ombrogenous blanket peat started growing in the Atlantic period. This is consistent with other work previously done in the Pennines (chapter 3.1). Despite this agreement on an Atlantic inception for most of the Pennine blanket peats the most recent work by Tallis (1964), suggested that the exact date of the start of peat growth is metachronous in topographically different areas. The reason for this metachronous inception of peat in different, perhaps fairly adjacent, areas is not surprising in view of the mode of peat formation.

Auer (1930) attributed the local inception and growth of peat deposits to the process of paludification[5], which Godwin (1956: 30) suggested was principally affected by precipitation, evaporation and drainage factors. This process may involve one or all of the following:-

a. Paludification of depressions caused by surface water due to topographic features and soil characteristics. Tallis (1964) pointed to this process at work on the southern Pennines. Pearsall (1950) suggested that continuous leaching of upland soils in oceanic climates caused increasing acidity by podsolisation and paludification, except where the base supply was maintained by flushing or calcareous rock breakdown.

b. Paludification caused by a rise in the water levels due firstly to a change in the precipitation:evaporation ratio (Godwin, 1956; Johnson, 1963; Pennington, 1969), and secondly, to the sudden disappearance of trees. Both processes change the water economy and unless evaporation is sufficient paludification sets in and peat forms (Auer, 1930; Pollett, 1965).

c. Paludification due to the spreading of previously formed bogs. This depends on biological, edaphic and topographic factors. The process consists of the peat plants growing upwards thereby raising the water levels hence increasing paludification (see b. above) and the outward spread of peat. In this way peat extends uphill.

d. Paludification due to water flowing from peat bogs at higher altitude.

In these ways peat growth is initiated and in areas where there is a sufficiently high precipitation:evaporation ratio peat may spread over extensive areas (chapter 3.1). The surface depressions and structural benches in which reedswamp peat underlies the blanket peats could have provided a nucleus from which the peat could spread without any environmental change, even into fairly base rich localities (see Coombe and White, 1951). However, much of the Reserve at altitudes in excess of 1700 ft (517 m), which today are largely peat covered, carried at least scrubland (see 2 above and table 16) during the early part of the Atlantic period. Therefore, some change in the water economy must have taken place, either a change in the precipitation: evaporation ratio or the disappearance of the tree/scrub cover (process b. above). Such changes would have the effect of initiating peat growth and allow peat to spread from the existing nuclei.

Conway (1954) suggested that the continuous leaching of upland soils described by Pearsall (1950: 59 ff) led naturally to the replacement of woodland by ericaceous heath or bog in the southern Pennines, although the corollary is not true (i.e. leaching is a pre-requisite for bog growth) (Coombe and White, 1951). Simmons (1962) questioned whether bog could effectively displace forest while admitting that soil leaching, which caused bog formation, could prevent regeneration. In the absence of wood remains at the base of the Dartmoor blanket peats he concluded that forest did not become displaced by bog but that there was a transition between forest and bog conditions.

On the Reserve the earliest peat started to form in localities which topographically favoured the presence of surface water (chapters 6, 8 and 11.1). Although ombrogenous peat of the Atlantic period may have formed initially in small depressions as Tallis (1964) suggested, there is no direct palaeoecological evidence. Most of the blanket peat, which rests on the inorganic soil surface rather than overlying fen peat, covers a mineral soil (chapter 3.1), usually fairly strongly leached, although with little evidence of an iron pan. The lack of wood remains at the base of many of these peats suggests that intense leaching, as shown in the soil profile, caused a grandual wood-bog transition similar to that indicated by Simmons (1962).

Intense leaching may be caused by an increase in precipitation or deforestation. An increased precipitation which resulted in a changed precipitation:evaporation ratio is perhaps reflected in the increased alder frequencies during the Atlantic period (although see 2 above) and also in the presence of a birch layer in the fen peat at Fox Earth and Black Hill. But there is also evidence to suggest some deforestation occurred in the Atlantic period which might have caused an increase in leaching. A noticeable feature of many of the blanket peat on the Reserve is the presence of heather charcoal near the base. The destruction of the existing vegetation by climatic and/or biotic factors has already been suggested (see 2 above, 4 below, also McVean, 1950) as one of the reasons for the expansion of alder in the Atlantic period. This same destruction would have resulted in a changed water economy so that increased precipitation allied to some deforestation might have started local bog growth or caused a more acidophilous vegetation in those sites already occupied by organic deposits.

Once peat has started to form the communities which it supports on its surface are able to spread by raising their own water level (see c. above). Thus, in the early stages of blanket peat development a mosaic of ombrogenous peat and inorganic soils could exist at any one time, depending on the presence or absence of the factors (a-d) above. In time, with the process of increased leaching, a peat mantle would cover everywhere except in those places where an adequate base supply and drainage existed (Pearsall, 1950). Although peat might not be able to encroach upon and 'take over' woodland where there was considerable base supply and drainage, it might easily have been able to take over the areas of scrub (Pollett *pers. comm.*) which existed in Boreal and Atlantic times away from the limestone outcrops on the thinner and base deficient soils, particularly if fire was prevalent as seems likely. These scrub areas would almost certainly be shallow rooting and therefore would be liable to wind throw, which might aid in their destruction. The blanket peat probably only encroached on the patches of deciduous woodland at a later stage when some degradation of their habitat had taken place (chapters 8 & 9, 4 below).

The question of the ability of bog to destroy woodland is further complicated by the fact that under certain climatic and edaphic conditions bogs exist in the high level Lake District oakwoods (Yapp, 1953: 378), which may represent the kind of tension that existed during zone VIIa between the vegetation communities on the fell top. Thus slight changes in climatic and edaphic conditions might have resulted in some bog encroachment into woodland, perhaps involving some biotic factors which may or may not be observable in the pollen spectra or bog stratigraphy.

The majority of the remains at the base of the ombrogenous peats examined are similar. All are dominantly monocotyledonous with abundant grass and sedge remains and frequent rush fragments. This type of deposit is consistent with the development of peat from a woodland/scrub humus. The presence of heather remains and abundant heather pollen does not contradict this as a heath community may have existed under trees and shrubs during Atlantic times, just as it exists in oakwoods today (see above). The main emphasis therefore on the initiation of blanket peat appears to be on the destruction of the Atlantic vegetation rather than on a deteriorating climate, although on the poorer soils peat could probably have been the natural outcome of climatic deterioration (see also Dimbleby, 1965). If Pearsall's (1950) conclusion, that with increased leaching peat might cover extensive areas where base deficient soils and impeded drainage exist, can be regarded as valid then it is doubtful whether, without the intervention of man or some other biotic agency, those areas adjacent to the present limestone and sugar limestone outcrops would have become peat covered even with a changed precipitation: evaporation ratio. There is every reason to suggest that the process of blanket peat formation was not a simple, continuous and synchronous process and that the statement, 'with a change to wetter climate at the opening of the Atlantic period blanket peat began to form and spread until even the highest fells were peat covered' (Pennington, 1964: 124), is perhaps placing emphasis on the wrong process in this area.

12.4. The degeneration of the woodland cover

The decline of the woodland cover in Atlantic and subsequent times, especially in upland areas, has been attributed to climatic deterioration (Godwin, 1956: 340) which was contemporary with, and possibly related to, blanket peat inception (Morrison, 1956).

From the palaeoecological data in Section B speculation on climatic change as a factor in the degradation of the woodland rests on two features, firstly the inception of ombrogenous peat, and secondly the course of the elm curve. The main mechanism for blanket bog growth appears to be anthropogenic in the few sites examined, which all show the presence of nearby well established mixed oak woodland communities. In sites where peat was already growing, both in the valley (Dufton) and on the fell (Fox Earth, Black Hill) a change of peat type can be seen at a time when blanket bog started to grow extensively. The remains of more acidophilous plants in these peats suggests a change in the base status of the bog surrounds which might be caused by increased precipitation. The patches of mixed oak woodland however, appear largely unaffected, suggesting that the climate in fact deteriorated little and that factors other than climate brought about the change in the base status. Hence climate does not appear to be the dominant factor in the distribution of the vegetation at this time (see also 2 above).

The explanation of the slow decline in the elm frequencies found at Dufton Moss and Long Crag which might indicate soil degradation limiting favourable habitats for elm, should therefore be considered in terms of human activity upsetting the delicate organism-environment relationship, which it is suggested might have existed.

Features in the pollen diagrams which could be considered being due to changing climatic conditions in the Atlantic period: the irregular heather, sedge and bog moss curves at Dufton and the declining tree line at Cronkley Pastures are in fact equivocal anthropogenic features and may reflect continuing soil degradation, first started by man, under conditions of high precipitation. Similarly a gradual elm decline might reflect continued human activity. The lack of a dominant climatic control is suggested by the temporary re-establishment of trees during the Sub Boreal period at Cronkley Pastures, when the process of soil degradation was interrupted.

The increased acidophilous remains in the peat of the Atlantic-Sub Boreal period has also been found in central Wales by Moore and Chater (1968), whilst stratigraphic changes during this period have been noted by Conway (1954) in the southern Pennines and Smith (1958) in Westmorland. These are postulated to be due to the prevalent climatic conditions. However, there is no need to suggest changing climate for, as already pointed out, soil degradation might have been prevalent resulting from increased grazing pressures at a time which broadly corresponds to the Neolithic period (see Ratcliffe, 1959).

More emphasis has recently been placed on prehistoric activity[5] as a factor in woodland degeneration. It seems that man has had an important effect on the vegetation of the Upper Teesdale N.N.R. since Atlantic times. From an examination of blanket peat growth and subpeat soils on the Reserve, and comparison with other areas, it has been suggested that blanket peat commenced in response to changed soil conditions in areas where there was a delicate balance between precipitation and evaporation (chapter 3.1), as a result of climatic or anthropogenic factors (see 3 above). Despite the possibility of large areas of scrub or woodland cover being depleted by the progressive leaching of the soil at these high altitudes, some anthropogenic factor would appear to have been at work for a considerable period of time.

