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HUMIC AND POLLEN STRATIGRAPHY

AT QUICK MOSS, NORTHUMBERLAND

THELMA KATHLEEN ROWELL, B.Sc. (Dunelm)

Being a thesis submitted for the degree
of Master of Science of the University
of Durham.



DEPARTMENT OF BOTANY

UNIVERSITY OF DURHAM

SEPTEMBER, 1982

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KATHLEEN ROWELL

Abstract

This study involves the selection and use of suitable methods for measuring a) the rate of peat growth and b) the degree of humification of peat at Quick Moss, an area of blanket peat in the northern Pennines where the earliest peat is about 8,000 years old.

The stratigraphy of the peat section is examined systematically for a) variations in peat growth by adding tablets containing spores of Lycopodium clavatum to peat samples during routine pollen analysis and b) the degree of humification of the peat by chemical extraction and assay of the humic acids present in each sample.

Two distinct regions are identified in the peat section and a change in the relationship between growth and humification is found to take place at the boundary between the two. The growth rate and degree of humification of the peat, and consequently the relationship between growth and humification at a specific level in the section, appear to have been principally controlled by the prevailing climate, through its effect on humidity and temperature at the bog surface at the time the peat forming plants were growing.

The radiocarbon-dated pollen diagram indicates possible local Mesolithic activity, small scale Bronze Age deforestation and an extensive clearance beginning in pre-Roman times and continuing through and beyond the Roman period. A late expansion of alder, the transition from woodland to bog and a rather prolonged elm decline can be seen on the diagram.

INTRODUCTION1. Peat Stratigraphy and Growth

Early this century, variations in the appearance of peat from different depths were recorded by Weber (1900) in raised bogs in Germany and he related them to changing growth patterns in the peat. A distinct boundary, which he called the Grenzhorizont, was seen to divide a lower dark, highly humified peat from an upper pale, slightly humified peat. The change in the structure of the peat at the Grenzhorizont was attributed to a sudden change in climate from extremely dry conditions, under which existing peat ceased to grow and became progressively more humified, to very wet conditions which stimulated rapid growth of Sphagnum. Artefacts found in the peat in Germany showed Weber's Grenzhorizont to have formed at the end of the Bronze Age, about 500 BC; a time which equated with the transition from the Sub-Boreal to the Sub-Atlantic period of Blytt and Sernander, and also with Godwin's zones VIIb/VIII. These schemes for subdividing the Post-glacial period are described by Pennington (1974). It is generally accepted that there was a widespread deterioration in climate at this time but whether peat growth had halted completely in a particular bog before the renewal of growth is uncertain.

In addition to the major boundary recorded by Weber, some investigators have described other horizons. Whilst working in Sweden, Granlund (1932) was able to identify five horizons which he called 'recurrence surfaces'; the main feature of each being a renewed growth of peat, seen as a band of light coloured peat following a region of dark



peat produced during a period of slow growth. The five recurrence surfaces were named and dated as RYV = 2,300 BC, RYIV = 1,200 BC, RYIII = 500 BC, RYII = AD 400, RYI = AD 1,200. Granlund equated RYIII with Weber's Grenzhorizont.

At a later date, Nilsson (1935) identified nine recurrence surfaces at a different bog in Sweden.

Until radio carbon dating of peat allowed more precise studies of bog stratigraphy, the dating of levels showing obvious changes in peat growth was based on changes in the relative frequencies of different taxa in the corresponding pollen diagram. Difficulties arose in correlating recurrence surfaces as pollen zones were found to be chronologically inconsistent from site to site.

On pollen evidence alone, Conway (1954) suspected that the major change in S. Pennine peat was earlier than the Grenzhorizont and more likely to correspond to RYIV than RYIII. In interpreting recurrence surfaces she also described the importance attached by von Post to a 'moisture threshold' which must be exceeded before bog growth will accelerate. Von Post proposed an interesting interpretation of Granlund's five recurrence surfaces, suggesting that they resulted from rhythmic climatic cycles with a period of 900 yrs. (Conway 1948).

More recently, and with the benefit of radio carbon dating, Tallis and Switsur (1973) identified the main recurrence surface in peat at a S. Pennine site at bc 735, about the date of the Grenzhorizont.

In her work at Tregaron, Turner (1964), in addition to dating the main recurrence surface, used a series of radio carbon dates to calculate the rate of peat growth before and after the event. She found that growth had been very slow for 700 years and gave way to rapid growth at about 700 BC; a date consistent with the Grenzhorizont and RYIII.

Less pronounced changes in peat texture were also noted at later dates.

Some workers, e.g. Overbeck et al. (1957) in Germany and Lundquist (1962) in Sweden, have found variations between the dates of their recurrence surfaces and those of others. In some bogs different dates have been obtained from the same recurrence surface (Godwin 1975) and in others, e.g. Dickinson (1975) the recurrence surfaces have been found to be synchronous across the bog. Although climatic change is thought to have played a major role in controlling peat growth rate and hence recurrence surfaces, the variations caused by climate at different bogs, and even at separate sites on the same bog, have probably also been modified by local conditions such as altitude, proximity to the sea, and the drainage system of the bog. In the light of this work it follows that attempts to explain growth patterns in peat from one bog in terms of major climatic shifts in prehistoric times need care because of the specific conditions which may have prevailed locally.

Two periods, however, have been shown by several workers in N. Europe to have undergone a change from extreme dryness to wet conditions. A resurgence of bog growth at the level of Weber's Grenzhorizont is a widespread phenomenon confirmed by radio carbon dates to have occurred about 2,500 BP. Both trees and man-made log trackways have been recovered from peat of this age showing how they were overwhelmed by Sphagnum as it responded to the increased wetness (e.g. Godwin 1975). A similar occurrence at the Boreal-Atlantic transition (7,000 BP) has been identified by Nilsson (1964) and Hibbert, Switsur and West (1971) by estimation of peat growth rates from radiocarbon dates. This horizon, in the lower amorphous peat, would be less distinct visibly than the Grenzhorizont and it is earlier than the oldest recurrence surface of Granlund. Dating has been useful in its identification and also in confirming the change in climate suspected by Blytt and Sernander when they zoned the Post-glacial period.

Another feature, which was noted and recorded as early as the 17th century (Barber 1981), is the frequent presence of wet hollows and dry hummocks on bog surfaces. Many workers in the first half of this century attributed this phenomenon to a cyclical ecological succession in which a wet area gradually filled with rapidly growing Sphagnum which then rose above the water table to form a hummock. A subsequent collapse of the dry hummock due to retarded Sphagnum growth, death and then humification was thought to have resulted in flooding of the area once more.

More recently, however, Aaby (1976) has shown that, at Draved Mose in Denmark, hummocks have been in the same place for 2,500 years and they have not been replaced by wet hollows although the hummocks have fluctuated in size. The dates of the fluctuations were found to correspond with recorded changes in climate.

A detailed consideration of the investigations of earlier workers, particularly those conducted since 1960, together with his own extensive investigation of the stratigraphy of cut peat faces at Bolton Fell Moss in Cumbria, led Barber (1981) to reject the earlier hollow-hummock theory of raised bog growth in favour of his 'Phasic' theory which proposed wet and dry periods of climate as the principal factors responsible for controlling bog development, including recurrence surfaces. He considered local conditions to be of secondary importance to climate.

Much of the work described so far has been done on raised bogs, mostly at low altitude and many outside Britain. In most cases peat growth and possible controlling factors, such as climate, have been investigated and, since Weber's time, visible changes in the degree of humification have been taken to indicate changes in the peat growth. There have, however, been few investigations into the nature of humification itself and how it may be involved in peat growth.

With these points in mind it was decided to investigate the rates of growth and degrees of humification of the blanket peat at Quick Moss, a high altitude site in the northern Pennines, and to see how they are related. Quick Moss was chosen partly because little work on this aspect of the subject has been done in the immediate area and partly because much of the earlier work on the nature of peat growth and its relationship to humification has been done on bogs at lower altitudes where the peat has grown under different physical conditions. At the same time it was planned to do a pollen diagram from the site to show the general vegetational history of the Quick Moss region and how it compared with that from other northern sites and to show any particularly 'local' features.

It was necessary to select practical qualitative methods for determining growth and humification before the project could begin. Several techniques which had been used by others were considered.

Methods of measuring the rate of peat growth

As Clymo (1970) points out, the term growth is difficult to define for a bog. It is difficult to make a clear division between live plants, dead plants and peat. In this study, unless otherwise stated, the term growth refers to the accumulation of peat. The net production of surface vegetation is considered later but only as a factor associated with peat accumulation.

Active growth of a bog can be estimated over short periods by observing the movement of the surface against static marker stakes driven into the ground below the peat. For buried peat, a close series of radiocarbon dates from a profile can give an approximate idea of how long it took 1 cm. of peat to accumulate. This technique was demonstrated

by Aaby and Tauber (1974) when they estimated peat growth, at Draved Mose in Denmark, from a series of 55 radiocarbon dates over 2.5 m. depth of peat. The large number of radiocarbon dates was needed to build up an accurate picture of growth rate as otherwise significant changes of short duration would have been missed.

A possible alternative approach is to use, in a modified form, one of the methods developed for determining pollen concentration in a peat sample although this method is only applicable when one can demonstrate that pollen influx has been constant. If pollen has fallen on to the bog and become incorporated into the peat at a constant rate, then the number of grains in a unit volume of peat will depend on how long the peat has taken to accumulate. A known volume of quickly growing peat would contain fewer pollen grains than the same volume of peat which had taken longer to grow. By the same reasoning a sample of peat yielding a high pollen count will have grown slowly and a sample of the same size containing fewer pollen grains would have grown more rapidly. When a peat profile is tested at several points for pollen concentration, a picture of how peat growth increased and decreased during its history can thus be built up. This method does not give an absolute measurement of growth rates but it does indicate relative rates. The actual rate of peat growth can only be calculated if the method is used in conjunction with radiocarbon dates of selected horizons. It must be remembered, however, that using pollen concentration as a guide to growth rates in peat is only valid when pollen influx has been uniform. If the pollen data from Quick Moss suggest this has been so then a method for determining pollen concentration can be adapted to show peat growth rates.

Methods of measuring pollen concentration

Several methods have been used for determining pollen concentration. In each method the technique depends on counting the pollen grains in an extract of deposit which has been accurately measured by weight or volume and which has a known size relationship to the sample from which it was taken.

An early procedure described by Conway (1947) used peat samples of unit weight from which standard volume extracts were mounted on slides after acetolysis. The number of traverses needed to count 150 tree pollen grains gave a measure of peat growth. Since then three basic methods have been used. Some workers, e.g. Jørgensen (1967) weighed the initial sample of deposit and re-weighed it after acetolysis and suspension in glycerol. All the pollen grains in a small weighed extract of the suspension were counted and the results were used to calculate the numbers of grains in the initial sample. Other workers adopted a similar procedure but used accurately measured volumes of sample and extract, as described by Davis (1966) in her work on lake sediments. A third method, which avoids having to count all the pollen in the extract, was introduced by Benninghoff (1962). He used large quantities of easily recognisable pollen grains, which were not naturally found in the sample, as a standard. These grains or 'exotics' were suspended in glycerol and their concentration was found by a haemocytometer count. A known volume of exotic suspension was added to the weighed residue of a weighed sample after acetolysis. Routine counting of the grains in a small extract of the residue/exotic mixture revealed the ratio of exotics to pollen. Since the number of exotics added was known then the total pollen in the initial sample could be calculated.

Other workers have developed variations and improvements of

Benninghoff's method. Some have used different exotic grains and Craig (1972) experimented with pollen-sized plastic balls instead of natural material. In some cases the suspension medium has been modified to stop the exotic grains settling out. An attempt to achieve a more homogeneous final mixture of grains led to adding the suspension of exotics to a measured sample before acetolysis. Details of these variations are described by Matthews (1969), Bonny (1972) and Dickinson (1975).

The principal disadvantages of the Benninghoff method and its variations lie in maintaining an exotic suspension of constant concentration and in the need for regular use of a haemocytometer to check the concentration of the suspension.

More recently Edwards and Gunson (1978) have shown that small tubes of exotic grains in glycerol can be prepared in large quantities and can be stored for at least 5 years without deterioration. By using a Coulter Counter, rather than a haemocytometer, the pollen concentration in the suspension can be quickly found. This method was thought to be an improvement if large numbers of samples were to be examined.

An alternative to a liquid suspension of exotics was devised by Stockmarr (1972a). Spores of Lycopodium clavatum were used as exotics and, after being homogenised with powdered chalk, they were compressed into tablet form using pharmaceutical equipment. Standardising the tablets was first done by counting all spores in weighed subsamples and later by using an electronic particle counter or Coulter Counter (Stockmarr 1972b) and the numbers of spores in the tablets was found to be consistent. The tablets provide a convenient way of adding a known number of exotic marker grains without the need to assay a suspension. In addition they can be commercially produced and thus made widely available.

It was decided to use Stockmarr tablets for this study as they are convenient to use and have been found to be a reliable alternative to a liquid suspension (Edwards and Gunson 1978). The tablets were preferred to other methods because of the need to treat the samples from Quick Moss over a period of several months during which it might have been difficult to maintain a homogeneous suspension of exotic grains in a liquid medium. Haemocytometer assay of exotic grains in a suspension would also have been essential at regular intervals.

Use of Stockmarr tablets

Each tablet contains $11,850 \pm 200$ spores of Lycopodium clavatum which are easily recognised. Lycopodium clavatum spores have not been found in significant numbers in northern Pennine peats and may thus be considered exotic. Although L. clavatum is an upland plant it grows in drier habitats and not on bogs.

When a tablet is added to a known volume of peat and the peat is then prepared for pollen analysis, a known number of Lycopodium spores will be processed with the pollen in the peat. On adding the tablet a ratio is established between the number of spores added and the number of pollen grains contained in the peat sample. Providing the mixing is thorough, the ratio remains constant in any subsample or extract taken from the mixture, whatever its size. If the same number of spores, e.g. 1 tablet, is added to each of several samples of peat of equal volume then a different ratio of spores to pollen will be established in each. The size of the ratio will be determined by the number of pollen grains in each sample, since the spore number is constant. After acetolysis the same ratio persists in the very small extract mounted on a slide for pollen analysis. Routine counting of Lycopodium spores and pollen grains reveals the ratio and it can then be used as a possible

peat growth indicator. If a large number of samples from a peat profile are treated in this way, provided pollen influx has been more or less constant, the results can be plotted against peat depth to give a pattern of growth changes during the life of the bog.

Although the number of Lycopodium spores in each tablet is known, the actual number is not important in this test, providing it is the same for all tablets.