In many pollen diagrams from different sites the fluctuations in the pollen frequencies, caused by the gradual climatic deterioration and local bog dynamics, become involved with, and to a large extent indistinguishable from, fluctuations caused by human activity after the Atlantic period. Therefore, there is often no simple explanation of Post-Atlantic pollen curves. For example, interference on the vegetation increases the effect of a high precipitation: evaporation ratio and may result in increased leaching (see 3 above) and the formation of blanket peat. Thus, human activity becomes an integral part of the vegetation changes portrayed by the pollen spectra in this instance. Prior to the VIIa/VIIb boundary prehistoric man was assumed to have played no greater part in altering the vegetation than any other animal (Godwin, 1956), although this has been proved to be incorrect (Clark, 1954; Walker, 1956; Dimbleby, 1962; Simmons, 1964, 1969), and his effects are quite marked.

Although the nature and effect of various human activities can be seen clearly in the pollen diagrams presented in Section B, the cultures involved are problematical without radiocarbon dates. A tentative relative chronology has therefore been used:

a. Mesolithic - pre VIIa/VIIb boundary.

b. Neolithic - around the VIIa/VIIb boundary.

c. Bronze Age - zone VIIb.

d. Iron Age - immediately preceding the Calluna horizon.

e. Roman - immediately postdating the Calluna horizon.

f. Anglo-Saxon.

Several difficulties arise from using such a chronology. In addition to the telescoping of late Mesolithic, Neolithic and Bronze Age cultures in the northern Pennines, there are the existence of a microlithic hunting tradition on the fell tops long after the Mesolithic period when Neolithic or Bronze Age peoples occupied the valley (chapter 3.3) and also the possible metachroneity of the Calluna horizon (chapter 5.6 and below). However, allowing for these inconsistencies a fairly coherent picture of man's activities may be evolved from the pollen diagrams which correlates with the known history of Upper Teesdale, briefly described in chapter 3.3.

Fire

Fire has played a significant part in the evolution of the present vegetation of the Reserve, as can be seen from the abundance of charcoal within the peat. Most fires in the world today are caused deliberately or accidentally by man (see footnote 6), and the same must have been true for a considerable period of time (Harris, 1958), but lightning may be important in certain restricted localities (Jones, 1945; Allison, 1952; Weatherall, 1952). The effect of fire on any vegetation type is considerable; it changes the normal vegetation pattern, even of bog areas, and alters the physical and chemical character of the soil. Fire is an important agent of deforestation which may result in the paludification of the soil surface and the initiation of blanket peat growth, as already discussed (see 3 above), but not only can fire result in paludification and the promotion of peat growth, it may also result in the cessation of peat growth (Auer, 1930; Pollet, 1968). Therefore, the process of burning may not result in similar vegetation patterns, hence a similar pattern in the pollen curves, even in areas of homogeneous vegetation.

There is abundant evidence for burning on the Reserve throughout the Post Glacial period. In most of the peats examined at least one layer of heather charcoal was found.

Mesolithic

These peoples were migratory hunters and food gatherers so that their influence on the vegetation might be expected to be transitory and slight. However, Dimbleby (1962) noted the marked effect of these peoples on the North York Moors, and suggested that this might have been due to their use of fire to drive game. In this way he suggested their effect on the vegetation might have been totally out of proportion with their numbers, although little is known about the extent of burning.

The presence of birch charcoal in fig. 29 suggests that fire may have aided hazel in its development during late zone V (see also Smith unpub.). Although the hazel maximum is generally regarded as climatic, Rawitzcher (1945) pointed to the European species of hazel being fire resistant and certainly if the placing of the M3 diagram (fig. 29) before the M1 diagram (figs. 25-26) in a relative chronology is correct, then fire may have been one of the causative factors in producing base rich soils, thus promoting the rapid Boreal expansion of hazel into the open birch woods in certain localities.

During the late Boreal period (zone VI) Simmons (1964) noted a forest recession in the oakwoods of Dartmoor, which he ascribed to the influence of Mesolithic man. Similarly, Durno and McVean (1959) showed that fire during zone VI and subsequent times resulted in the decline of the pinewoods on Bienn Eighe, although they were unsure as to the origin of the fire. Steven and Carlisle (1959), on the other hand, considered Mesolithic man had little effect on the vegetation and pointed to the present day limited burning which causes the natural regeneration of the forest rather than the destruction. Correlative evidence from other areas therefore, tentatively suggests that it is quite feasible for Mesolithic man's presence in Upper Teesdale during zone VI, although there is no evidence of his activities.

In pre-Atlantic vegetation there is some correlation between fire and vegetation change in Upper Teesdale, but there is no real proof of anthropogenic activity. Natural fire (i.e. caused by lighting etc.) may have accelerated the differential migration rates for different species, soil changes and the effects of climatic change.

The main body of evidence concerning Mesolithic man today points to him not being as dependent on his environment as previously thought. From a variety of sites there is evidence for early zone VIIa interference on the vegetation, indeed it is possible that some of the Atlantic vegetation of Britain was composed of secondary communities (Morrison, 1956). Pre-elm decline clearances in Ireland (Jessen, 1936, 1949; Smith, 1964) and England (Walker, 1956; Johnson, 1963; Simmons, 1969) show a general limited tree clearance during this period of time.

From the palaeoecological evidence two environments can be seen in Atlantic times (see 2 above). A fairly dense oakwood dominated in the valley, whilst a heterogenous vegetation predominated on Cronkley Fell (table 16). In both these environments evidence of possible anthropogenic activity is found. At Dufton Moss (figs. 25-27) the decline in total trees along with rises in the hazel, plantain, docks, birch and heather curves and a decline in the oak and elm curves, suggests some openings in the canopy causing soil degradation and the establishment of the light demanding rowan (Sorbus aucuparia). This appears to be a temporary effect on the vegetation, although birch values remain high and elm values steadily decline. Thus, the processes initiated by local, temporary clearances proved inimical to the former 'stable' forest trees of the Atlantic period. On the fell top the widespread occurrences of charcoal in peat of Atlantic age has already been attributed to Mesolithic man, who appears at least partly responsible for the initiation of blanket peat accumulation. Similar occurrences of charcoal have been found by Smith and Pilcher (unpublished observations) in the Sperrin mountains. The lack of a uniform pattern in the pollen curves following the charcoal layers, may substantiate the idea that heterogenous communities were present on the fell top at this time, although a noticeable feature of the curves is that the mixed oakwood constituents, oak, elm, ash and alder, do not appear to be affected (see 2 above). In view of the hunting and food gathering economy of the Mesolithic peoples (chapter 3.3) the clearance of widespread areas, covered by scrub, may have been the result of their firing of the vegetation whilst engaged in hunting. The Mire Holes site (profile R1, chapter 9), adds confirmatory evidence to the suggestion that springhead sites may have been particularly favourable for human activity, where early man might have camped during hunting forays (chapter 3.3; Johnson, 1963; Simmons, 1969).

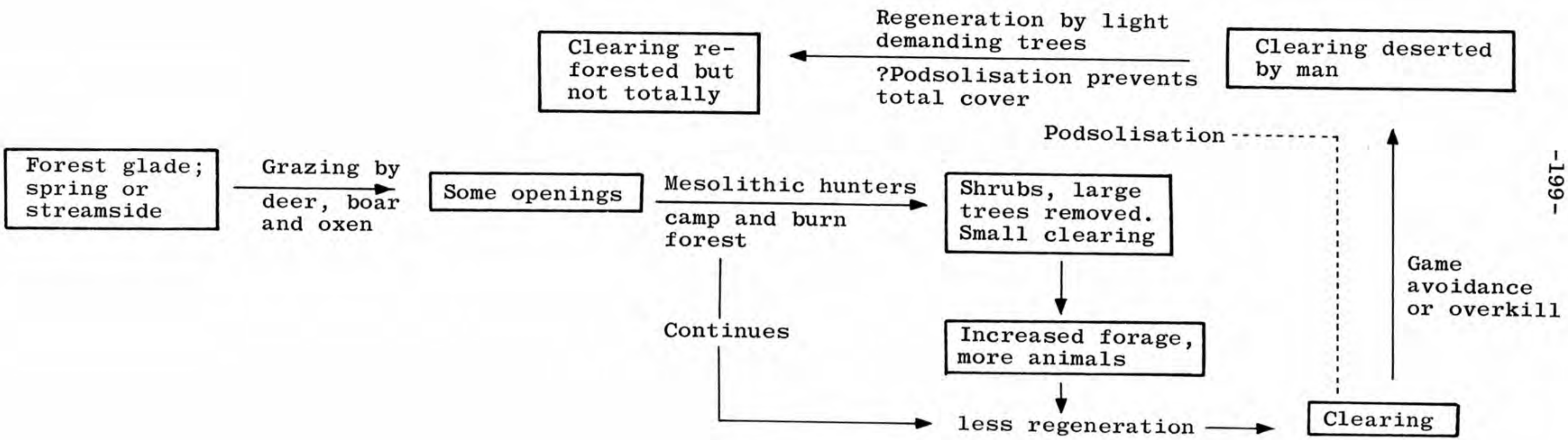
The possible mechanism for Mesolithic clearing in upland areas suggested by Simmons (1969) for the North York Moors (see table 17), may well be correct for human activity in the valley where a dense mixed oakwood existed. However, this mechanism might need modification if applied to the fell top where environmental conditions ensured heterogenous vegetation, including large areas of scrub and woodland which were less dense than in the valleys. He postulated:

a. Woodland broken or thinner in certain localities.

b. Mesolithic man camped in the vicinity, thereby creating open ground, and used fire to clear underbruch and corral game.

c. Repeated use of fire killed regenerating trees and

<u>TABLE 17.</u> A possible mechanism for the sequence of clearance by Mesolithic man in Upland areas (after Simmons 1969).



more animals, resulted in increased grazing and prevented colonisation.

d. If the system broke down because game avoided the area regeneration would take place via hazel, birch and ash, although in some circumstances soil degradation set in, preventing the regrowth of forest trees, so that permanent clearings might be formed.

In this way Mesolithic man might have exerted a strong influence on vegetational development in upland areas where soil was changed easily by rapid pedogenic processes, such as podsolisation after clearance, and were possibly important in initiating blanket peat. There is reason to suppose that early man cleared part of the woodland and/or scrubland, and perhaps the undergrowth from the woods on the fell top in the Reserve by his hunting activities. This resulted in soil acidification which may have allowed heather to become part of the ground flora. Therefore, differences in the heather curve between diagrams might be attributed to metachronous human activity, which eventually resulted in the widespread growth of blanket peat discussed earlier (see 3 above).

The evidence from the Reserve does not allow any definite conclusions to be put forward regarding the controversial elm decline. Anthropogenic activity would seem to be prevalent in some localities during the Atlantic period, and under deteriorating climatic conditions might cause soil degradation which resulted in the elm decline. The nature of the curve (i.e. whether gradual or sharp) does not offer further information.

Whilst there is some evidence therefore for Mesolithic man changing the composition of the woodland in the valley and initiating environmental change on the fell top, it is interesting to speculate whether in fact man initiated or merely speeded up woodland degradation. It has already been suggested that in certain localities ombrogenous peat might have been the end product of an upland climate, without human interference (see 3 above). Furthermore, Walker (1965) suggested that the elm decline might be interpreted as a stage in the replacement of pine by oak and elm, which is seen during the late Boreal-early Atlantic period (1 above).

In any woodland there are variations in the density of tree and ground cover and also in the dominant tree in any one locality. During the Atlantic period such variations appear to have occurred on the Reserve. At one extreme Dufton (chapter 6) shows that a fairly dense mixed oakwood existed in the valley. In this type of woodland it is not unlikely that closely spaced trees covered the ground, and regeneration only occurred where breaks were present in the canopy because of wind-throw or limited Mesolithic activity (see above), or by shade tolerant species. At the other extreme oak-birch scrub existed on the poorer soils (table 16). This gradation of communities, which may be termed oakwoods, are to be found today in the Lake District (Yapp, 1953).

At the maximum limits of the present deciduous woodland in the Lake District (i.e. where oak-birch scrub predominates), conditions are created which render regeneration impossible and ultimately the land reverts to heath with birch and ash only surviving in specific favourable localities (Yapp, 1953). If present day conditions are representative of Atlantic conditions then, during zone VIIa, the birch scrub might become heaths naturally or bear a heathy ground flora. This explanation might partly account for the dissimilar nature of the heather curves at different sites and might explain the frequent heather twigs in the base of some blanket peats. Yapp (1953) further pointed out that in the absence of nursery shrubs (e.g. hawthorn, cherry, rose or even bracken) small amounts of grazing could prevent regeneration in the high level oakwoods. Simmons (1965) concluded that in the absence of a shrub layer, high altitude, exposure and thin soil in conjunction with shade prevents the regeneration of woody plants in the Dartmoor oak copses. These conditions (i.e. the absence of small shrubs and 'nursery' trees) could well have been prevalent in certain areas of scrubland on Cronkley Fell at the extremes of tree growth during Atlantic times. Whilst there is no evidence from the pollen diagrams, evidence from elsewhere in Teesdale (Johnson, 1963) suggests that red deer (Cervus elephas) and indigenous wild cattle (Bos spp.) were present on the fell tops and might have aided in the woodland degradation by grazing without any help from man (see Clark, 1947).

Neolithic

The distinction between the vegetation of the valley and the fell top was very pronounced by the end of the Atlantic period. Mixed oakwoods were still predominant in the valley (table 8) whilst isolated patches of oak and alder woodland interspersed amongst the large areas of ombrogenous peat occupied the fell top (table 16). The continued presence of man on the higher land is indicated by the remains of charcoal in some sites (e.g. Mire Holes). It is difficult both to assess the effect of these people on the vegetation and to definitely distinguish their culture. From the pollen diagrams the culture would appear to be Neolithic because of the position of the charcoal, approximately at the VIIa/VIIb boundary, although as shown in chapter 3.3. Mesolithic and Neolithic cultures overlapped. Therefore, there is no proof that this charcoal denotes the presence of Neolithic man; its presence may indicate the continued existence of Mesolithic man. Although these peoples would almost certainly be attracted to, and would have settled in, cleared sites which existed in the valley and perhaps extended these clearings (Roberts, pers. comm.), they probably hunted on the open uplands. From Dufton Moss there is no evidence of continued clearance, closed woodland was still prevalent. The pastoral activities of these ?Neolithic peoples appear to have had little immediate effect on the valley woodlands, although on the fell top burning and grazing continued the degradation of the local woodland patches and perhaps aided in the extension of the blanket peat.

Bronze Age

A secondary elm decline can be seen on most of the diagrams along with obvious signs of human activity above and below this level, for instance charcoal and a declining

AP:NAP ratio (Dufton Moss site, Fox Earth Gill site). This could reflect Bronze Age activity and concomitant blanket peat extension. The early Beaker peoples are known to have migrated onto the drier land in the valley, whilst the fell tops remained the domain of the hunter. The widespread alteration of the few remaining local woodland patches on the fell top is apparent by the considerable palaeoecological evidence for anthropogenic activity which is severe in places (sufficient to cause bare ground-chapter 9). Most of the pollen spectra show irregular fluctuations suggestive of continued interference from midway through zone VIIb.

The major clearance phase shown at Cronkley Pastures (figs. 30-32) has been assigned to activities of Bronze Age man. Without any radiocarbon dates there is no real justification but the Iron Age clearance, which is in evidence at the top of Dufton Moss and at Fox Earth Gill diagrams (see below), appear to be restricted to the valley bottoms, there being few trees on the fell or hillside during this phase of human activity. Clearance of local alderwoods in such a locality as Tarn Dub was effected because of some local advantages (chapter 7.4). During the Bronze Age the axe-hammer became an important tool and in view of a quartz-doleritic axe-hammers being found in various localities, Shotton (1968) concluded that he could imagine many working sites (i.e. sites where these tools were made) below the Whin Sill crags of Northumberland or the Pennine Escarpment or in Teesdale. Although no such sites have yet been located perhaps one might have been beneath Cronkley Scar where abundant raw materials were available and there was shelter from the wind, local water was available and there was easy access to the open moorland and the woodland in the valley. By the end of the 'Bronze Age' period much of Cronkley and Mickle Fells, except for isolated trees, were blanket bog covered. Grassland occurred where human activity, in the form of burning, and other environmental factors prevented blanket peat spreading (see Auer, 1930; Pollet, 1965; General introduction). The severity of the clearance seen at Cronkley Pastures is unusual but indicative of the dominant role man was starting to play on the hillside and in the valley.

Iron Age

The Iron Age period has been placed immediately below the Calluna horizon and a phase of clearance is seen at Dufton Moss and Fox Earth Gill. Similar pollen analytical features to those found at Dufton and Fox Earth, a sharp rise in the Calluna frequencies, have been dated on Widdybank Fell as 2570 ± 80 B.P. or 620 BC. (Hewetson, unpub.). However, the Calluna horizon occurs after the second elm decline at Dufton and at the point of this decline at Fox Earth. Two possibilities exist, either the Calluna horizon in these two diagrams is metachronous and possibly reflects different processes, or the second elm decline is metachronous and some elm trees existed in patches on the remaining base rich soils on the fell top. Whilst it is easy to suggest a non-synchronous Calluna horizon, even with a radiocarbon date (see chapter 5; Pennington, 1964), it is more difficult to envisage a secondary elm decline in the valley occurring as a result of human interference (chapter 6) but the same process, or environmental conditions which accompanied this interference, allowing the re-establishment or regeneration of elm on the fell top. The distinct clearance phases in both diagrams followed by subsequent regeneration and final clearance appear too well documented to suggest they belong to different periods (although the Fox Earth diagram might possibly reflect later Iron Age activity on the uplands). It is possible that elm and some oak may have regenerated on the fell top, as a result of human interference which retarded bog encroachment on the limestone soils, at a time when the climate is thought to have deteriorated (Godwin, 1956). The lack of the regeneration of the tree before this time may reflect its inability to recolonise certain areas, particularly in such exposed localities, without some instigating mechanism which was provided by man, or it may merely reflect the slowness of its natural succession in an upland environment under slowly deteriorating climatic conditions (see above).

The major deforestation belonging to the 'Iron Age' period appears mainly to affect birch and alder, and whilst it is likely that the fell top and hillsides would be used for grazing and hunting purposes, as they had been used previously, the poorer and damper soils in the valley carrying a lighter vegetation cover might be cleared for limited cultivation (chapter 6). This is the period when the Brigantes controlled a substantial part of Teesdale and therefore there might have been sufficient 'political stability' for settled communities to become engaged in some fairly extensive cultivation for the first time in the Upper Tees valley.

The Calluna horizon

Difficulties inherent in using such a horizon have been suggested (chapter 5). The reason usually cited for the Post Glacial increase in heather are:

a. The extension of ombrogenous peat growth in response to a sudden deterioration in climate around 500 B.C. (Godwin, 1956).

b. The start of peat erosion (Johnson, 1963; Pennington, 1964).