2. Humification of Peat

Granlund (1932) suggested that the degree of humification of a peat surface reflected the rate at which the peat forming plants were growing when at the bog surface. Highly humified peat would have been produced in dry periods and less humified peat in wetter conditions when the plants were growing rapidly. Results of subsequent investigations have led some workers to agree with this but others, e.g. Aaby and Tauber (1974), have not been able to show a clear correlation between peat growth and degree of humification. After investigating 2 vertical series of contiguous samples at Draved Mose, a low altitude raised bog in Denmark, Aaby and Tauber (1974) were able to demonstrate only a partial correlation between peat growth and humification although a clear negative correlation was shown between humification and the humidity at the time the peat flora was growing at the surface. Humidity in this case was deduced from the numbers of the rhizopods Amphitrema and Assulina counted during pollen analysis. Their siliceous tests resist acetolysis and, in life, their numbers increase with wetness in raised bogs. It is surprising that humification appears to be related to surface wetness but not always to the rate of peat growth when peat growth itself is thought

to be controlled by wetness.

Humification is a natural process, brought about by aerobic saprophytic microorganisms in soil, and it results in the change of dead organic remains, through stages of disintegration, to humus: a black, structureless, colloidal mass. Humic acids accumulate as by-products but they are quickly neutralised by naturally occurring bases in most soils. Moorland bogs are almost devoid of minerals, as rain is the main water source, so humic acids are not neutralised and they accumulate resulting in a low pH. Bacterial and fungal activity is inhibited by the acidity and by the anaerobic conditions caused by waterlogging so normal processes of decay are severely retarded. Incompletely decayed (partially humified) bog plants accumulate as peat instead of forming humus. The extent of the humification which has taken place is shown by the colour of the peat. It ranges from pale brown in slightly humified layers to very dark brown where humification is almost complete.

Most peat is currently below the water table of the bog in anaerobic conditions therefore, because oxygen is necessary for the metabolism of decay - causing bacteria and fungi, any humification of the peat must have taken place nearer the bog surface, above the waterlogged level. This has been demonstrated experimentally by Clymo (1965) in a bog near Moor House in the northern Pennines at almost the same altitude (575 m. O.D.) as Quick Moss. Sphagnum was found to break down rapidly in the aerobic zone at the bog surface and very slowly in the waterlogged anaerobic zone. The anaerobic zone was identified by its blackening action on buried copper wire due to the activity of anaerobic, sulphate reducing bacteria, e.g. Desulphovibrio. In the experiment, bundles of Sphagnum were buried at varying depths in the bog and decay rates were noted. When this was repeated in a lowland bog in the south of England, where the climate was warmer, a more rapid breakdown

was observed. It follows then that, provided the temperature remains fairly constant, the longer a plant remains in the upper aerobic region of the bog the more broken down and humified it will become.

It has been shown in Clymo's investigation that the depth at which the anaerobic zone begins fluctuates throughout the year, probably due to seasonal variations in the water table. Over a period of years small scale oscillation could vary the water table level more markedly, increasing or decreasing the time taken for dead plants to reach the anaerobic zone and so affecting the extent of humification. The water table level would also fall if bog drainage increased, either naturally by erosion or by man's activity such as peat cutting or digging drainage channels. Since the metabolism of microorganisms proceeds best at an optimum temperature, which is probably only achieved in the summer, then cold weather also will retard humification and freezing of the bog surface in winter will halt it completely.

In addition to the physical factors involved, the composition of the bog flora may affect the degree of humification. Identification of recognisable plant remains in peat shows that the dominant species vary and experiments have demonstrated that the rate of decay also varies in different plants. Clymo (1965), for example, found that different species of Sphagnum had different rates of decay. In a given time S. papillosum, a coarse leaved species, showed about half the decay, measured by weight loss, shown by S. cuspidatum and S. acutifolium. It was also found that roots of living Eriophorum plants were sometimes found 75 cm. deep in the anaerobic zone, leaving little possibility of decay after the death of the plant. Highly humified, waterlogged peat frequently contains pieces of Calluna stem as well as partly decayed Eriophorum remains but no recognisable Sphagnum. Tough plants, which take longer to decay, probably reached the anaerobic zone

in a better state of preservation than more delicate plants like certain of the Sphagna.

Humification in peat can therefore be seen to be a natural biological process which can be accelerated, retarded or suspended by the local conditions existing in the bog. While a plant is above the water table of a bog it will continue to humify at a rate controlled by temperature and the species involved. Many factors interact to determine the level of the water table including climate, the growth and decay rate of plants at the surface and natural drainage. A lowering of the water table may also result from human activity, e.g. burning, grazing and artificial drainage of the bog.

Although these points associated with humification stress the aerobic nature of the process, it is possible that further changes to the peat may take place once it has become waterlogged. As Aaby and Tauber (1974) pointed out, compression of lower layers could cause changes, since there is a great mass of vegetation pressing down on these layers. There is also the possibility of continued decay by slow anaerobic microbial action

Methods of measuring the humification of peat

Mention of the extent of humification in peat has so far been only descriptive, e.g. 'highly' humified, and classification of peat types in this way is purely subjective. Some form of measurement is needed for greater accuracy. A method which is simple, fairly accurate and useful in the field was devised by von Post and Granlund and described by Faegri and Iversen (1975). When a handful of peat is squeezed the colour and texture of the exudate indicates humification on a scale 1 - 10. The exudates range from a clear pale liquid (1) to a very dark gelatinous

material (10). This method can be extended by microscopic examination of the peat and a standard based on the degree of preservation of Sphagnum remains is used. A general agreement between the colour of the peat and the appearance of the Sphagnum remains was found by Dickinson (1975) when she used the state of preservation of the Sphagnum as an indicator of degree of humification. However a more accurate chemical method has been developed and it was decided to use this in this study. It was first developed by Overbeck, modified by Bahnson and subsequently published in an English translation by Aaby and Tauber (1974). The method is based on the assumption that humic acids accumulate in peat in direct proportion to the humification, or decay, which has taken place. Humic acids are extracted from peat samples of constant weight by dilute sodium hydroxide solution and a small proportion of each extract is tested in a colorimeter. As in von Post's quick estimation of humification, the colours of extract vary from pale yellow to very dark brown. The light absorption, as measured by a colorimeter, is proportional to the amount of humic matter present in each sample. A conversion factor, which can be used to convert colorimeter readings to percentage humification, has also been worked out by the above authors in the following way. Serial dilutions of a commercially prepared 100% humic acid standard were tested on a colorimeter and the results produced a calibration curve with the formula $y = 0.12x - 0.1$ where y is the colorimeter reading and x is % humification of the standard. % humification (x) for a peat extract can therefore be calculated from $x = 8.3 (y + 0.1)$.

When Aaby and Tauber used this method they were able to show small but distinct variations in % humification as well as more pronounced changes throughout their profile. The observations do not support the ideas of some early workers who predicted a gravitational movement of humic acids within the peat. If this had happened then a gradient of humification values moving towards a maximum value at the base of the

peat would have been found. Peat appears to remain in discrete layers, each with its own degree of humification which can be measured.

Layers with visible colour variations, showing that the degree of humification has varied throughout the profile, are clearly seen in sections at Quick Moss in deep erosion channels, and the deep blanket peat represents a long period of growth. It is therefore a suitable site for a series of growth and humification measurements.

3. Quick Moss

Quick Moss (or Quick Cleugh Moss) (NY 852422) is a large area of blanket peat occupying between 1.5 and 2 km² of moorland at the northern end of the Pennines (Figs. 1.1 - 1.4). It lies at an altitude of 510 m. O.D. in the county of Northumberland, near the boundary with the N.W. corner of County Durham, and 1.5 km. N.N.E. of the point where the county boundary crosses the minor road from Eastgate in Weardale to Allenheads in Allendale. This area of upland forms part of the watershed between the valleys of the Tyne and the Wear. Two rivers, the Derwent and East Allen, which flow northwards towards the river Tyne rise in this area and so does the Rookhope burn which flows to the south towards the river Wear. Water draining from Quick Moss gives rise to the Quick Cleugh Burn, a tributary of the river Derwent.

Although there are no meteorological records from the immediate area of Quick Moss, evidence from other stations gives an idea of the prevailing climate. In the 1930's Manley (1936) began to collect records at Moor House in Upper Teesdale at almost the same altitude as Quick Moss. His findings, together with those of more recent workers in many areas of County Durham, have been presented in a comprehensive account

by Smith (1970). Records from the Pennine upland region of the county indicate an extreme climate with winds from varying directions reaching gale force from time to time throughout the year. It has been estimated that annual rainfall in Upper Weardale totals 1650 mm., compared with only 630 mm. at the coast, and that it falls on a total of 220 days in the year. Records from Moor House show that mean winter temperatures are below freezing point and, at times, the surface peat has frozen to a depth exceeding 30 cm. Snow is frequent in the winter and can cover the ground for several weeks. All of these factors combine to produce a much harsher climate, with a growing season 2 months shorter than that of the surrounding lowlands. This fact was emphasised by Manley who concluded that temperatures in the high Pennines are equivalent to those at sea level 10° of latitude further north which is almost at the Arctic Circle.

The tract of moorland in which Quick Moss is situated forms part of the Allendale estates and is managed for grouse shooting and sheep grazing. In the interests of providing young heather shoots, to feed the grouse, and moorland grasses for the sheep, the vegetation is burnt on a 10 year rotation (Estate Keeper). The advantages to the owner of this period of rotation over a longer cycle are pointed out by Rawes and Hobbs (1979) who studied the effects of fire on moorland vegetation at Moor House in the northern Pennines. They discovered that if the time interval between burning episodes on an area is longer than 10 years then Calluna is able to grow to its maximum size and when burnt the intensity of the fire retards regeneration of new plants. A 10 year cycle allows immediate recovery of Eriophorum followed by young Calluna springing from surviving side shoots. The young Calluna produces many more flowers than the older plants so Calluna pollen would also be well represented in the peat after burning.

Rawes and Hobbs (1979) have also shown that reducing the number of sheep favours the growth of Calluna instead of Eriophorum. Some Calluna is needed at Quick Moss to feed the grouse so presumably a balance is achieved between the two interests by regulating the number of sheep. Parallel ditches, which can be seen clearly on the aerial photograph of the bog (Fig. 1.5), have been dug into the surface peat, at an unknown date, to drain water from the bog into a tributary of Quick Cleugh Burn. The resulting drier conditions on the bog surface would be expected to favour growth of Calluna and Eriophorum, at the expense of Sphagnum, for the benefit of sheep and grouse. This is one way in which man can create drier conditions and so cause increased humification in the peat. In the opinion of the Keeper though, the bog is still too wet and more drains are needed.

The blanket bog at Quick Moss has some very wet areas, especially on the almost level land near the ridge. Actively growing communities of Sphagnum and other bog species are found in pools and on hummocks. Drier tracts dominated by Calluna and Eriophorum are encountered where the slope increases. On the slope dissection of the blanket peat has developed: water draining from the bog has formed a series of pot holes most of which have coalesced to form deep channels in the peat. The channels vary in width and the drainage streams in the bottom of each flow down a fairly gentle 6% gradient. A mixture of grey mud and broken sandstone pieces from the underlying bed rock forms the bed of each stream. The sides of the channels show the full depth of peat which has been exposed by erosion and it varies in thickness from place to place between 20 cm. and 300 cm. Variations in peat depth seem to reflect the topography of the underlying mineral surface as the modern peat surface presents a fairly uniform slope. This point was demonstrated by Rendell (1971) who did a series of borings along a 0.75 km. transect, one end of which was 1 km. south of Quick Moss. He found that the depth of peat

varied between 30 cm. and 433 cm. along the transect, although the surface was fairly uniform, so he concluded that deep peat had formed in natural hollows and the underlying ridges had a thinner cover.

The system of streams draining the bog can be seen in the aerial photograph (Fig. 1.5). They converge to form Quick Cleugh Burn which flows away to the N.N.E. to join the river Derwent. Immature drainage channels appear as isolated dark marks on the photograph. They are isolated from the main channels by a continuous peat cover but in most cases an underground connection exists and one day the surface peat will collapse and reveal the stream which has been eroding the lower layers of peat.

A sampling site was chosen in one of the deeper erosion channels where 3 m. depth of peat had been exposed. Although the site itself is just off the aerial photograph the terrain is very similar to that which can be seen on the photograph (Fig. 1.5). Since the growth of 3 m. of peat will have covered a long period of time then it seems appropriate to consider the local history.

4. History of the Quick Moss Area

This area of northern England has few prehistoric monuments but it is known, from a variety of artefacts found over a large area, that man has been present since Mesolithic times, although perhaps not continuously (Fig. 1.6).

Many flints, ranging from Mesolithic to Bronze Age types have been recovered in the Upper Wear Valley by Fell and Hildyard (1953), and others, from places where the soil has been disturbed, e.g. in ploughed fields and

in excavations for a new water main. The upland soil surfaces are mostly covered by a thick layer of peat but this has eroded at Rookhope Chimney (NY 906444), following the destruction of the surface vegetation by arsenic fumes, and an assemblage of flints of Mesolithic, Neolithic and Bronze Age types has been revealed. Although the remaining peat may be concealing other useful evidence, the Rookhope Chimney finds show that man has been present within 4 km. of the Quick Moss site at various periods in prehistory.

Most of the scattered finds can be classified by type but have not been found in a datable context. Johnson and Dunham (1963), however, discovered Mesolithic microliths associated with horn fragments from ancient cattle (Bos primigenius and Bos taurus taurus) embedded in deep peat on Cross Fell (see Fig. 1.2). Pollen analysis of the peat inside the horns showed it to have formed during the Atlantic period (from about 5,000 BC) and this agrees with dates for similar finds in other parts of the Pennines (e.g. Walker 1957). There have been no such finds at Quick Moss but numerous microliths of a similar type have been found at Greenfield Quarry (NY 852422), only 5 km. away from Quick Moss, where a Mesolithic flint chipping floor has been identified.

It seems likely that the Pennine uplands were widely used for hunting in Mesolithic times although it has been suggested that it may have been a seasonal activity from more permanent settlements near the coast. Probably the lightly wooded uplands with small streams provided a more suitable habitat for large herbivores, than the dense woods of the valleys, and consequently a richer hunting ground. Simmons et al. (1981) have presented the evidences for climate at this time. It is thought the average temperature was 2^oC higher than today, giving a longer growing season and less extreme winters, although wind and rain were increasing in the uplands. During this time the climatic optimum

occurred, when temperatures reached a maximum after the last glaciation and this was followed by a slow decline beginning around 4,000 BC. The upland conditions must have been much less harsh than in later periods.

A cultural change from a hunting to a farming economy marked the beginning of the Neolithic period. Concentration of activity in one area led to the growth of settlements and religious and burial sites which can often be detected today in some parts of the country. With the exception of one possible long barrow at Ireshopeburn (Clack and Gosling 1976), Neolithic remains have not been found in the study area. Neolithic artefacts are however widespread; flints have been recovered from several sites in the valleys and on the fells around Weardale and Allendale. Either the associated settlement sites have not been detected or they were some distance away, perhaps nearer the coast; the flints having been used by occasional hunting parties. Many polished Langdale stone axes of this period have been found in Weardale suggesting that the valley may have been part of a West to East trade route. It seems that during Neolithic times the area may not have been permanently populated but that man passed through from time to time. Some workers think the climate had deteriorated in the uplands by this time, as discussed by Smith (1981), and this may partly explain the apparent absence of habitation.

Immigrants from the continent of Europe introduced copper working techniques, and new customs, which were gradually adopted by the native British population from about 2,500 BC to 700 BC. During this Bronze Age period it is known that man was associated with the study area because of flint finds and, most notably, the hoard of bronze implements from Heathery Burn, Stanhope (Britton 1971) and a similar hoard from neighbouring Eastgate (Cowan 1971) in Weardale. Quite a late date, 8th century BC, has been given to the Heathery Burn hoard because of the

lead content of the bronze. A bronze axe of this period also was found in Allendale (Clack 1980).

It appeared that, like the Neolithic period, there were no signs of human habitation in the area, except for possible occupation evidence from Heathery Burn Cave. More recently though, a possible cairnfield near Heathery Burn and a possible group of round burrows near Eastgate have been recognised (Clack 1980) so settlements may yet be found.

The evidence for permanent occupation in the uplands during the Bronze Age is still inconclusive although Bartley et al. (1976) have shown, from pollen diagrams, extensive clearances representing concentrated human activity in the lowland areas of S.E. Durham from about 1600 BC.

Throughout this period the uplands probably became less suitable for habitation due to a deterioration in climate which gave way to a wet, cool period around 800 BC, near the end of the Bronze Age.

From about 700 BC the inhabitants of Britain began to apply iron-working technology, newly introduced from the continent. The Iron Age culture developed over the next 800 years but then underwent varying degrees of modification during the Roman Occupation, which in northern England spanned the period between approximately AD 80 and AD 410. In contrast with the durable monuments left by the Romans, the remains of native buildings of the pre-Roman period have not been found in the northern Pennines, although there are many in the hills of Northumberland. In spite of this, however, it is probable that parts of the area were reasonably well populated as pollen diagrams from several sites indicate clearance of forest and an increase in agriculture in pre-Roman times (Turner 1979).

It is difficult to say what influence, if any, the Romans had on the British people living in the northern Pennines but, since Quick Moss is in an exposed position and completely surrounded by Roman remains (Fig. 1.7) at distances between 11 km. and 25 km., some general conclusions may emerge from a study of the pollen record of the bog. The Roman roads encircling this upland area, many of the forts and Hadrian's Wall had been completed by AD 130; tasks which must have involved native labour and an increased demand for food. Large scale forest clearances and increase in pasture plants, arable weeds and cereals are recorded in many pollen diagrams at this time (Turner 1979). There is also evidence that a period of improved climate persisted throughout most of the Iron Age and Roman times (Turner 1981) and this would have favoured crop growth. The site at Bollihope in Weardale shows a different pattern in that it appears not to have been used until Roman times (Turner 1979). It is in this area also that possible native settlements of the Roman period have been found: one at Bollihope and three others not far away, recently identified on aerial photographs (Clack 1980).

There were no Roman roads in Weardale and Allendale so the study area remained isolated from direct Roman influence. Even so, the discovery of commemorative altars at Bollihope and Eastgate shows that Weardale was known and used at least by Roman officers on hunting expeditions. A route across the Allendale Fells, to the north of Quick Moss, was probably used to transport Alston lead to Corbridge. The mines are known to have been supervised by the Romans during the third century and traces of the lead have been discovered at Corbridge (Richmond 1963).

After the Romans withdrew in about AD 410, there follows a period of uncertainty. The pollen record suggests that farming continued for a time and that eventually trees regenerated in some areas. It is thought

that the climate deteriorated also. Apart from three possible Anglo-Saxon settlement sites in Weardale (Clack 1980), there is no recognisable evidence of human habitation in the area. It is likely though that small populations persisted during the period and that they gave rise to the people mentioned in Boldon Book, the first documentary record in the 12th century. Boldon Book was compiled for Bishop Puiset about 1180 and contains an inventory of the resources of his estates including lead, coal and iron mines in Weardale so it may be assumed that people were living in Weardale at that time.

This and other information is included in a comprehensive survey of the history of man and his activity in Weardale from Roman times, based on pollen diagrams, documentary and archaeological evidence and place names, presented by Roberts et al. (1973). Farming and mining seem to have been the main occupations and the size of the Weardale population appears to have fluctuated as local conditions changed. A population reduction in the 14th century could have been caused by factors such as famine, plague, deteriorating climate or Scottish raids. The expansion of the lead industry from 1660 to 1800 resulted in a notable population increase and an associated small change in land use. Miners cultivated pieces of marginal moorland, or intakes, next to their upland cottages but when the industry declined around 1880 many people left the area and the cultivated land reverted to moorland.

During this time further oscillations in climate have been recorded. A warm period is noted in the 12th and 13th centuries, swinging to very cold conditions by the 17th and 18th centuries and since 1900 there has been a general rise in temperature (Lamb 1977).

These examples illustrate the value of documentary evidence in indicating with more certainty the size of populations and possible reasons for fluctuation, the occupations of people, pressures on vegetation

and the effects of climatic changes. Unfortunately, 800 years of recorded history is a short period compared with 7,000 years of human occupation in the area. For a better understanding of man's activity during most of this time, information must be gleaned from sources other than documents. The pollen record in peat deposits is one such source.

Fig. 1.1 - Fig. 1.4

A series of maps with increasing scale showing the location of Quick Moss within the British Isles

The small rectangle marked on each map shows the area enlarged in the next map. The rectangle on Fig. 1.4 is the approximate area of the aerial photograph (Fig. 1.5).

Pollen Sites

Fig. 1.2 includes pollen sites in the study area which are referred to in the text.

Key to sites

B	Bollihope
F	Fellend Moss
H	Hallowell Moss
P	Pow Hill
S	Steward Shield
V	Valley Bog