The climatic deterioration resulting in recurrence surfaces of which the Grenzhorizont is one, has been shown to be of approximately 4000 years duration (Von Post, 1916; Godwin, 1956; Morrison, 1956). It is therefore hard to envisage the precipitation:evaporation ratio becoming changed suddenly causing a synchronous growth of blanket bogs over widely differing communities. (The same argument has been used to reject a climatic cause for the elm decline, see Oldfield, 1960). It is particularly difficult to imagine this on the Reserve since present day heather communities are characteristic of dried out blanket peat rather than growing blanket peat. Often in the diagrams the sedge curves does not rise with those of heather, which might be expected if this heather increase reflects an extension of the blanket peat areas, especially as heather-sedge communities are characteristic of present day actively growing blanket peat. At Dufton and Cronkley Pastures the heather curves rise at the top of the diagram and it is noticeable that in both cases this rise post-dates considerable human interference and precedes the continued clearance at the top of the diagrams. Thus, there is a suggestion here that anthropogenic activity might have aided the extension of blanket peat at lower altitudes or at least allowed heather to become a significant part of the flora for the first time by initiating, or continuing, soil degradation.

This explanation does not appear to fit the evidence from sites on Cronkley Fell. It has already been suggested (above), that there is perhaps some reason for accepting a relatively synchronous Calluna horizon below 1700 ft (517 m). In many of the upland sites (i.e. above 1700 ft (517 m)) however, heather frequencies increase long before this horizon sometimes in response to human interference (fig. 39), and the horizon has been drawn at the maximum occurrences of heather. In the topmost diagrams, Mire Holes, Long Crag and Mickle Fell, heather declines in the face of increased grasses. This might indicate that the blanket peat started to erode at this point, possibly because of a deteriorating climate or human activity during the ~~Non~~ Iron Age period. The extension of the grassland communities may be a direct result of this erosion (see Hornung, 1968).

Roman and Anglo-Saxon times

If the assumption of extensive Iron Age clearance is valid then the period of the regeneration of the woodlands might correspond to the Roman period, during which time the dale became a notable hunting area (chapter 3.3). The major, continued deforestation which can be seen, especially at Dufton (figs. 25-27), following this regeneration would therefore correspond to the time of the Anglo-Saxon occupation. The Anglo-Saxons first settled in Teesdale in the seventh century. Their economy was largely based on agriculture, therefore large areas of valley woodland would be cleared whilst the fell tops would be used for hunting and grazing. Thus, it seems likely that the present land use pattern was established during this time.

1. The lack of documentary evidence is principally due to two factors, firstly the unsorted nature of many of the Raby Estates records, which concern the lands north of the R. Tees, and secondly the destruction of most of the Strathmore Estates records.

2. The dates quoted are merely intended to give a general chronological framework for the vegetation changes described. Where radiocarbon dates are quoted they are specified as such.

3. Although Godwin and Clapham (1951) showed the continued solifluxion until zone V around Cross Fell, it is perhaps reasonable, in the absence of evidence to the contrary, to suggest unstable conditions at lower altitudes which may be attributed to periglacial activity.

4. Pollen zones are delimited upon the characteristics of the vegetation: at certain times each zone has specific features in terms of vegetation. Pollen curves may be assigned to a particular zone even if one of the features is anomalous (e.g. pine in VIIb in fig. 33). High pine is usually attributed to zone VI but the subzoning of this period is dependent on the nature of the oak, elm, alder and hazel curves. Hence it would seem logical to suggest that if the curves for oak, elm, alder and hazel indicate VIa, VIb or VIc, then the diagram can be so zoned and the pine maximum may therefore occur in one of these subzones rather than throughout zone VI.

5. Paludification was a term first used by Von Post to describe the process of bog expansion caused by a gradual rising of the water table as peat accumulation impedes drainage (Auer, 1930).

6. Prehistoric activity may be divided into:
   a. Interference with the vegetation to improve pasture.
   b. Destruction of vegetation during the process of driving game.
   c. The accidental destruction of vegetation.

7. In Miss V. P. Hewetson's diagram from Tinkler's Sike, Widdybank Fell, the radiocarbon date was obtained from peat taken from a horizon where Calluna and Gramineae frequencies rise sharply.

Chapter 13. CONCLUSIONS

13.1. The Post-Glacial environment

The approach outlined in the General Introduction, that of subjectively selecting a number of sites over an extensive north-facing slope in the northern Pennines, places emphasis on the study of an area. The investigation elucidates the vegetational history of an area which is unique in terms of its present assemblage of plants. A chronology of forest history is an important consideration in any assessment of the present status of the rare species, especially if some Post Glacial diminution of the habitats at present occupied by these species has occurred. Because of the problem of identifying pollen of the rare species or their ecological associates, pollen data has been used to suggest palaeo-environments which might have permitted the continued existence of the rare plants in Post Glacial times. Throughout the interpretation and discussion however, it must be borne in mind that not all the environments which were present at any one time, are portrayed in the pollen spectra and also the difficulties of interpretation of pollen curves in upland areas, because of: the metachronous growth of blanket peat, strong winds effecting long distance transport of pollen grains and the permanent tension which exists between the various components of the ecosystems, especially between vegetation and soil.

The following main conclusions can be drawn from the presented palaeoecological data (see table 18):

The earliest organic deposits were formed in persistently waterlogged localities, such as surface depressions or hillside structural benches, where Phragmites became prevalent in zone V.

During zone V open birchwoods, along with immigrating hazel and pine, was the predominant vegetation type, at least around 1200 ft (365 m) in the Tees valley.

Hazel had its maximum Post Glacial values in subzone VIa when it formed birch-hazel woods, with perhaps some hazel thickets, in the Upper Tees valley and may have extended to considerable altitudes on Cronkley and Mickle Fells. This large hazel increase can be attributed to the predominance of fresh calcareous soils, due to the late cessation of solifluxion, and increasing temperatures.

Pine expanded into the early zone VI birch-hazel woods and became a major constituent in the valley woodlands late in subzone VIa. It expanded mainly at the expense of hazel during a time of rising water levels and formed birch-pine woods, possibly with a hazel understorey. Oak and elm were constant components of these woods but in relatively small amounts. As pine declined during subzone VIb + c in the face of increased oak and elm, it became more important in the vegetation of Cronkley Fell where it expanded at the expense of birch and hazel to form discrete areas from the already well established oak and elm. The tree appears to have invaded the drier limestone areas when water levels were rising. Drying conditions at the end of the Boreal caused pine to decline on the Fell.

Throughout the late Boreal (zone VI) unstable environmental conditions, caused by increasing temperatures and fluctuating water levels, allowed the greatest variety of trees in the Reserve and the greatest competition for

TABLE 18. Correlations between the woodland history as shown by the pollen diagrams from the major sites (chapters 6-10). Most likely correlations are indicated.

Tentative Cultural Period	Zones	Dufton Moss NY 872293 1200ft (368m) table 8	Cronkley Pastures NY 857288 1300ft (395m) table 9	Fox Earth Gill NY 842282 1750ft (531m) table 11	Mire Holes NY 849267 1850ft (562m) table 12	Long Crag NY 835255 2200ft (669m) table 13
Anglo-Saxon		More or less permanent woodland clearance				
Roman	Calluna horizon	Calluna becomes important. Regeneration apart from the base demanding Ulmus & Fraxinus.	Calluna becomes important in the flora. Extension of ombrogenous peat.	Expansion of moorland communities (for definition of moorland see chapter 3.2).	Reduction of woodland areas due to blanket peat extension	Blanket peat dominates except in areas of: a. base rich soils b. steep slopes c. erosion.
Iron Age		Clearance of secondary communities in the valley woodland, decline of Betula, Alnus & Corylus.	Decreased amount of woodland in the valley.			
			Temporary establishment of local tree growth.	Re-establishment of Ulmus.	Limited woodland regeneration.	
			Decline of trees.			
			Reduction of local Alnus woodland. Extension of grass & sedge communities.			Human activity causing the removal of the limited woodland and allowing ombrogenous peat to encroach upon these areas and the areas of scrub.
	VIIb	Human interference	Re-establishment of Alnus woods.		Some burning	
Bronze Age			Destruction of local Alnus and Betula woods.	Human alteration of the local woodlands.		
		Re-establishment of Ulmus.	Unstable morainic banks. Local Betula woods. Local Alnus woods. Remnant Pinus coms.		Ombrogenous peat extension at the expense of the local woodland comms. and the Betula-Corylus scrub.	
Neolithic))) Mesolithic)		Ulmus decline.		Ulmus decline.	Decline of Ulmus by clearance. Extension of Alnus & Corylus.	Ulmus decline.
				Start of ombrogenous peat growth. Some human interference affecting Ulmus localities.		
	VIIa	Mixed oakwood with Quercus, Alnus and Ulmus.		Mixed oakwood with Quercus & Alnus. Decreased Betula-Corylus scrub. Fraxinus represented.	Mixed oakwoods with Corylus on spring surrounds. Similar local comms. on limestone outcrops. Betula-Corylus scrub extensive.	Damp mixed oak woodland in patches. Extensive Betula-Corylus scrub.
	VI c	Betula-Pinus woods with Quercus, Ulmus and Corylus.		Open Pinus-Quercus woods. Local growth of Betula & Corylus.		
	VI b			Betula-Corylus woods with local Salix. Quercus & Ulmus in favourable localities.		
	VI a	Betula-Corylus woods.				

available space. The picture of local vegetation appears dependent, to a large extent, on topographic and edaphic differences.

Alder expanded in certain localities during the Atlantic period as a result of an increased precipitation:evaporation ratio and changed edaphic conditions causing an increase in habitats suitable for its expansion.

The Atlantic woodland of the Upper Tees valley was fairly dense and largely composed of oak, elm, birch, alder and hazel, although these components varied considerably from locality to locality. On Cronkley and Mickle Fells a more heterogenous vegetation existed, whose dominants were dependent on soil differences. The presence of oak or alder dominated woodland above the postulated limit of closed deciduous woodland, 1700 ft (517 m), is attributable to limited amounts of soil capable of supporting even such base demanding species as elm and ash. No conclusion can be drawn concerning the limit of these woodland patches but it is possible for them to have existed to the summit of Mickle Fell (2600 ft 790 m). Over much of Cronkley and Mickle Fells during zone VIIa birch scrub (including birch-hazel and birch-oak) and blanket peat was predominant.