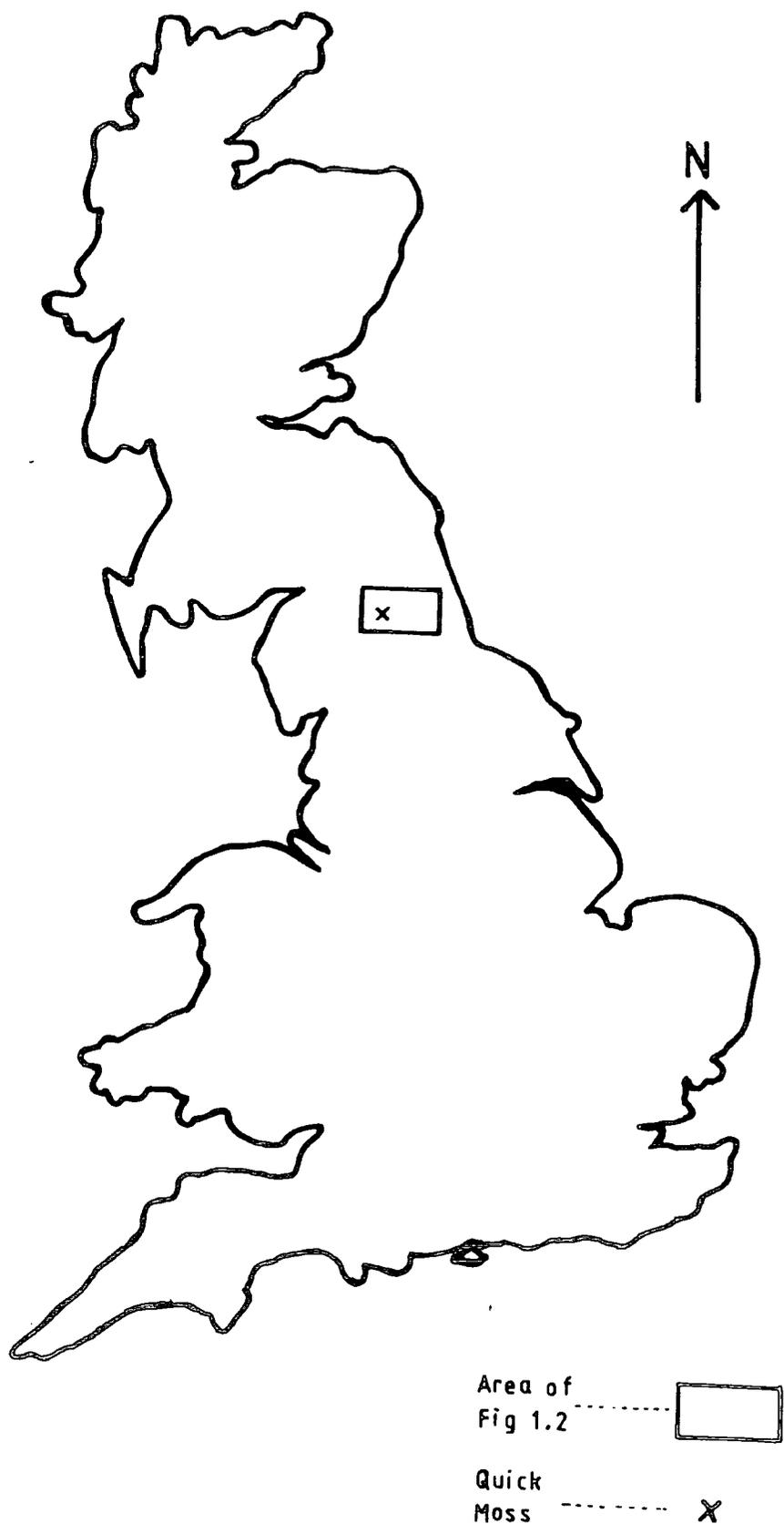


Fig. 1.1

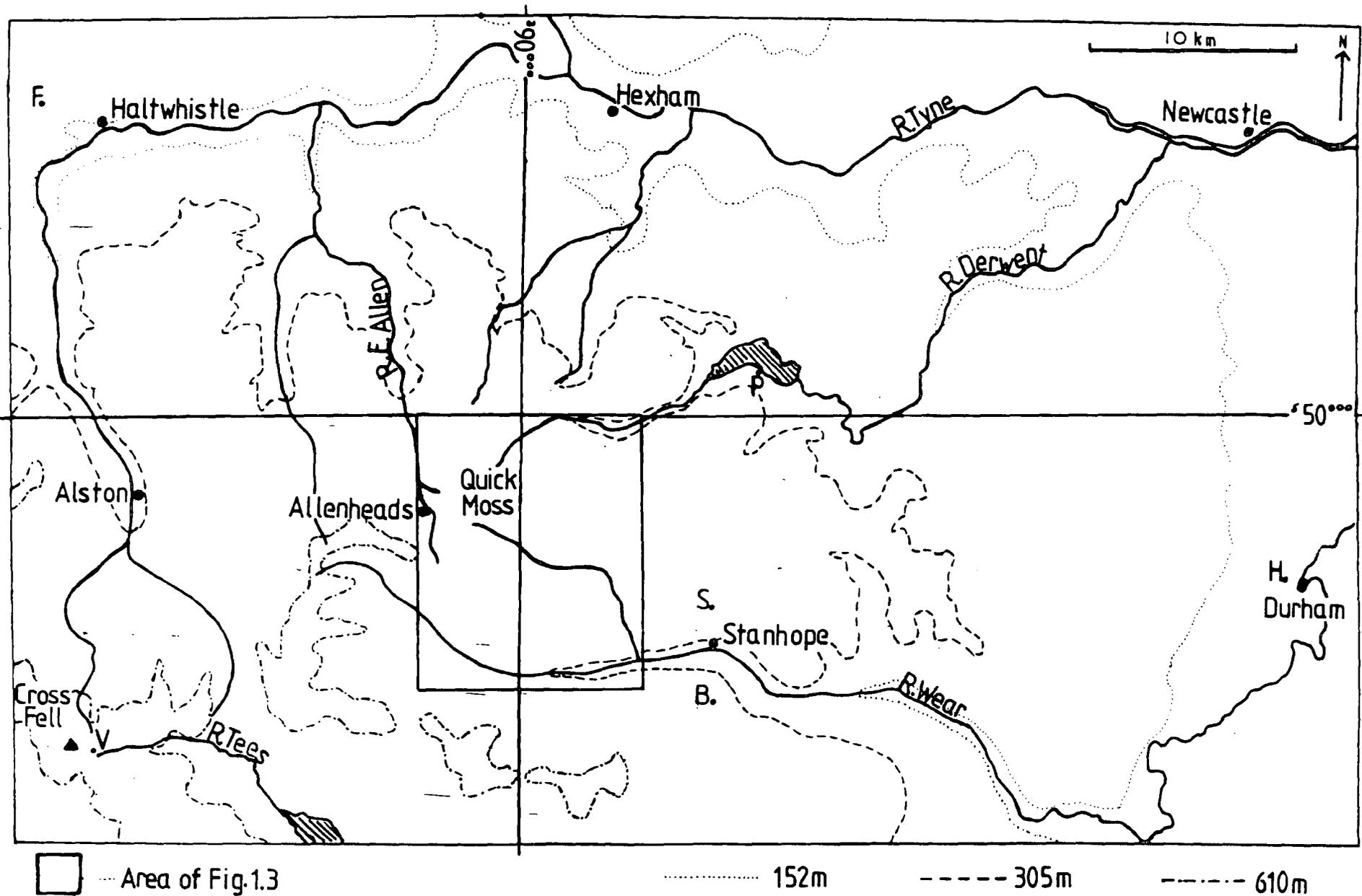


Fig. 1.2

27

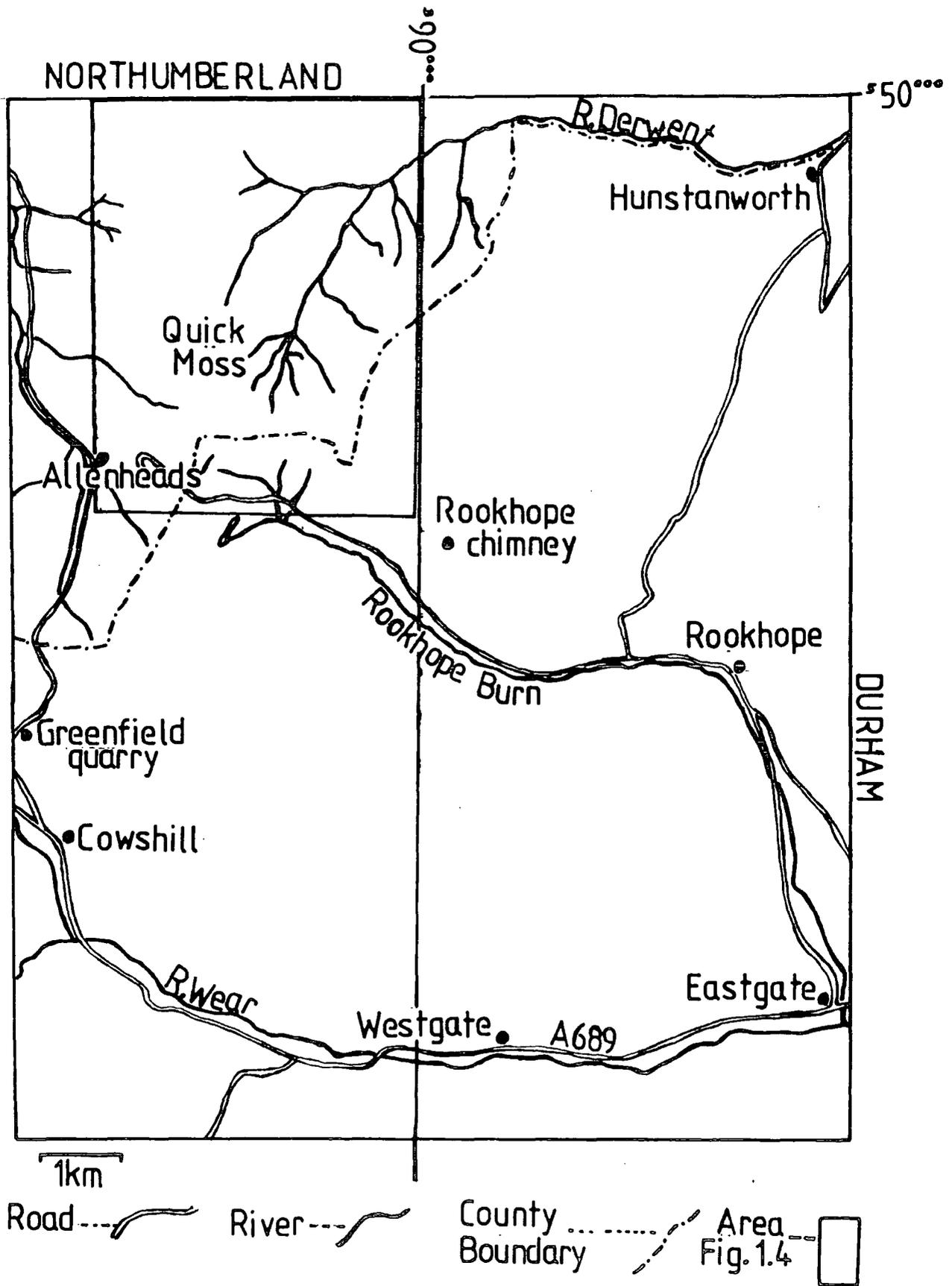


Fig. 1.3

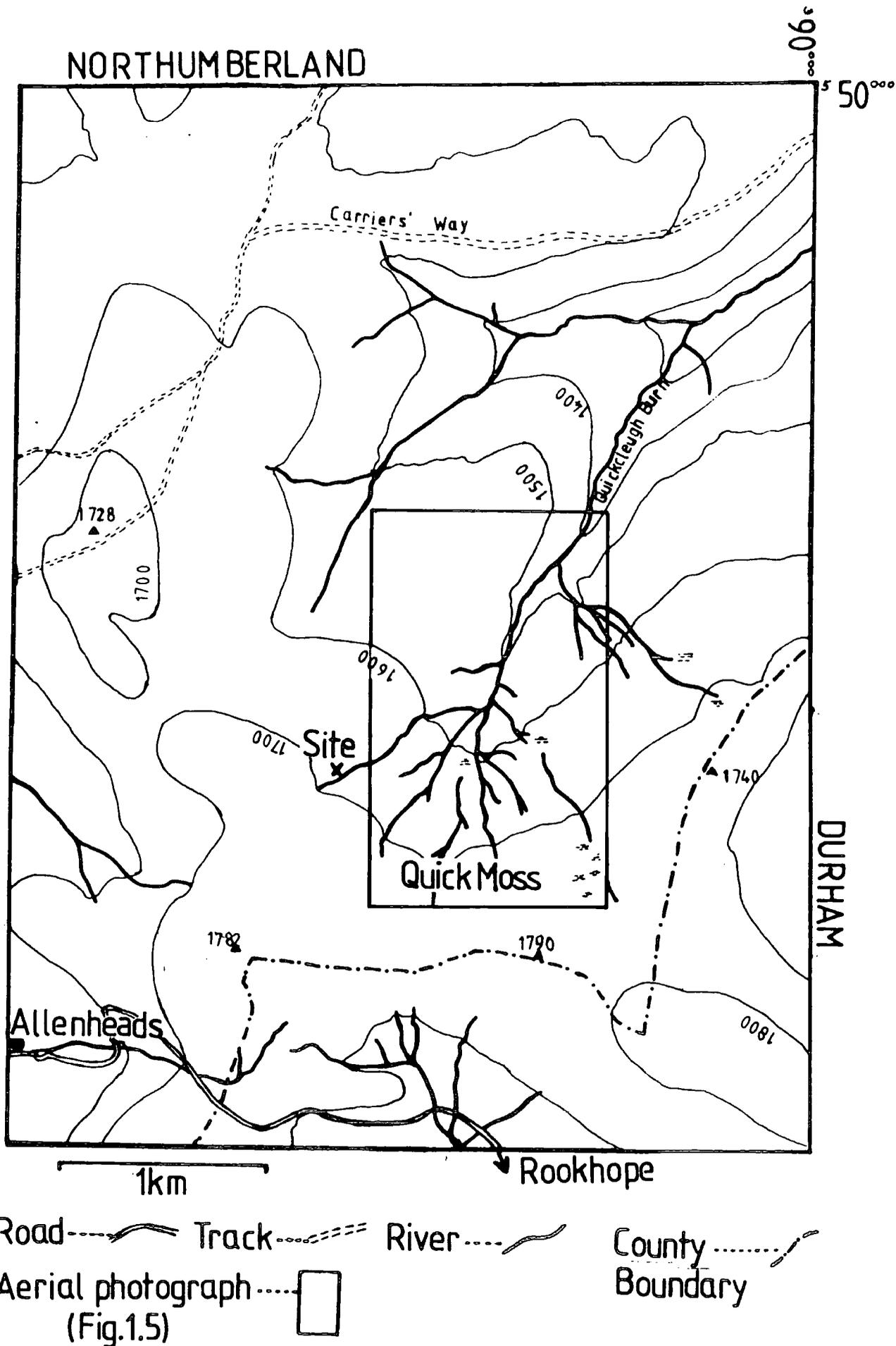


Fig. 1.4

Fig. 1.5

Aerial photograph of Quick Moss

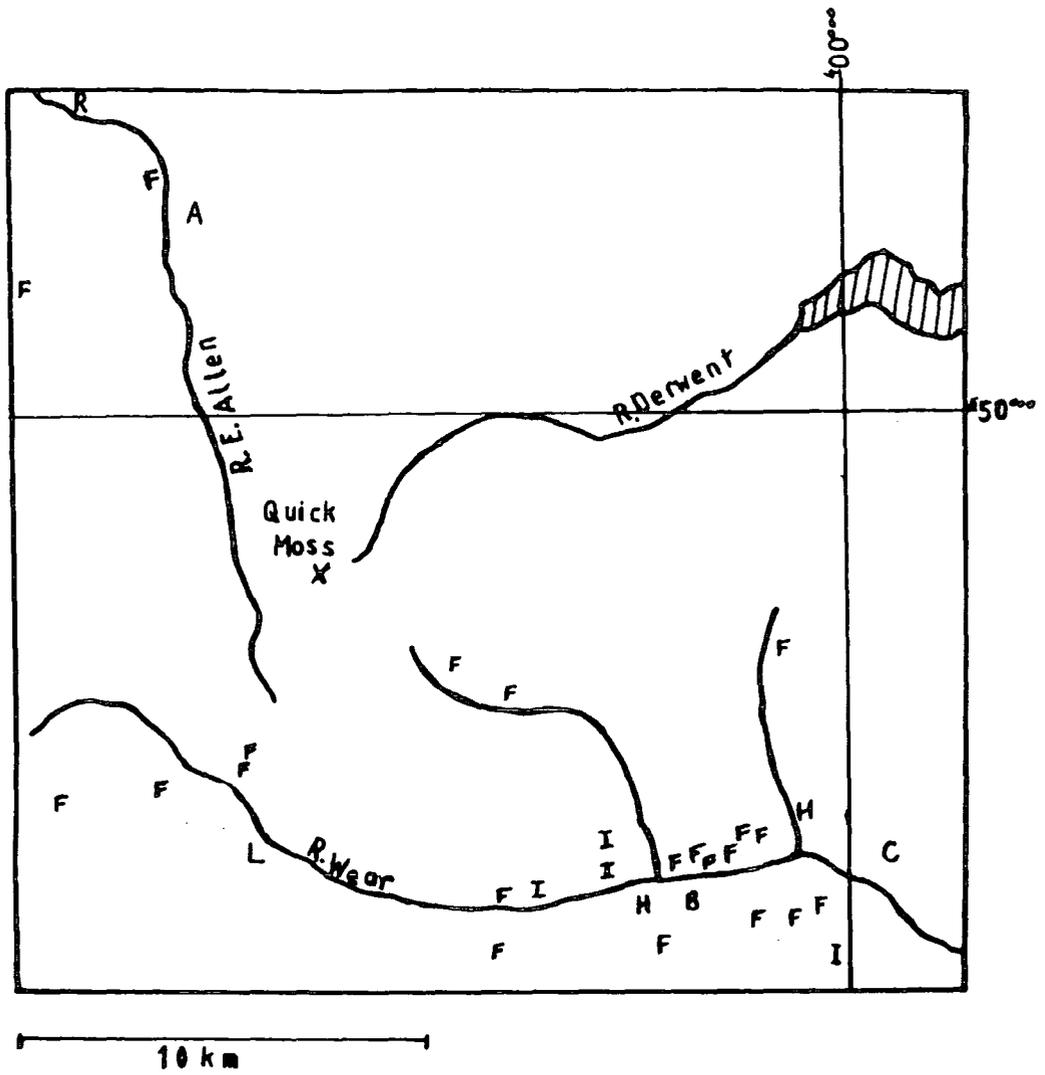
(R.A.F. Crown Copyright)

<u>Key</u>	A	Sample site (100m W. of A)
	B	Quickcleugh Burn
	C	Modern drainage ditches
	D	Immature erosion channels
	E	Deep erosion channels



Fig. 1.6

Map showing recorded prehistoric sites and suspected sites in
the Quick Moss area



KEY

- | | | | |
|---|---------------|---|---------------|
| A | Bronze axe | H | Bronze hoard |
| B | Round barrows | I | Iron Age site |
| C | Cairns | L | Long barrow |
| F | Flint site | R | Roman fort |

Fig. 1.6

Fig. 1.7

Map showing the remains of the Roman occupation of northern England
which surround Quick Moss (after Ordnance Survey 1956)

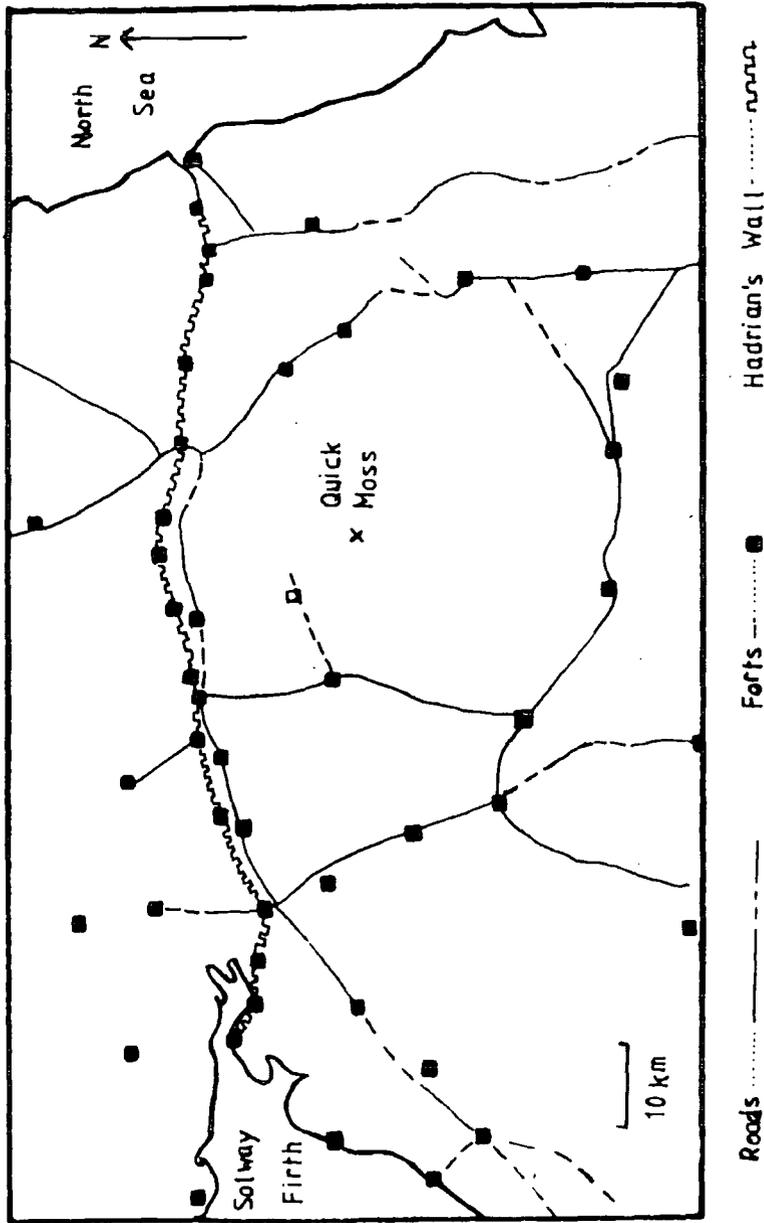


Fig.1.7

METHODS1. Collection of Samples

A monolith of peat was removed in 11 blocks from one side of the erosion channel (Fig. 2.1). The surrounding peat and surface vegetation was first cleared with a spade until a near vertical face was exposed. A large clean sharp knife was then used to cut the sides of the peat blocks. Each block measured approximately 30 cm x 25 cm x 25 cm and, when removed, it was wrapped in polythene and labelled so that its position and orientation relative to the other blocks was known. The polythene prevented drying out and contamination of the peat.

It was found necessary to 'step' the monolith between blocks 6 and 7 and between blocks 8 and 9, otherwise the volume of peat to be dug out would have been too much. As nearly as possible the horizontals were kept constant at the steps so that a continuous sequence of peat development was obtained. The depth of each step was recorded in case duplication or omission was suggested by the results at these levels.

Treatment of blocks

In the laboratory, each block was trimmed to remove surface contamination, and cut into 2 cm thick slices. As each slice was cut it was sealed in polythene and labelled with its depth. Correct orientation of the sample was ensured by marking one corner of the wrapper with a cross. The slices were packed in boxes and kept in a cold store at 4°C. Drying out and contamination were prevented by the

Fig. 2.1

Section through the erosion channel at the sample site showing the
position of the peat monolith and the individual peat blocks

(not to scale)

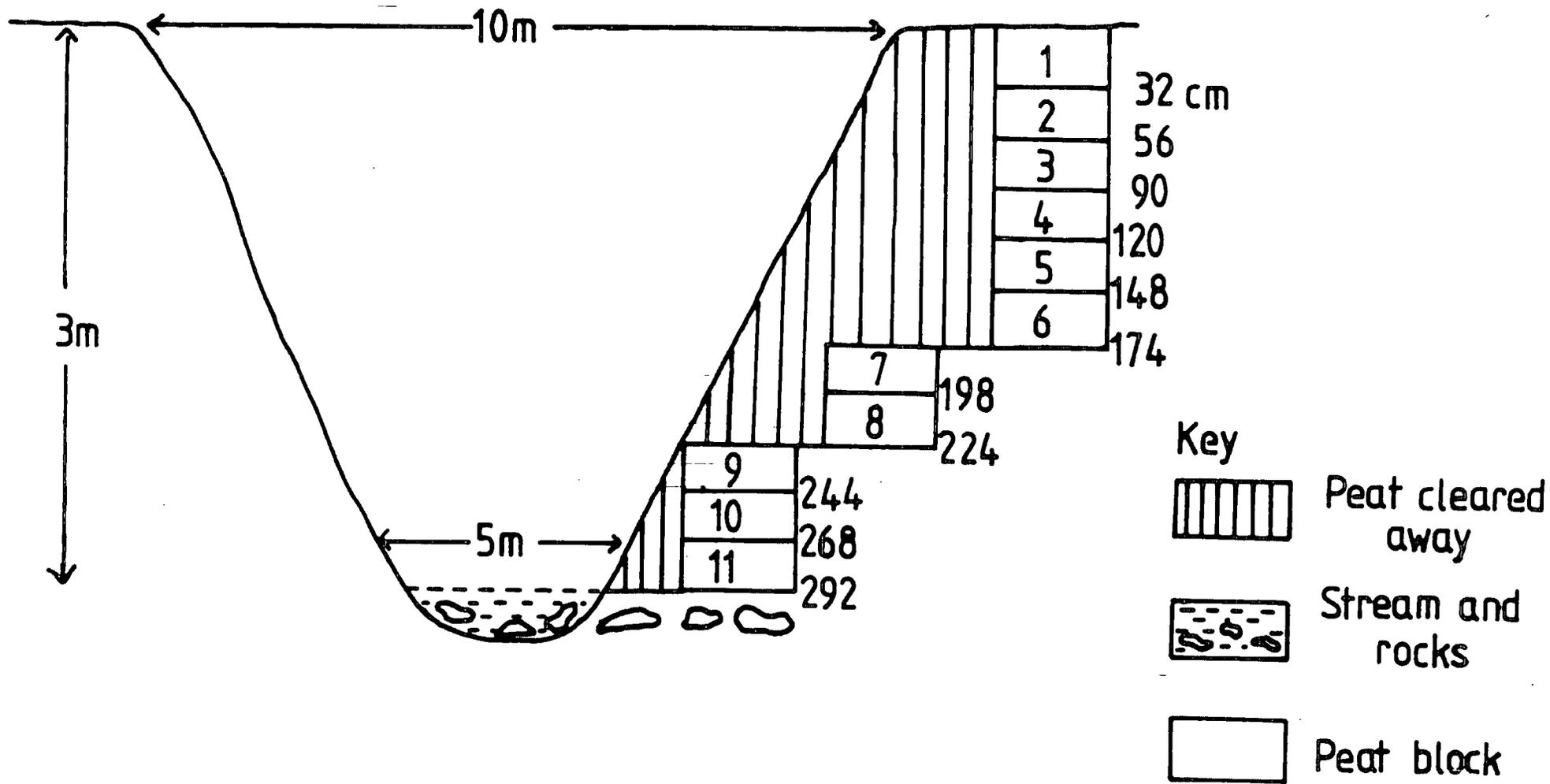


Fig. 2.1

polythene and decay was inhibited by the temperature so the peat was maintained in its freshly dug condition.

Subsamples were later removed from the marked corner of each slice for laboratory investigation. Seven of the slices, which were subsequently shown by pollen analysis, % humification determinations and peat growth estimation to contain important evidence of vegetation changes, were reserved for radiocarbon dating.

2. Peat Growth and Pollen Analysis

A method was needed for ensuring constant volume peat samples from slices taken at intervals from the profile. Davis (1969) used a 1 cm³ porcelain spatula to scoop out consistent samples and Dickinson (1975) measured 2 cm³ samples by displacement of water in a small narrow measuring cylinder. Since, in this investigation, smaller samples were needed, as explained later, it was decided to develop an alternative method. After several tests the following procedure was adopted.

A sharp cork borer, diameter 1 cm, was used to remove a cylinder of peat from each slice adjacent to the position of the humification subsample. Using a cutter made from 2 accurately spaced razor blades, a pellet 0.32 cm long was cut from the centre of the cylinder. This pellet had a volume of 0.25 cm³. The spacing of the cutter blades was achieved by screws and lock nuts so they could easily be adjusted to obtain pellets of different lengths and hence different volumes.

It was found that this method worked well with highly humified peat and there was no distortion of the peat during cutting. Peat from

90 cm to the surface was less humified and it tended to compress and crumble when cut. In these cases the problem was overcome by freezing small subsamples of the peat slices, wrapped to avoid contamination, and cutting them while still frozen with a warmed cork borer and razor blades. There was no apparent damage to the peat or pollen by this process and samples of the correct size were obtained without distortion or crumbling of the peat.

Further preliminary tests were made to find the most suitable size of peat pellet. It proved difficult to keep pellets of 1 cm³ and 0.5 cm³ evenly mixed with the Lycopodium spores during acetolysis. With pellets of 0.25 cm³, settling out of sediment was avoided giving a final preparation with a more accurate representation of the relative proportions of pollen grains and Lycopodium spores. 0.25 cm³ was therefore adopted as the most suitable size of peat pellet.

The number of Lycopodium tablets to be added to a pellet of peat before acetolysis depends on the pollen concentration in the peat and not on the pellet volume. It was therefore necessary to carry out a series of trial runs with 0.25 cm³ pellets of peat and varying numbers of tablets to determine the most suitable number of tablets to use. After acetolysis a pollen count was done for each and it was found that two tablets provided a convenient number of spores for counting in the highly humified peat, i.e. about the same number as the tree pollen grains. One tablet proved adequate in the less humified peat where there was less pollen.

During the trial runs it became apparent that it was difficult to achieve a homogeneous suspension because of the calcium carbonate with which the Lycopodium spores had been mixed during manufacture of the tablets. Experimentation showed that adding 2 cm³ 10% hydrochloric acid to the peat and tablets, before acetolysis, helped to disperse the

Lycopodium spores.

When the procedural details of the practical investigation had been worked out, the peat slices were treated in the following way. Cylinders of peat were removed from slices at 8 cm intervals throughout the profile and a 0.25 cm³ pellet was cut from the centre of each cylinder. 2 Lycopodium tablets and 2 cm³ 10% hydrochloric acid were added to each pellet in a boiling tube then the peat pellet was prepared for pollen analysis by the acetolysis method described by Faegri and Iversen (1975). Extra treatment with hydrofluoric acid was needed with the bottom sample of peat because it contained sand grains. At each stage care was taken to keep the suspension thoroughly mixed to prevent settling out. Finally, extracts of the residue were mounted on slides in glycerine jelly and safranin. Pollen grains, spores and Lycopodium spores were identified using the scheme of Moore and Webb (1978) and were counted on each slide until 150 tree pollen grains had been recorded. As explained on p. 9, the ratio of Lycopodium spores to total pollen revealed by the pollen count is the same as the ratio in the tablet and peat pellet mixture before processing. Since a constant number of Lycopodium spores was added to each peat pellet then variations in the ratios obtained from different pellets indicate differences in peat growth. Allowance was made for the fact that one rather than two tablets was used with some samples.

Peat growth for each pellet was expressed as:

$$\frac{L}{P}$$

where L = number of Lycopodium spores/150 tree pollen grains

and P = total pollen grains and spores (excluding bog species)/150 tree pollen grains.

Peat growth was plotted against depth, for each slice of peat tested (Fig. 3.4).

A pollen diagram was also drawn from the results of the counts (Figs. 3.1 and 3.2). Frequency expressed as % tree pollen (AP) was used for each taxon and a ratio of Trees:Shrubs:Herbs was calculated from the total pollen count at each level.

Note on the calculation of total pollen

Locally produced pollen and spores will have varied in number and type in the peat as the bog vegetation has changed. Those produced near the sampling site may have been overrepresented so it seemed advisable to remove this possible source of exaggerated variation by omitting bog plants from the calculations. Betula, Salix, Cyperaceae, Ericaceae and Sphagnum were excluded from the total pollen score, the calculations for peat growth and the Tree:Shrub:Herb ratio. Macroremains in the peat show these plants to have grown at the sampling site at some time during the history of the bog.

3. Humification of the Peat

This method is based on the one used by Aaby and Tauber (1974) although it differs in the quantities of materials used. To suit the available 250 cm³ volumetric flasks the size of samples and volumes of reagents were adjusted so the concentration of the final extract would be equivalent to that produced in 200 cm³ flasks by Aaby and Tauber. This was necessary so that the conversion factor obtained by them to convert colorimeter readings to % humification values could be used (see p. 14). The main points in the experimental procedure are described below.

A subsample, approximately 4 cm x 4 cm x 2 cm was cut from the marked corner of alternate slices of peat thus making it possible to obtain % humification values at 4 cm intervals in a narrow vertical column through the peat profile. Each subsample was air dried, ground to produce powder and oven dried at 100°C until consecutive weighings were constant. Humic acids were extracted by boiling 0.25g dry powder with 125 cm³ 0.5% sodium hydroxide solution for one hour then distilled water was added to make 250 cm³. The resulting suspension was filtered and the filtrate was diluted with an equal volume of distilled water. Two small samples of the diluted filtrate were tested for light absorption on an EEL colorimeter with a No. 626 filter, the zero having been set with distilled water. The filtrates varied from pale yellow to dark brown. The very dark liquids needed a further dilution to improve the accuracy of the reading and the extra dilution was taken into account in the calculation.

Some intermediate slices were later assayed to clarify trends in humification at selected points. Colorimeter readings were obtained for 98 subsamples and the conversion factor $x = 8.3 (y + 0.1)$ where $x = \% \text{ humification}$ and $y = \text{colorimeter reading}$ was applied. The results are presented in Fig. 3.5: a graph of % humification plotted against depth of peat.

The data for % humification resulting from this experiment were compared statistically with those from the peat growth investigation to detect any relationship which might exist between them.

4. Stratigraphy of the Peat

Peat stratigraphy was investigated in 2 ways. Firstly, the appearance of the peat profile in the field was examined: the depth of

visible horizons and structural differences in the peat being noted. Secondly, a more detailed microscopic examination was made of the residues left on the sieve in the early stages of acetolysis of the peat pellets. Recognisable plant remains and their state of preservation were recorded and, where possible, the species of Sphagnum were identified using the key produced by Proctor (1955).

The results of these observations are presented in Table 3.1 and Table 3.2.

Some workers have used the state of preservation of Sphagnum remains as a convenient way of judging the approximate degree of humification of a peat sample (see p. 14). It would be interesting to see how closely Tables 1 and 2 agree with the experimentally determined humification (Fig. 3.5).

Since one of the factors controlling the rate of growth of peat may have been the type of vegetation forming the peat, the identifiable plant remains could also be relevant in the interpretation of peat growth results (Fig. 3.4).

5. Radiocarbon Dates

Samples of peat from 7 levels in the profile in which notable changes in pollen frequencies, humification and growth rate occurred, were reserved for dating.

Determination of the ^{14}C dates for these samples was generously undertaken by Dr. V. R. Switsur at the Godwin Laboratory, Cambridge. A quantity of wet peat, which would yield 100g when dried, was required for

^{14}C determination at each level. Tests on wet peat showed that two of the 2 cm thick slices would produce at least 100g dry material. Two adjacent slices of wet peat, total thickness 4 cm, were therefore submitted from each level and, for discussion purposes, the mid point of each 4 cm has been taken as the level to which the resulting date applies.

It has been recognised for some time that the radiocarbon calendar does not correspond with sidereal years, particularly during the period before 2,000 bp. Correction curves based on radiocarbon estimates of tree rings of known age from long lived specimens of Pinus aristata in California are available and, using that of Switsur (1973), corrections were obtained for all dates except the deepest level which falls beyond the correction curves.

The dates and corrections are given in Table 3.3.

Levels selected for dating

It was hoped that dating the following levels would prove useful in the interpretation of peat and pollen changes as well as providing an alternative method for estimating peat growth.

(i) 44 - 48 cm (46 cm) A marked decline in pollen of Gramineae, Plantago and in Pteridium spores with an increase in Betula pollen suggests the start of forest regeneration after a major clearance. On the bog, growth is rapid and humification low although an increase in Calluna pollen is noted. Sphagnum imbricatum remains in the peat reach a maximum at this time.

(ii) 82 - 86 cm (84 cm) The beginning of a large man-made clearance is indicated by rapid increases in the pollen of Gramineae, Plantago and other herbaceous taxa, and in Pteridium spores. Moderately

humified peat contains prominent Eriophorum remains mixed with Sphagnum leaves of the Acutifolia type. (S.imbricatum has not yet appeared.)

(iii) 110 - 114 cm (112 cm) Sphagnum leaves are first recognisable at this level - all Acutifolia type - and the peat has become less humified. Although recorded growth is not exceptionally high until later, this could be the level of a major recurrence surface on the bog. Small fluctuations in Gramineae, Betula, Ulmus and Quercus pollen are also seen.

(iv) 144 - 148 cm (146 cm) This marks the end of the very high values for humification and the growth rate is also lower than before. Small increases in the pollen of Gramineae, various herbaceous taxa, Betula, Ulmus and in Pteridium spores show that man was probably active in the area at this time.