The base of the blanket peats, which started to form in Atlantic times, suggests that initially much of the peat developed from a woodland/scrub humus and the presence of charcoal points to the destruction of the existing vegetation being important in its initiation, although a deteriorating climate was contributory. Blanket peat growth did not affect the local patches of deciduous woodland.

Man has had an important effect on the vegetation[1] since Atlantic times, largely by the use of fire which caused or allowed the initiation of blanket peat growth. It is possible that man was present in the upper Tees valley and on the uplands in Boreal times, although there is little conclusive evidence. During the Atlantic period Mesolithic man appears to have made small temporary clearances in the mixed deciduous valley woodlands and to have cleared extensive areas of the birch scrub on Cronkley Fell. Clearance on the upland was probably effected by fire, used both as a means for driving game during hunting expeditions and to improve the grazing for the native fauna. The patches of localised oakwoods were not affected by these early activities perhaps because prehistoric man found the scrub areas were more easily cleared. Neolithic peoples might have settled in any valley clearings but there is no evidence for valley woodland destruction. There is evidence however, for the continued burning and grazing on Cronkley Fell along with the concomitant extension of blanket peat. The severe burning, seen at the Long Crag site (chapter 10), has been attributed to Bronze Age peoples' activities when the alteration of the remaining local woodland patches occurred. It is from midway through zone VIIb, which has been correlated with the Bronze Age cultural period, that many of the pollen spectra show evidence of continued and expanded human activity. Cronkley Pastures (chapter 7) was the site of considerable Bronze Age activity and could have been the site of a Bronze Age axe-hammer factory. The major deforestation of the valley woodland started in the

Iron Age and mainly affected birch and alder, probably in the areas of less dense woodland (e.g. secondary woodland communities) and around the river or other water bodies. From this period came the first cultivation although there is little evidence. By this time the Fell was largely treeless, except for isolated trees, and was principally used for hunting and summer grazing. The woodland in the valley regenerated to a certain extent during Roman times when the dale was extensively used for hunting purposes, but settled Anglo-Saxon communities in the seventh century ensured the continued degradation of the woodland with extended areas of cultivation and the continued use of the open, largely peat covered, Cronkley and Mickle Fells for hunting and grazing.

13.2. The Post Glacial status of the Teesdale 'rarities'

The hypothesis with which this work was started, namely one in which the rare plants were postulated to be relics of a more widespread vegetation which existed in Late Glacial times and had survived the Climatic Optimum and the maximum forest expansion, was evolved with little knowledge of the ecological history of Upper Teesdale. It was evolved from a comparison of the present flora of Upper Teesdale with the flora found in Late Glacial times in other areas, by analogy with the present vegetation and vegetational history of similarly floristically rich areas. The suggestions and conclusions put forward above enable a comparison to be made between the present environment of the rare plants and the palaeo-environments which were present during Post Glacial times.

The present environment of the Teesdale assemblage is the product of unstable conditions and is characterised by the absence of competition from trees and the presence of soils or water with a high base status (see General Introduction). Essentially therefore, in an examination of palaeo-environments, evidence of instability might suggest the presence of conditions favourable for the survival of the rare species. There is abundant evidence for unstable conditions causing fluctuating water levels during the late Boreal period (zone VI). Earlier, in zone V, the prevalence of solifluxion at higher altitudes (over 1700 ft, 517 m) ensured continued instability from the Late Glacial period. After the Boreal period, in Atlantic (zone VIIa) times, Mesolithic man's activities further ensured some areas of unstable soils where the tension between vegetation and soil was at its greatest, and therefore plants requiring minimal competition for their existence might survive. This alteration of the vegetation by man, first started some 7000 years ago, has continued until the present day. Conditions throughout Post Glacial times therefore, never seem to have been totally inimical to the survival of the Teesdale 'rarities'.

The possibility of the rare species existing above the tree limit must undoubtedly be questioned if trees, in one form or another, existed to the summit of Mickle Fell during the maximum forest extension as seems likely. This being so, the density of the tree/scrub cover becomes an important consideration as does the existence of rock outcrops and calcareous flushes and springs, which would have remained devoid of trees. Above 1700 ft (517 m) patches of deciduous woodland existed in the areas of base rich soil with extensive birch scrub where thinner or poorer soil occurred. In both of these environments unstable base rich conditions, such as those shown at Mire Holes (chapter 9), undoubtedly existed and provided the competition from trees was minimal the now rare plants could survive. Similarly, once blanket peat started to form in most areas those localities with base rich soils and free drainage would favour the rare species, since many of them are quick to propogate under these conditions, particularly if prehistoric man destroyed the existing vegetation on the thinner soils of the margins of limestone outcrops.

The description of the present limestone grasslands as biotic plagioclimaxes (Shimwell, 1968, 1969) places emphasis on the destruction of the original vegetation by man, particularly through grazing. From palaeoecological evidence this description seems appropriate as man appears to have been a most important agent in the formation of the present day communities on Cronkley and Mickle Fells. His persistent destruction and degradation of the Atlantic and post Atlantic vegetation, especially in areas of thin limestone soils, bare rock outcrops and springheads, has enabled the survival of the former, were widespread Teesdale 'rarities'.

13.3. Other plant refugia

At Cwm Idwal (Snowdonia) and Lochan nan Cat (Ben Lawers), Godwin (1955) and Donner (1962) respectively suggested that areas which were free from forest and the development of peat favoured the survival of similar communities to those of Teesdale. The closest analogy to Teesdale is Cwm Idwal, since Donner suggested that large forest-free areas existed on the Grampians, where the rare plants were able to survive, at considerable altitudes. At Cwm Idwal Godwin found no evidence for the persistence of any rare species, although he suggested some open habitats within the forest and peat areas where they might persist. He pointed out that the species may have been favoured by deforestation and grazing since Neolithic times.

From the present study of the vegetational history of Upper Teesdale since the late Boreal period (zone VI) and comparison with the vegetational histories of similar phytogeographically remarkable areas, such as Snowdon and Ben Lawers, the general course of the development of the present day vegetation appears similar.

1. However this does not mean either
   a. a dense settlement or any settlement at all;
   b. continued activity.

Intermittent activity could produce similareffects. This activity might be on a small scale and the various signs of such activity, which can be seen from site to site, may not be correlative.

APPENDICES.

APPENDIX A.

The genus *Quercus* L. in Atlantic times

(This discussion has been placed in an appendix because there is insufficient knowledge of the detailed history and ecology of the oak in Teesdale to draw any definite conclusions regarding which species of *Quercus* was predominant in the Post Glacial period, especially since the distinction between the pollen of Britain's indigenous species of oak, *Q. robur* and *Q. petraea*, is not clear (see however Van Campo and Elhai, 1950). Many of the tentative conclusions drawn below, concerning these two species, rest on evidence concerning their ecology provided by their present distribution in England, and on evidence concerning the 'Atlantic environment' provided by the palaeoecological investigations).

Both *Q. petraea* and *Q. robur* have similar climatic requirements, although at present *Q. petraea* is the principal species of oak in much of the hill country of the Pennines and the Lake District. The upper limit of oak woodland is 1000 ft (300 m) (Jones, 1959) where *Q. petraea* is predominant although both Leach (1925) and Yapp (1953) noted this species at 1400 ft (440 m) in Cumberland. In this northern upland area Moss (1914) described *Q. petraea* on the Carboniferous grits of the Peak District, whilst he observed *Q. robur* on the Carboniferous Limestone. Pearsall (1923) found a similar distribution pattern on the North York Moors, although Jones (1959) noted that *Q. petraea* was the dominant species on Carboniferous Limestone in Westmorland, a fact which Tansley (1939) later ascribed to the predominantly high rainfall.

The present distribution of Q. petraea and Q. robur shows that there is a tendency for the former to prefer the upper slopes and hilltops, where acid well drained soils are to be found, whilst the latter has a preference for valley bottoms, where soils which are moist and heavy but rich in mineral nutrients occur. However, the distribution is by no means discrete and both species hybridise freely.

In Upper Teesdale the few scattered oaks that occur appear to be more or less pure Q. robur (Hadley pers. comm.), which is not what might be expected, although Betula spp. are the dominants of the remaining woodland patches. The prevalent soils under these woodland patches are brown forest soils which occur over Carboniferous Limestone and Whin Sill, and which show a tendency to podsolise with the removal of trees.

In zone VIIa a whole range of woodland communities is envisaged, from dense mixed oak woodland to oak-birch scrub, a range which was apparently influenced by edaphic differences (chapter 12.2).

In the Upper Tees valley a fairly dense woodland composed of oak, elm, birch, alder and hazel existed on what was probably a mature soil (see Dimbleby, 1965; Pennington, 1965). The changed precipitation:evaporation ratio which resulted in increased dampness and allowed alder to expand, perhaps ensured that soil conditions were moist. This moistness, allied to the calcareous nature of the soil parent material (chapters 2 and 3.1), would probably lead to conditions more suited to Q. robur than Q. petraea. Jones (1959) suggested that there was no reason to doubt that forests in which Q. robur was one of the principal species once occupied large areas in the valleys of rivers such as the Thames, Severn and Ouse. The same may be true for Teesdale, the rich hay meadows being derived from ' the better types of woodland' (Pigott, 1956: 551), in which Q. robur was dominant, although Q. petraea was also present. The remnant Q. robur trees might thus be explained.