(v) 188 - 192 cm (190 cm) Ulmus pollen decreases markedly. This may be the level of the elm decline although there is also a later fluctuation in Ulmus pollen between 176 cm and 186 cm. A continuous record for Fraxinus pollen begins at this level. Humification reaches a very high level and growth is low.

(vi) 230 - 234 cm (232 cm) Alnus and Quercus pollen are increasing steadily. Betula pollen is decreasing and Pinus pollen has decreased. There are few herbaceous pollen grains except for a temporary high level of Melampyrum pollen (2nd 'Melampyrum episode'). Humification and growth are increasing simultaneously.

(vii) 286 - 290 cm (288 cm) This is the lowest level of true peat which merges into the mineral subsoil. It marks the beginning of the bog growth. Humification and growth values are both low. The pollen of Gramineae and various herbaceous taxa are well represented and the increase in the pollen of Alnus has not yet begun.

A summary of these changes in the peat and the corresponding radiocarbon dates are given in Table 3.4.

RESULTS1. Pollen Diagram

The pollen diagram (Figs. 3.1 and 3.2) has been divided into six local pollen assemblage zones identified as QMa - QMf as proposed by West (1970). The zones are based on changes in frequency of various pollen types, especially where these correspond with changes in the nature of the peat. This zonation is specific to Quick Moss and was not based on zonations adopted by workers at other sites. It provides a framework within which changes in pollen and peat can be examined and related to the radiocarbon dates, and possibly compared with evidence from other sites in the area.

An important point to be considered is that, because the bog covers a large area in an exposed position, it is likely that the only truly local pollen recorded is that of the bog plants. Pollen from the lowlands, picked up by thermals and blown along by high altitude winds, may be washed onto the bog surface by the considerable rainfall which occurs throughout the year. As previously mentioned (p. 16) the wind direction has been shown to be very variable on the high points of the Pennines so the origin of the components of the pollen rain at Quick Moss could be at a distance of several km in one of many directions. Interpretation of the diagram must therefore be in the context of changes taking place both locally and some distance away at different altitudes.

Dates for the boundaries between the zones have been estimated from Fig. 3.3 where the levels do not coincide with the radiocarbon dated samples.

Pollen assemblage zones

QMa (290 - 250 cm) 8010 - 6800 bp (approx.)

The dates and pollen values for QMa are consistent with those given for the Boreal period (Blytt and Sernander) and zone VI (Godwin). The end of the zone probably corresponds with the Boreal-Atlantic transition which is usually dated between 8,000 and 7,000 BP.

In this zone values for Alnus pollen are very low whilst Betula and Pinus pollen is well represented. There is a gradual rise in the Quercus and Ulmus frequencies from a low level and a variety of herbaceous pollen taxa is also present. The bottom sample, which marks the point where a thin layer of mineral soil gave way to peat, has markedly different frequencies: Corylus, Salix and Filicales being very high.

A picture emerges of fairly open woodland with wet areas bordering the streams, including the sampling site, where peat began to grow slowly. Wood preserved in the peat shows that at least Salix and Betula were growing at the site in this zone although by the end of the zone Salix pollen has almost disappeared.

As the Salix pollen decreases there is a temporary rise in pollen of Melampyrum, a herb which is found today growing on the edges of woods even at fairly high altitudes. The fluctuations of the curves of Salix and Melampyrum are complementary to each other until Melampyrum reaches a maximum value 32% AP at 256 - 258 cm. Melampyrum then falls rapidly

but Salix does not recover and remains low throughout the profile. This is the first 'Melampyrum episode'.

A similar sequence was described by Simmons (1969) from blanket peat on the North York Moors. He linked the occurrence of Melampyrum pollen in the deeper layers of peat with the activity of Mesolithic man. At one site (North Gill), charcoal was also found in the peat at the level of an increase in Melampyrum pollen, suggesting that man may have used fire to help to open up the woodland. A subsequent decline in Salix pollen was also noted. Charcoal has not been found at Quick Moss but otherwise there are similarities between the evidence from the North York Moors and that from Quick Moss. In a later publication, Simmons (1975) has presented an interpretation of the life activities of Mesolithic man in the uplands of Great Britain during this period.

Since there is little contemporary change in pollen values for other taxa, except Salix, at Quick Moss, it seems probable that the increase in Melampyrum pollen reflects one or more small, temporary, very local disturbances in the vegetation rather than a larger one at a greater distance from the bog. It is unlikely that appreciable quantities of Melampyrum pollen grains would have been carried by the wind since the flower is insect pollinated and its stamens are enclosed within a hooded corolla (Clapham, Tutin and Warburg 1962). This also suggests that the plants were growing at, or very near the sampling site.

Evidence from artefacts (p.19) confirms that Mesolithic man was active at some time on the Pennine uplands probably with the object of hunting. That he appears to have created temporary openings in the woodland suggests a degree of organisation in his activity. Interpretation of the purpose of the cleared areas is difficult but two possibilities are the provision of places for temporary camp sites and the improvement

of grazing for herbivores, e.g. wild cattle and deer, which could then be hunted.

The evidence for burning in the uplands of Britain in this period of prehistory is increasing and some workers e.g. Jacobi et al. (1976) think it may have been an early attempt to manage the land to increase the wild herbivore population. Even the possibility of a 10 year rotational burning is proposed by Jacobi et al. and this may be compared with the modern practice in this area (p.16).

At Quick Moss there is a surprising absence of increase in grass and herb pollen when the Melampyrum increases; only Cyperaceae pollen increases a little. Perhaps grazing suppressed flowering in most of these plants. On the other hand, Pearsall (1950) has described an observation in the Scottish Highlands which shows Melampyrum can not resist grazing pressure. It readily sprang up in fenced-off areas, together with seedlings of young trees, but it did not grow where deer had access. Perhaps the peak of the Melampyrum curve at Quick Moss indicates the point at which woodland began to regenerate in the open areas after being abandoned by man and wild herbivores. Alternatively it has been suggested by Godwin (1975) that Melampyrum regenerates very rapidly after fire has been used to clear ground so, although charcoal was not found in peat at Quick Moss, fire could have been used and this may be why other herbs are present only in small quantities at this level. Much more evidence is needed before an accurate interpretation of this type of temporary clearance activity at Quick Moss can be made.

QMb (250 - 212 cm) 6,800 - 5,500 bp (approx.)

This zone shows a steady increase in Alnus pollen, a feature typical of the Atlantic period (Godwin zone VII), although the maximum value is not realised until soon after the end of the zone (i.e. after

5,500 bp). Alnus maxima at lowland sites are generally much earlier e.g. Neasham Fen (Bartley et al. 1976) at 6,972 bp.

The high altitude Valley Bog in Upper Teesdale shows the Alnus rise at 6,000 bp (Chambers 1978) which is later than the lowlands but earlier than the date from Quick Moss (after 5,500 bp). A late arrival of Alnus is also noted by Turner and Hodgson (1981) at Pow Hill in the Derwent Valley, 15 km N.E. of Quick Moss, where the rise took place around 5,300 bp.

Pinus pollen at Quick Moss has fallen to a low level by 6,120 bp in contrast with Pow Hill and sites in Upper Teesdale (Turner et al. 1973) where high levels persist until much later. As Pinus and Betula pollen decrease at Quick Moss there is a rise in Quercus pollen and a scarcity of pollen of herbaceous plants. There were probably areas of dense woodland which discouraged the growth of some herbaceous plants and restricted pollen dispersal of others.

A second 'Melampyrum episode' with a maximum at 232 - 234 cm, occurs in this zone. Its features are similar to the one described in QMa with slightly more grass pollen but without the fluctuation in Salix pollen which is at a low level throughout. The end of the episode coincides with the end of zone QMb and with the point at which the steadily declining wood remains in the peat finally disappear. It may be assumed that the bog at the site had become devoid of trees by 5,500 bp. Perhaps, as some workers have suggested (e.g. Moore 1973), there is a link between the activity of prehistoric man and the deterioration of woodland to bog or perhaps, as others have suggested, a change in climate was responsible. A combination of the two explanations seems most likely at Quick Moss. The many boggy areas in wet hollows probably encroached on previously dry areas which had been denuded by felling or

burning and where increased rainfall had leached the soil so it was unsuitable for regeneration of trees.

Evidence and opinions from various sources concerning the involvement of man's activity and, or, climatic change in the initiation of peat growth in previously wooded areas are discussed by Simmons et al. (1981). They point out that there are some sites where Sphagnum growth appears to have resulted from human influence alone but peat growth at Quick Moss begins around the Boreal-Atlantic transition when the climate is known to have become wetter (p. 3).

QMc (212 - 178 cm) 5,500 - 4,400 bp (approx.)

A prominent feature of this zone is the large increase in pollen of Cyperaceae and then Calluna. These were the principal peat formers of this period on the now treeless hill tops. Pollen of herbaceous plants is almost absent showing the surrounding forests were closed so that only a few wind-dispersed fern spores reached the bog. Quercus, Alnus and Corylus pollen is well represented but the Betula and Pinus frequencies are low.

The Ulmus curve appears to show 2 declines: ED 1 at 192 - 194 cm and ED 2 at 178 - 180 cm. A ^{14}C date for 190 cm fixes ED 1 at just before 4,900 bp. ED 1 is accompanied by a slight rise in Plantago pollen and Pteridium spores such as might be expected to follow the removal of trees. ED 2 occurs at an estimated date 4,400 bp without any increase in herbaceous pollen and at a time when the forest cover reached its maximum.

A double elm decline has been detected in lowland north west England by Oldfield (1960), Pennington (1970) and more recently Garbett (1981). Garbett's detailed study shows the two-stage episode to have

taken place within 100 years and that pollen grains of clearance plants do not appear until the second stage, the first stage being identified by a fall in elm pollen alone. The possible double elm decline at Quick Moss differs from that of Garbett in the time span: 400 years, and in that the few recorded pollen grains of clearance plants occur in the first stage and are absent in the second. However, these are tentative observations and a much more detailed study of the Quick Moss peat is needed before any meaningful comparison can be made.

Dates from several lowland sites in Co. Durham (Bartley et al. 1976) show the elm decline before 5,200 bp which is much earlier than at Quick Moss. At Valley Bog (Chambers 1978), an upland site, the date for the elm decline, 4,794 bp, falls between the dates for ED 1 and ED 2 at Quick Moss. If we accept that man was generally responsible for the sudden reduction in elm pollen which marks the elm decline (Troels-Smith (1960) and others e.g. Garbett (1981)) then it appears that he was first active on the coastal plain and penetrated the uplands at a later date. There is, as yet, no evidence of Neolithic settlements in the area of Quick Moss although Neolithic type artefacts have been found locally (Fig. 1.6). It is more likely that man passed through the region from time to time and his spasmodic presence could explain the rather indefinite nature of the elm decline at Quick Moss.

QMd (178 -112 cm) 4,400 (approx.) - 2,249 bp

A gradual opening of the forest accompanied by a small but persistent increase in the pollen of herbaceous plants occurs in this zone. Most of the herbs recorded are those generally associated with agriculture e.g. Gramineae, Plantago, Rumex, Urtica, Artemisia and Chenopodiaceae. It is probable that the centre of activity was some distance from Quick Moss as the herb values are low. A form of mixed

agriculture is suggested by the presence of arable weeds, e.g. Artemisia and Chenopodiaceae, and of others which are thought to be more representative of pastoral activity.

Midway through the zone (144 - 146 cm) the values for Gramineae, pollen of various herbaceous plants and Pteridium spores rise temporarily, suggesting a clearance of trees somewhere in the pollen catchment area, followed by regeneration of forest. Some herbs persist however and the proportion of tree pollen does not return to the pre-clearance level. The peak of the temporary clearance has a radiocarbon date of 3,130 bp which corresponds with the time of the Bronze Age. A similar small clearance was noted by Chambers (1978) at Valley Bog and its date was estimated at 3,300 bp. An earlier date, 3,688 bp, for a short-term clearance at Fell End Moss, a lower altitude site in Northumberland, near Hadrian's Wall and 20 km distant from Quick Moss, is given by Davies and Turner (1979). Pollen values for clearance indicators at Fell End Moss are higher than at Quick Moss which suggests the centre of the clearance was probably fairly local.

Fraxinus, a tree of more open habitats, shows an increased pollen frequency from the beginning of QM and the first of the infrequent records of Fagus is found in this zone.

The bog vegetation is well represented. There is a notable rise in Cyperaceae pollen followed by a rise in Calluna pollen and then a fall in Cyperaceae pollen. Macro remains in the peat confirm that many Eriophorum and Calluna plants were present at this time. The relative proportions of the two pollen taxa may have varied with climate but it is interesting to note that the Cyperaceae pollen maximum occurs at the level of the clearance described above and the Calluna pollen frequency rises later. Although the time scale is much longer, the sequence is the same

as that resulting from modern moorland burning. It is worth noting that changes are seen in the bog vegetation at the same time as man appears to have been exerting an influence on the vegetation in the surrounding area.

QMe (112 - 46 cm) 2,429 - 1,470 bp

The largest clearance recorded on the diagram is found in this zone. Gramineae pollen increases progressively to 85% at 64 - 66 cm. There is a corresponding, but smaller, increase in Plantago and Rumex pollen as well as in that of a wider variety of arable weeds, now including Compositae, Cruciferae, Caryophyllaceae and Umbelliferae. Occasional cereal pollen grains, probably blown in from some distance also occur. By the end of the zone the clearance indicators have decreased; presumably agriculture had become less widespread.

Marked changes in tree pollen frequencies are also shown. That of Quercus decreases, as might be expected at a time when trees were being felled, and that of Betula, a plant which begins to form scrub when clearances are not maintained, rises markedly to its highest recorded level at the end of the zone. A value of 90% AP is recorded for Pteridium spores at the time of maximum clearance. Bracken spreads rapidly when competition from trees is removed and is a good indicator of forest clearance (Turner 1964, 1965). Both the Alnus and Corylus frequencies decrease temporarily as the woodland is cleared, but soon rise again, and the Fraxinus frequency continues to increase steadily. Salix pollen also shows a small increase at the time of maximum clearance.

A large part of the countryside in the pollen catchment area probably supported crops and stock, managed in areas cleared of large trees, and showed increased growth of those trees and shrubs which would not have survived in a dense forest. Towards the end of the zone,

agriculture had contracted and the natural succession which leads to forest was under way.

On the bog there is a marked increase in Cyperaceae and Calluna occurring concurrently with the clearance and following a pattern somewhat similar to that seen in QMd at the time of the small clearance. Again, the question of the causal factors; climate, man or other influence, may be considered. The nature of the peat also changes at the beginning of this zone, from an amorphous type to one in which Sphagnum remains can be recognised.

Radiocarbon dates show that this major clearance was underway by 2,035 bp (and possibly began as early as 2,200 bp). It ended around 1,470 bp with a maximum at an estimated 1,750 bp. Historically, this period begins in the pre-Roman Iron Age and the peak of agricultural activity occurs during the Roman occupation, around ad 230. The period continues until about 100 years after the Roman withdrawal in AD 410.