At the opposite extreme, where oak-birch scrub was dominant, the prevalent leaching and consequently acid although well drained soil would be more suited to Q. petraea, which has long since been destroyed by the growth of blanket peat and human activity (chapter 12.4). Here podsols would probably be prevalent so that an analogy may be drawn between these communities and the present-day Quercetum-Betuletum, which Etter (1943) described in Switzerland where Q. petraea is dominant.

Between these two extremes was a large altitudinal gap which in many places carried an 'oak woodland' of sorts. During the period of the Climatic Optimum climatic conditions almost certainly would have allowed both Q. petraea and Q. robur to grow, therefore edaphic conditions once again would have been of great significance. On the upper slopes of the valley, below the limit of the closed deciduous woodland, conditions might tend to favour Q. petraea, although very little can be said regarding the woodland at these altitudes (1200-1700 ft, 365-517 m) in the absence of palaeoecological data. Of most interest is the species of oak on and around the limestone outcrops. The base-rich and fairly well drained soils might favour Q. robur, especially since

Weimark (1947) described the detrimental effect of calcium carbonate on _Q_. _petraea_ seedlings, however Etter (1943) pointed to the dominance of _Q_. _petraea_ on rendzina soils (pH 7.3) in Switzerland. The evidence appears equivocal, and without further detailed ecological studies little more can be said.

APPENDIX B.

Sugar Limestone Outcrops

Little has been said about these purposely because little, if anything, can be inferred from the pollen diagrams. Because of this, reference has been made to 'limestone outcrops' in the text. There is no reason why the 'sugar limestone' outcrops should not be included in this generic term. If 'sugar limestone' and limestone may be equated in Post Glacial vegetational history the 'sugar limestone' outcrops would perhaps carry a light scrub cover or even pine, and there would be some development of a soil profile. There is no evidence of this but in view of the present rapid erosion of the limited outcrops on Thistle Green and White Well Green, it may be questioned whether, given some shelter by the local tree or scrub cover which existed in Atlantic times, a skeletal soil might not have evolved. According to table 6 if the present grazing and disturbance were removed, some soil development might be expected along with the establishment of limestone grassland communities.

APPENDIX C.

The Use of Computers in the Presentation of Pollen Data

(This Appendix is the result of research undertaken in conjunction with Dr. A. P. Holder, formerly of the Geology Department, University of Durham, and consists in part of a paper accepted for publication in the New Phytologist).

The Problem - The problems specifically associated with the comparison of pollen diagrams, namely those which arise from the use of a variable pollen sum, have received little attention in the Literature, although Faegri and Iversen (1964) have discussed the more general problems of pollen data presentation. This is surprising in view of the value of pollen diagrams, the tool of the pollen analyst, in comparative studies (cf. Godwin, 1934). Comparison between diagrams is often essential, although hazardous (cf. Davis, 1963; Faegri and Iversen, 1964, *inter alia*), but frequently depends on correlations between differently presented data and sometimes results in dubious or even incorrect interpretations. This Appendix describes a semi-automatic method for producing standardised pollen diagrams, thus curtailing the time involved in the transformation of data into comparable forms and eliminating the necessity for correlation between different forms of presentation.

Description - A programme, written in IBM 1130 FORTRAN IV which is a subset version of FORTRAN IV, has been developed to draw pollen diagrams, using an IBM 1130 computer with a 1627 graph plotter (Model 1) and a 1403 printer[1]. This was developed from a programme by Mr. C. W. A. Browitt of the Department of Geology, University of Durham, which plots seismic traces adjacent to one another, and uses standard plotting subroutines supplied by IBM.

The flow diagram of the programme is shown in Fig. 1. The main operations involved are:

1. The reading of systematically classified pollen data for a profile.
2. The conversion of part of this data into percentages of a specified total.
3. The plotting of these percentages at specified depths on the 1627 plotter.
4. The tabulation of these percentages on the 1403 printer.

Input - Data are read into the computer on cards which have been punched from standard 80 column coding forms (Fig. 2). For ease of transferring raw data, which in this instance are pollen counts, onto the coding forms special count sheets were used (Fig. 3). These data, the format of which is fixed, consist of the following (Fig. 2):

1(a)[2]. The name and the label of the profile which are plotted on the diagram, on separate cards. These are incorporated into the programme deck.

2(b). Data card 1 (3F 10.4)[3] contains three factors controlling the scale of the plotted diagram.

These scale factors are:

a. XSC (Upper case letters indicate the actual coding instruction). The X-direction (percentage) scale.

b. SCA. The Y-direction (depth) scale.

Both XSC and SCA are expressed as the reciprocal of the user's unit/inch. These units may be any linear measurement (e.g.

a desired scale of 100 units/inch =.01).

c. DEP. This is dependent on the maximum depth of the profile under investigation and the SCA used. If the SCA is of the order of .01 it is expressed to the nearest 100 above the maximum depth +0.5/SCA. If the SCA is of the order of .1 it is expressed to the nearest 10 above the maximum depth +0.5/SCA (e.g. a maximum depth of 342 has a DEP of 450 if the SCA is of the order of .01, i.e. 400 + 0.5/SCA). These factors ensure a consistent scale in both the X and Y directions and the marking and labelling of the depth axis in the correct places.

3(c). Data card 2 (2I4) contains two figures, the number of horizons counted and the number of taxa identified.

4(d). Next are the specified totals which may be the pollen sum used or the total pollen counted. These numbers must work down the profile. The format for each card is 10F6.1. Although these totals are invariably integers, floating point (without exponent) numbers have been used for two reasons, firstly to be consistent with the depths which might contain decimal places, and secondly to provide a check as the decimal points on all data cards, except 1 and 2, are in similar columns.

5(e). The depths of the horizon counted, as 4 above.

6(f). The names of the taxa identified (A5). During development it was found that the practical limit was four letters as any letter punched in column 1 was invariably overlooked by the computer.

7(g). The actual pollen counts as in 4 above. Counts for each taxa are read into the computer in the same sequence

as 6. Where a grain is recorded in the scan but not in the count the number 9001 is assigned to it.
If the number of taxa identified is represented by T and the number of horizons counted is represented by H, then the number of data cards necessary is:

$$2 + \left(\frac{H(2 + T)}{10}\right) + T$$

Initially the graph plotter pen must be placed 10 - DEP x SCA ins. from the right hand edge of the plotter, although it may be in the up or down position.

Limitations on input - Both XSC and SCA are fixed although they need not be the same. Both of them however are limited by the graph plotter pen which moves in steps of .01 in. The minimum scale factor is therefore .01 in (i.e. 100 units/inch) so that a factor containing three decimal places is not permitted. The percentage scale XSC must be chosen with horizontal extent of the diagram in mind which may become considerable and therefore unmanageable. Although the theoretical maximum extent of any diagram is 120 ft, the length of the graph paper, unnecessary lengthy lines are avoided by interrupting the plot where percentages exceed 500 and writing the actual percentage occurrence in figures .07 in. high. The depth scale SCA depends on the depth of the profile. The maximum width of paper available for plotting this depth is 11 ins. which means that if space is allowed for the labelling of the diagram only 9 ins. are actually available for plotting. Using a minimum SCA of .01 in. a maximum of 900 units may therefore be plotted. Where values exceeding 500 are reached by contiguous samples the choice of an unsuitable SCA may result in some overwriting.

There is a limit to the amount of data which can be stored in the computer used. To alleviate this potential problem the percentage occurrence of each taxon has been computed and plotted prior to the reading of data for the next taxon. In this way data concerning the totals, depths and names of taxa for a profile and the pollen counts for a particular taxon are stored at any one time. To avoid any possible loss of data which might occur the maximum number of horizons counted and the maximum number of taxa identified have been limited to 100 (i.e. a matrix of 10,000).

Output - Output consists of a scaled pollen diagram (Fig. 4), with those taxa coded as 9001. plotted as the character (X), and the rounded-off percentage occurrences of the taxa tabulated (Table 1). Those taxa recorded in the scan and coded as 9001. are tabulated as 9001.

Limitations on output - The time taken to carry out the operations described above depend on a number of factors. The speed and skill of the punch operator is a function of experience. The greater the experience the speedier the operation although cards only have to be punched once. The speed of the graph plotter, up to 18,000 steps/minute, cannot be improved and this may become critical if a limited amount of computer time is available. A matrix of 25000 (i.e. 50 horizons counted x 50 taxa identified) takes approximately 20 mins. of computer time.

Discussion - Despite the time taken for such a method of pollen data presentation it is only a fraction of the time taken to present data in a more conventional manner. The most laborious operation is the transference of the pollen counts onto coding sheets.

In addition there are other advantages. Fractions of percentages occasionally of considerable significance, may be plotted more easily and more accurately than by hand. Cards are easily stored and the data on them are readily available for further processing by statistical techniques (e.g. curve fitting) using a computer.

A rapid method of presenting pollen data is useful, firstly for transforming data into a comparable form and secondly for producing a skeleton diagram, prior to intercalating horizons. The production of a standardised diagram is a pre-requisite in comparative studies. It is not suggested however that all pollen statistics are presented in the same way because as Faegri and Iversen (1964: 95) point out, ' different purposes require different diagrams', neither is it suggested that the interpretation of computer-drawn diagrams will be suitable in all circumstances, but it is suggested that the interpretation of data which is illustrated in diagrams could be more useful if some transformation of the data took place similar to that outlined above.

With the advent of computers into palynology which, in addition to performing objective repetitive processes quickly, may be used to complement, 'a large variety of reference pollen preparations and published descriptions', (Walker, Milne, Guppy and Williams, 1968: 251) and the increased volume of pollen data available for comparative purposes new methods of data storage and access ibility must be examined. If a centralised data bank was initiated along the lines of The National Auxiliary Publication Service of the American Society for Information Service, which provides 'a central depository and reproduction service' for a variety of information, pollen data could be more readily available than at present and the method outlined above would become of greater value for the production of standardised diagrams. In this way the greater integration of analyses within a spatial framework might be possible resulting in the more effective interpretation of the patterns of vegetation change which are found.