Information about agricultural activity and its relationship to the Roman presence in the area, from several sites in N.E. England, has been presented and assessed by Turner (1979). In some cases clearances have begun before the Romans arrived and most continued until after their departure as also seems to have happened in the Quick Moss record. Two other sites which are near to Quick Moss, although at a lower altitude, show an increase in agriculture in pre-Roman times. These are Fellend Moss (Davies and Turner 1979) where the clearance begins at ad 2 and Steward Shield Meadow (Roberts et al. 1973) where it is dated at 110 bc. At a third site, Bollihope Bog, the increase is later (ad 220), by which time the Roman occupation of the district was established. All three sites retain open areas until post-Roman times. A similar record emerges from the lowland site, Hallowell Moss (Donaldson and Turner (1977)) near Durham City where the beginning of a major clearance coincides with the Roman

arrival and the open landscape persisted after their departure. The evidence from Quick Moss supports the theory that the native population had begun extensive farming before the Romans arrived and continued it for 100 years or more after the Romans withdrew. No doubt the increased population (p. 22) in the area during Roman times was at least partly responsible for the extensive agriculture at the maximum of the clearance but it seems only to have caused expansion of an already established industry.

Qmf (46 - 0 cm) 1470 bp to present

The forest has only partially recovered from the major clearance of QMe and throughout the zone small scale increases and decreases in tree cover are noticed, probably reflecting changes in human population size, the demand for wood for local industry and the need for agricultural land. Some high peat growth rates are recorded indicating wet periods e.g. 24-26 cm, which might also have affected the local economy.

Since the local history of this zone is well documented the pollen record may not be as useful for interpretation as in earlier zones. It is, however, interesting to note that that the estimated dates, 13th century and 17th century, of two small increases in Gramineae, Rumex, Plantago and Pteridium at Quick Moss correspond to two periods of increased human industry described by Roberts et al. (1973) (see p.23). The first of the two increases (24-26 cm) also features a low level of Quercus pollen, many trees probably having being felled, and a high level of Alnus pollen, possibly due to the wet climate mentioned above for this level.

Throughout the zone pollen production will have been influenced by the changing economy of the area including farming, use of wood for smelting lead and iron ore, conservation of woodland for hunting and modern forestry plantations.

QUICK MOSS — NORTHUMBERLAND

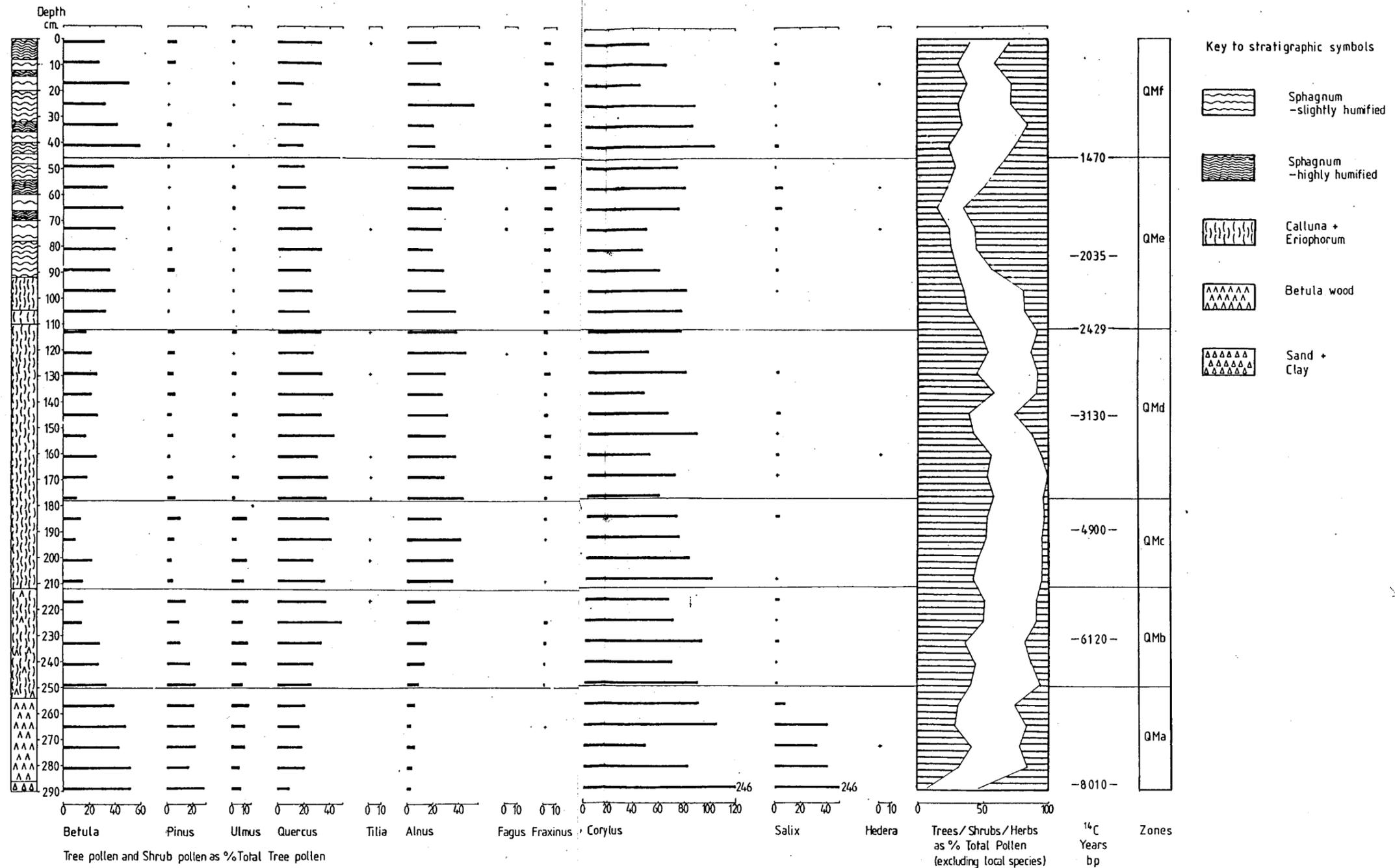


Fig. 3.1

Fig. 3.1

Pollen diagram from Quick Moss, Northumberland, showing bog stratigraphy, pollen frequencies of tree and shrub taxa, the ratio between tree, shrub and herb pollen, radiocarbon dates and pollen zones

QUICK MOSS — NORTHUMBERLAND

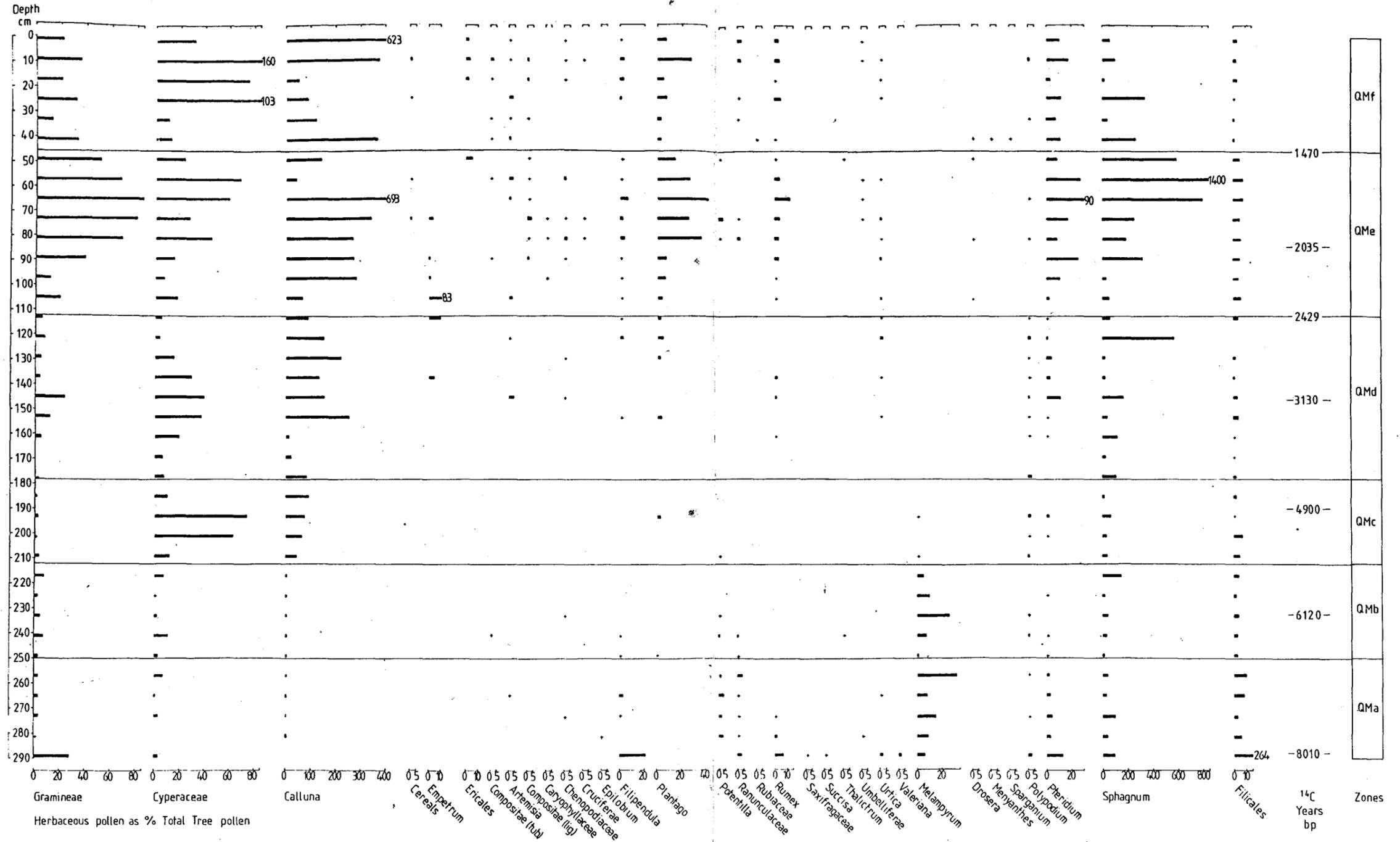


Fig. 3.2

Fig. 3.2

Pollen diagram from Quick Moss, Northumberland, showing pollen frequencies of herb taxa, radiocarbon dates and pollen zones

Fig. 3.3

Date estimation curve constructed from depth and radiocarbon dates
of 7 samples. Estimated dates and pollen zones are shown.

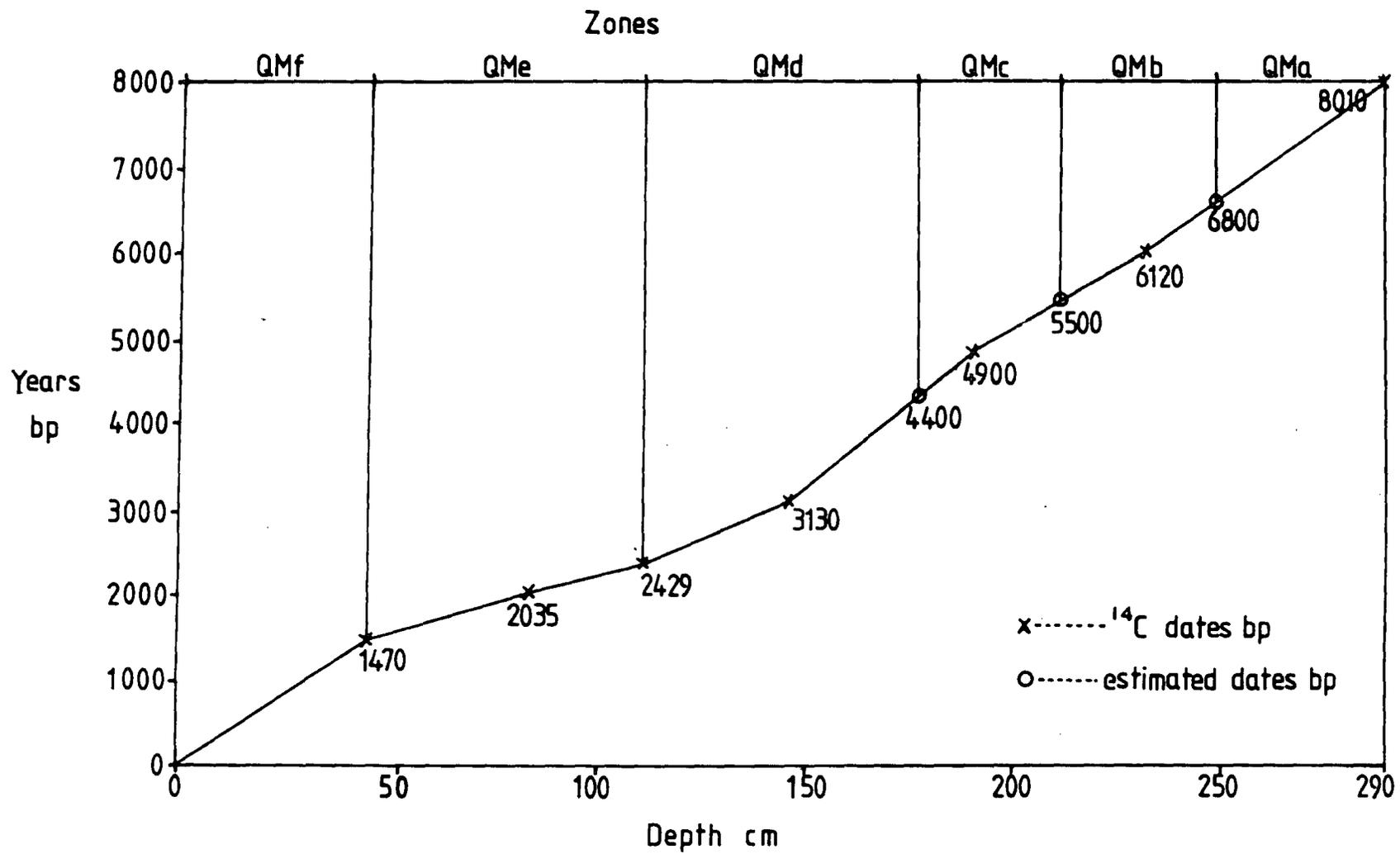


Fig. 3.3

2. Peat Growth

Fig. 3.4 shows a peat growth curve based on the pollen concentration at 8 cm intervals throughout the profile. The results cannot give an absolute measurement of peat growth (p. 6) but, if the underlying assumption for use of the method is valid, they could serve as a useful basis for comparison of growth at different levels. Although the samples were taken at regular spatial intervals, the time intervals between consecutive samples varies. When the peat was growing slowly, as in the lower layers, the time taken to accumulate 8 cm peat would have been much longer than in the rapidly growing upper layers.