The method outlined and discussed is in the early stages of development. This appendix is merely intended to show the type of problems arising from the comparison of diagrams which can be overcome by using a computer and to introduce a new method which is thought to have considerable possibilities in pollen analysis; already work has progressed a nd other programmes have been developed. Although the above description of the input specifications is sufficient for the utilisation of the programme it is not intended to allow manipulation of these specifications. It is hoped to publish details of the programme, permitting the input/output format to be changed and containing a description of the subroutines used.

[1]It should be noted that this programme was developed to run on the computer available at Durham, an IBM 1130, Where a different computer is used certain specifications and statements must be altered, although the principles outlined remain unaltered.

[2]The letters in parenthesis are the identifiers in Fig. 2.

[3]The format specifications.

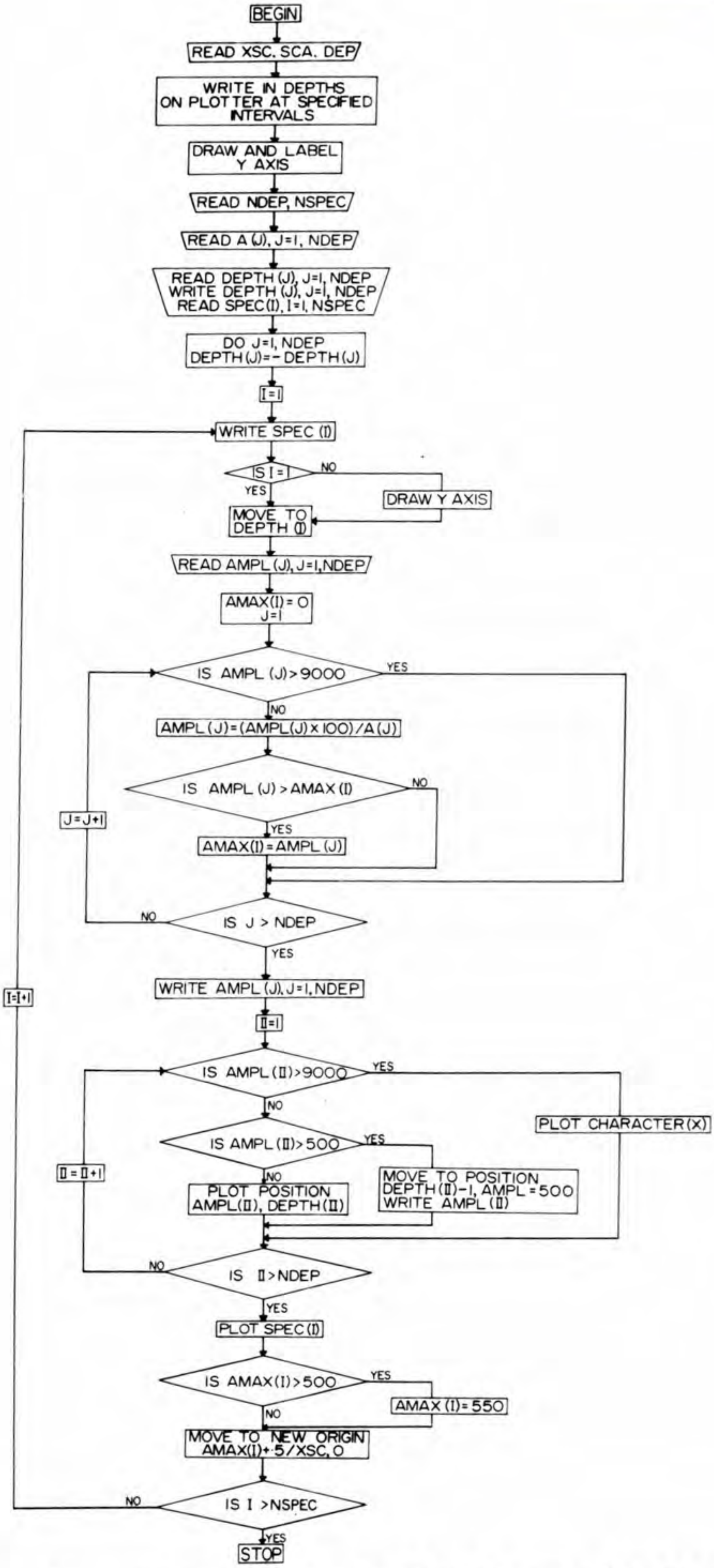


FIG. 1. Flow chart for Pollen Diagram Plotting Programme. (Drawn by Mr. P. Howe, cartographer, Geography Department, University of Durham).

NUMAC

IBM System/360 Assembler Coding Form

PROGRAM: PD1.RHS

PROGRAMMER: | DATE: | PUNCHING INSTRUCTIONS: GRAPHIC / PUNCH | PAGE OF | CARD ELECTRO NUMBER

```
    5 FORMAT('  DUFTON MOSS A 1968')            (a)
    6 FORMAT('  PERCENTAGE OF POLLEN SUM')      (b)
      .01          .01     150.
   5   5                                        (c)
  62.    74.    33.    89.    72.               (d)
   4.     9.    29.    38.    98.               (e)
BET                                             (f)
PIN
ALN
GRA
CYP
  10.  9001.     1.     1.     0.               (g)
   2.     2.     4.     6.     8.
  62.    71.    80.    71.    67.
  34.    43.    11.    10.     3.
   1.     0.     0.     0.     0.
```

FIG. 2. Standard 80 column coding sheet, (a) Title and label of the diagram. The results can be seen in fig. 4. These cards are incorporated into the programme deck; (b) XSC, SCA, DEP. (3F1Ø.4); (c) NDEP, NSPEC, FORMAT (2I4); (d) Pollen sums, FORMAT (1ØF6.1); (e) Depths

NAME DUFTON MOSS A 1969

XSCALE .01 YSCALE .01 DEP 150.

NDEP 5 NSPEC 5

POLLEN SUM	62	74	33	89	72
DEPTH	4	9	29	38	98
BETULA	10	9001	1	1	0
PINUS	2	2	4	6	8
ALNUS	62	71	80	71	67
GRAMINEAE	34	43	11	10	3
CYPERACEAE	1	0	0	0	0

POLLEN SUM CONSTITUENTS

FIG. 3. Count Sheets facilitating the transfer of raw data to coding sheets.

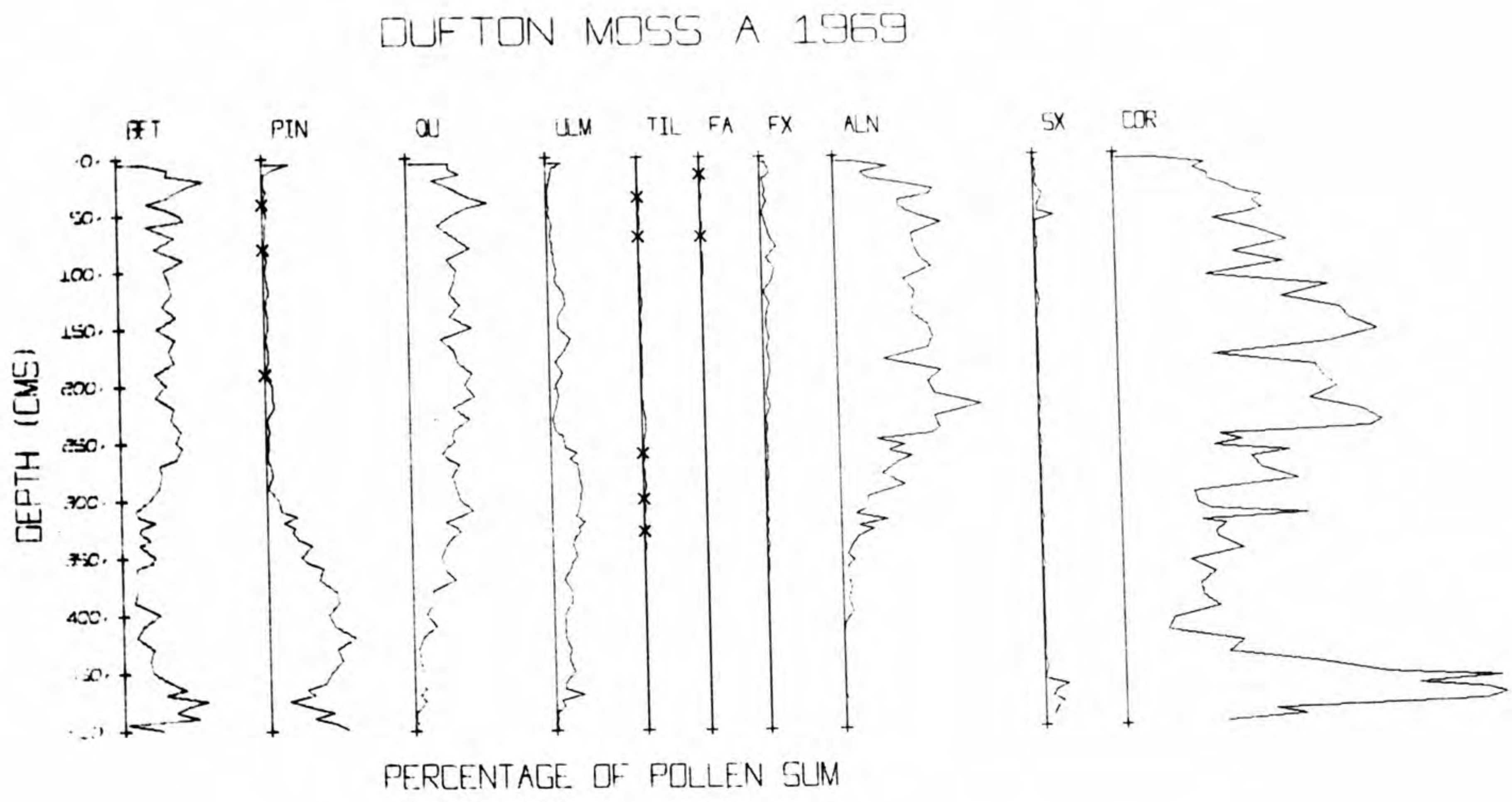


FIG. 4. Part of a scaled pollen diagram, not the product of the numbers in figs. 2 and 3.

CUFTCN MCSS A 1969
PERCENTAGE CF PCLLEN SUM

DEPTHS											
5.0	10.0	15.0	20.0	25.0	30.0	35.0	40.0	45.0	51.0	55.0	60.0
70.0	80.0	90.0	99.0	110.0	120.0	130.0	140.0	150.0	160.0	170.0	180.0
190.0	200.0	210.0	220.0	230.0	240.0	245.0	250.0	255.0	260.0	265.0	270.0
280.0	290.0	300.0	310.0	315.0	320.0	325.0	328.0	335.0	340.0	350.0	355.0
360.0	370.0	380.0	390.0	400.0	410.0	420.0	430.0	440.0	450.0	460.0	465.0
470.0	475.0	480.0	485.0	490.0	495.0	500.0					
PERCENTAGES											
BET											
23.4	42.8	42.0	72.5	58.9	48.5	42.3	24.6	41.7	53.4	56.4	23.6
48.1	30.6	54.9	39.3	42.6	45.0	37.1	48.3	31.8	47.2	42.3	46.1
29.7	38.9	29.9	44.5	43.0	50.6	48.8	47.3	52.3	48.6	46.8	32.8
33.5	32.4	24.2	12.3	14.1	27.5	16.1	14.6	23.2	14.9	27.1	24.6
12.5	11.9	12.1	10.3	30.6	17.0	11.0	25.3	21.8	24.2	39.7	51.5
34.8	70.0	53.3	44.3	61.5	42.7	31.6					
PIN											
23.4	8.9	0.9	0.5	1.3	2.8	0.7	9001.0	1.9	2.7	2.7	1.5
1.8	9001.0	2.8	1.3	3.1	4.2	1.2	3.2	2.5	1.3	3.2	2.5
9001.0	5.8	6.1	6.8	1.2	3.2	2.2	2.3	1.7	1.3	1.2	3.9
5.2	1.2	10.0	11.8	24.5	14.4	23.2	21.0	25.8	36.5	28.2	32.7
46.3	43.1	56.5	58.5	49.7	55.1	71.6	57.4	61.3	52.0	45.5	31.2
37.3	16.2	33.0	53.2	36.5	55.6	65.3					
CL											
36.1	35.7	44.8	22.2	34.4	42.8	51.8	69.0	49.6	37.6	32.6	26.1
39.3	52.5	33.0	40.6	38.8	34.5	43.5	35.4	52.8	27.0	37.8	40.9
53.3	47.0	55.1	36.9	49.6	36.8	36.0	36.5	31.3	26.7	32.2	40.7
35.2	37.5	41.4	52.1	41.2	28.9	38.0	40.7	32.9	28.7	24.6	25.9
26.0	36.3	16.6	16.5	10.9	19.0	8.1	3.8	5.0	7.3	7.0	9.3
5.0	8.7	6.0	1.1	0.6	1.5	2.0					
ULM											
12.7	5.3	3.7	2.9	1.9	1.4	1.4	0.7	1.9	0.6	3.4	3.5
3.1	3.6	4.9	6.6	6.3	13.3	14.1	8.3	8.2	17.5	12.8	4.6
11.4	5.1	6.9	5.4	2.4	3.9	9.7	11.3	12.2	21.2	16.4	21.7
22.5	25.4	23.6	22.0	20.0	26.8	21.9	22.9	18.0	16.7	20.0	16.0
14.5	8.5	14.6	14.3	8.6	8.7	9.1	13.3	11.7	16.4	7.6	7.8
22.7	5.0	6.7	1.1	1.2	0.0	1.0					
TIL											
0.0	0.0	0.0	0.0	0.0	0.0	9001.0	0.7	0.6	0.0	1.3	1.0
9001.0	0.0	0.0	0.6	0.6	1.4	1.9	0.0	1.2	0.0	0.6	0.5
0.6	0.0	0.0	0.6	3.0	3.2	2.2	1.1	0.5	9001.0	1.2	0.0
1.1	1.9	9001.0	0.5	0.0	0.0	0.6	9001.0	0.0	0.5	0.0	0.0
0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
0.0	0.0	0.0	0.0	0.0	0.0	0.0					
FA											
0.0	0.0	9001.0	0.5	0.0	0.0	0.7	0.0	0.0	0.0	0.0	0.5
9001.0	0.0	0.7	0.6	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
0.0	0.0	0.0	0.0	0.0	0.0	0.0					
FX											
4.2	7.1	8.4	2.3	3.3	4.2	2.9	4.9	3.3	1.3	3.4	3.5
7.5	13.1	3.5	10.6	8.2	1.4	6.4	2.5	3.1	5.4	3.2	5.1
4.7	2.9	2.0	5.4	0.6	1.9	0.7	1.1	1.7	2.0	1.8	0.6
2.3	1.2	0.5	1.0	0.0	2.0	0.0	0.6	0.0	2.3	0.0	0.6
0.5	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
0.0	0.0	0.0	0.0	0.0	0.0	0.0					
ALN											
17.0	46.4	23.3	28.6	58.9	83.5	79.5	54.2	54.3	63.6	74.8	89.9
65.0	66.4	71.1	81.3	56.6	66.1	64.7	63.8	77.0	81.0	76.9	39.3
87.1	76.4	80.9	121.2	80.6	84.8	78.9	32.3	54.6	42.4	61.3	48.6
36.4	54.1	23.0	22.0	12.9	38.6	14.8	26.7	14.1	10.1	4.6	10.4
4.6	4.5	7.0	4.6	8.0	0.9	0.4	0.4	0.4	0.0	0.0	0.0
0.0	1.2	0.7	0.0	0.0	0.0	0.0					
SX											
2.1	0.0	1.8	2.3	1.3	2.8	7.2	6.3	2.6	2.7	17.0	1.0
1.2	2.1	1.4	0.6	0.6	0.0	3.2	0.6	0.0	1.3	0.6	0.5
0.6	0.0	0.0	2.0	0.0	0.6	0.0	1.1	1.7	1.3	1.2	0.0
0.5	0.6	0.5	0.5	1.2	2.0	0.6	0.6	1.2	0.0	0.5	0.6
1.5	1.1	1.0	1.0	1.1	1.4	0.9	0.9	0.4	3.1	0.0	20.3
10.1	7.5	15.7	10.7	7.6	8.2	10.2					
CCR											
34.0	78.5	69.1	80.7	80.7	97.1	105.1	126.7	118.5	127.3	114.9	84.9
121.2	146.7	100.7	142.6	78.3	180.9	141.0	190.3	198.7	221.6	182.0	82.3
168.2	175.0	185.7	163.0	207.2	223.6	215.0	86.2	104.0	80.8	144.3	111.8
121.3	150.9	63.3	65.5	77.4	157.9	69.0	89.1	81.2	82.0	103.0	81.4
58.3	78.9	67.1	67.8	81.5	43.4	38.4	101.4	88.6	166.6	223.0	371.8
251.0	310.0	326.3	310.1	126.9	151.5	85.7					

FIG. 5. Tabulated pollen data which result from the same operation as that which produced fig. 4.

TABLE 1. Taxa abbreviations for data sheets (nomenclature after Faegri & Iversen, 1964)

ACE	Acer
ALN	Alnus
APO	Total tree pollen
ART	Artemisia
BET	Betula
CALL	Calluna
CAL	Caltha type
CAM	Campanula
CARY	Caryophyllaceae
CENT	Centaurea cyanus
CER	Cerealia
CHE	Chenopodiaceae
COL	Compositae subfam. Liguliflorae
COT	Compositae subfam. Tubuliflorae
COR	Coryloid
CRUC	Cruciferae
CYP	Cyperaceae
DRO	Drosera
EPIL	Epilobium
ERI	Ericales
FA	Fagus
FIL	Filipendula
FILI	Filicales
FRAX	Fraxinus
GRA	Gramineae
HED	Hedera
HEL	Helianthemum
HIPP	Hippophaë
IL	Ilex
LAB	Labiatae
LYS	Lysimachia type
MEL	Melampyrum
MEN	Mentha type
MER	Mercurialis
MYR	Myriophyllum
NAP	Total herb pollen
NAR	Narthecium
ONO	Ononis type
ONOB	Onobrychis type
OXA	Oxalis
PAP	Papilionaceae
PIN	Pinus
PLA	Plantago lanceolata
PLO	Plantago others
PMM	Plantago major/media
POB	Polygonum type bistorta
POC	Polygonum type convolvulus
POLY	Polypodium
POT	Potentilla type
POTA	Potamogeton
PTR	Pteridium
QU	Quercus
RAN	Ranunculus
RANE	Ranunculaceae
RCH	Rubus chamaemorus
RHI	Rhinanthus type
ROS	Rosaceae
RUB	Rubiaceae
RUD	Ruderals
RUM	Rumex
SAX	Saxifraga
SCR	Scrophularia
SEL	Selaginella
SOR	Sorbus type
SPA	Sparganium
SPER	Spergularia type
SPH	Sphagnum
SPO	Total shrub pollen
STEL	Stellaria
SUCC	Succisa
SX	Salix
TAX	Taxus
TEU	Teucrium
THA	Thalictrum
TIL	Tilia
TYP	Typha
ULM	Ulmus
UMB	Umbelliferae
URT	Urtica
VAL	Valeriana
VIC	Vicia type

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