Two regions can be recognised on the graph:

a. Below 122 cm Here the apparent growth values are variable but mostly low. Peaks occur at 160 - 162 cm, 208 - 210 cm and 232 - 234 cm, the first mentioned being the most pronounced.

b. Above 122 cm In this section there is considerable fluctuation between high and low growth values. A value of 8.5, the highest on the graph, occurs at 72 - 74 cm. There are also three periods of very slow growth at 16 - 18 cm, 32 - 34 cm and 96 - 98 cm.

Fig. 3.4

Variations in Peat Growth with depth over the whole peat profile

Peat growth is expressed as the ratio of Lycopodium spores : total pollen (excluding bog species)

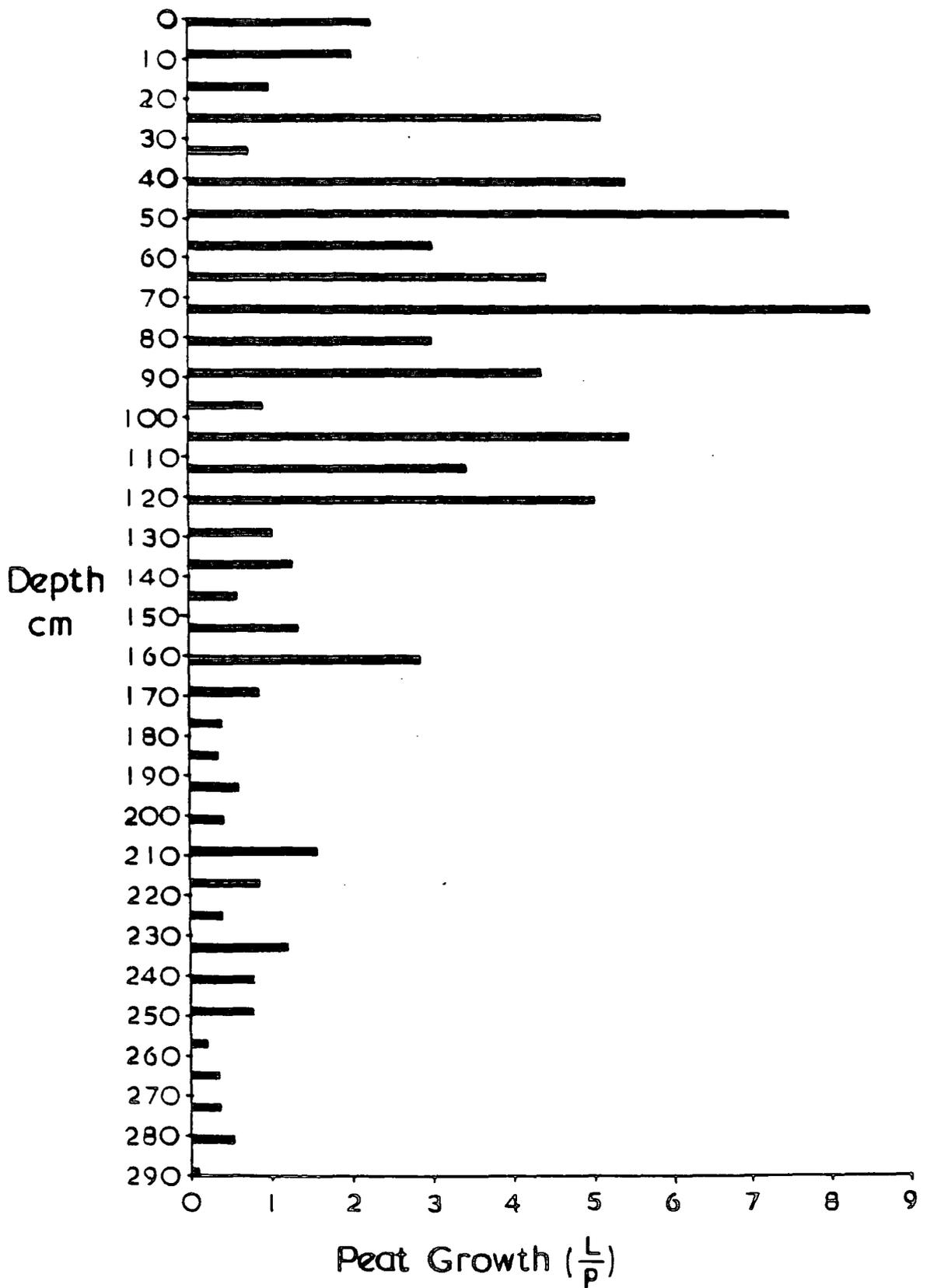


Fig. 3.4

3. Humification

Fig. 3.5 records % humification values at 4 cm intervals from the base of the peat at 290 cm to 112 cm and at 2 cm intervals from 112 cm to the surface.

Two regions can be seen:

a. Below 120 cm The trend here is for % humification to increase from a low value (27%) at the bottom to the overall maximum value (97%) at 172 cm and then to decrease again to 55% at 120 cm. Although the values oscillate the general picture in this region is of the accumulation of layers of peat which were successively more humified to 172 cm followed by layers of peat in which there was a gradual reduction in humification.

b. Above 120 cm Except for high values between 92 and 102 cm (75%), the humification percentages are, in general, much lower than in the peat below 120 cm. The pattern is one of alternate increases and decreases in humification with no obvious trend in either direction.

Fig. 3.5

Variations in % Humification of peat with depth over the whole
peat profile

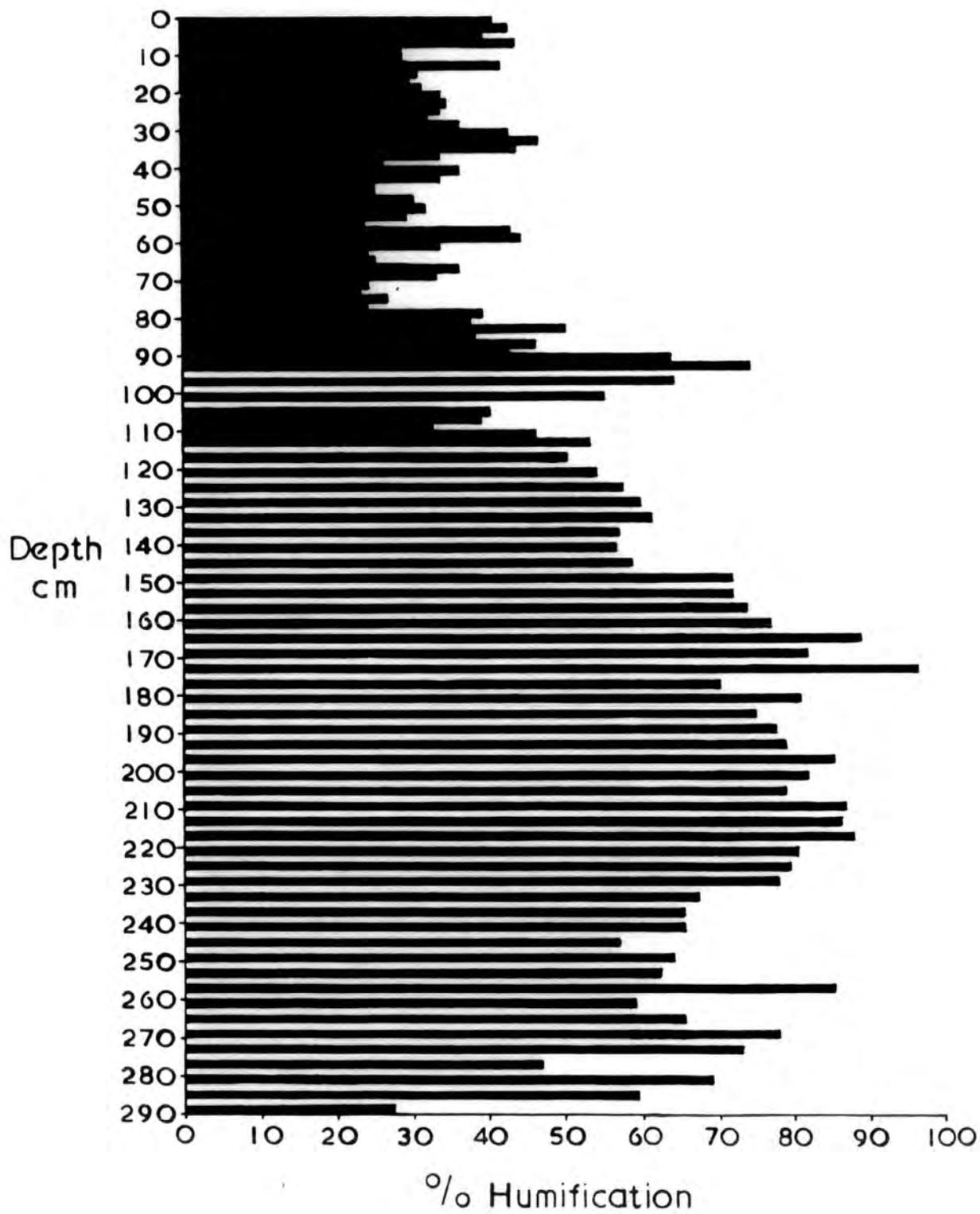


Fig. 3.5

4. Stratigraphy

Tables 3.1 and 3.2 summarise the results of this investigation. There is a distinct division of the peat as seen in the field into a lower dark, structureless zone with a few tough plant remains like Betula wood, Calluna stems and leaf bases of Eriophorum, and an upper, less humified peat in which Sphagnum remains can often be identified. It is difficult to pin point the exact boundary between the two zones as the lower layer gives way to a less humified band at 105 - 110 cm and this is succeeded by a 10 cm thick band of highly humified peat (95 - 105 cm) of a similar structure to the lower peat before the upper peat is really established at 95 cm. Tallis and Switsur (1973) also noted a thin band of highly humified peat in a similar position at a S. Pennine site. It was dated at between 301 bc and 78 bc: approximately the date of the Quick Moss dark band. The light band at 105 - 110 cm contains numerous unidentified thin unbranched stems, with no attached leaves, which have not been found in other parts of the peat.

Table 3.2 shows that recognisable Sphagnum occurs only above 114 cm but within this upper peat there is also a region where plants have decayed beyond recognition (90 - 102 cm) which is equivalent to the layer seen at 95 - 105 cm in the field. In the upper peat there are variations in the degree of preservation of the recognisable plants and the rise and fall of S. imbricatum can clearly be seen. S. imbricatum first appears in the sample 72 - 74 cm and increases to a maximum at 30 - 32 cm then declines to nil somewhere between 24 and 18 cm. At least 2 periods of high humification occur during the S. imbricatum phase which suggests the plant can tolerate dryness. S. imbricatum is well known to have been a major peat forming species in the past, but it has almost disappeared from bogs at the present day. At this site at Quick Moss, however, the pioneer growth in the upper peat was begun by a smaller leaved species,

of the Acutifolia type. This remained dominant for about 40 cm until S. imbricatum began to take over. It was difficult to identify accurately the 'Acutifolia type' but its leaves were recognised in most of the samples. Possibly it was S. robustum, a species which is found on the wetter parts of the bog today.

Several regions in the profile where plant remains are very disintegrated have been marked on Table 3.2 and the levels agree with levels showing a high % humification in Fig. 3.5. Some of these regions were also recognised in situ in the field and they have been marked on Table 3.1. These agreements confirm that, at Quick Moss, a reliable qualitative estimate of humification can be made from the colour and texture of the peat. It is important to note that increases in decay of peat plants, as seen under the microscope, (Table 3.2) correspond with increases in the % humification given by the chemical test (Fig. 3.5) and vice versa. The agreement between the results of the two methods shows that % humification values reflect the extent of decay of the upper peat in which the disintegrating plants can be recognised. It seems reasonable to suppose that the same principle also applies to the amorphous lower peat, where decay is so advanced that variations in colour and texture are difficult to identify visually but where % humification differences are revealed by the chemical test.

Table 3.1 Stratigraphy as seen in the field

Depth cm	Description of Peat
Surface	Modern vegetation, mostly <u>Calluna</u> .
*0 - 8	Dark, crumbly, almost dry, modern roots, <u>Calluna</u> twigs.
8 - 14	Lighter coloured, crumbly, some modern roots.
*14 - 19	Dark brown, dry, well humified.
19 - 95 *	Light brown, fairly loose, recognisable <u>Sphagnum</u> fragments. Some colour variation including dark bands at 32 - 36 cm and 60 - 64 cm.
*95 - 105	Dark, well humified, compact, tufts of <u>Eriophorum</u> and <u>Calluna</u> twigs.
105 - 110	Light coloured band, less humified, thin stems.
*110 - 212	Dark, well humified, <u>Eriophorum</u> and <u>Calluna</u> .
*212 - 288	Dark, well humified, <u>Betula</u> branches and twigs: frequency increasing with depth, <u>Eriophorum</u> .
288 - 292	Thin layer gritty organic soil, <u>Betula</u> wood.
Below peat	Light grey coloured gley soil composed of a mixture of sand and clay particles, forming an impervious layer, scattered sandstone rocks like those in stream bed.

* Denotes regions which are highly humified.

Table 3.2 Microscopic examination of peat profile

Depth cm	Description
*0 - 2	No recognisable remains.
*8 - 10	Disintegrating small <u>Sphagnum</u> leaves of <u>Acutifolia</u> type. 1 leaf <u>S. papillosum</u> .
*16 - 18	1 recognisable fragment of <u>S. papillosum</u> : very decayed.
24 - 26	Equal quantities of <u>S. imbricatum</u> and <u>Acutifolia</u> type leaves. Very small amount of <u>S. papillosum</u> .
30 - 32	Nearly all <u>S. imbricatum</u> , well preserved.
32 - 34 } 36 - 38 }	Very decayed. A few fragments of <u>S. imbricatum</u> and <u>Acutifolia</u> type leaves.
40 - 42	Mostly <u>S. imbricatum</u> , few <u>Acutifolia</u> type leaves, well preserved.
48 - 50	Equal quantities <u>S. imbricatum</u> and <u>Acutifolia</u> type leaves.
*56 - 58	Very decayed fragments <u>Eriophorum</u> . No <u>Sphagnum</u> .
64 - 66	1/3 <u>S. imbricatum</u> , 2/3 <u>Acutifolia</u> type leaves.
72 - 74	Very small number of <u>S. imbricatum</u> leaves.
80 - 82 } 86 - 88 }	All <u>Acutifolia</u> type.
88 - 89	Disintegrating leaves. Not recognisable.
*90 - 102	6 serial samples, all decayed, no leaves.
102 - 112	5 serial samples, all with abundant <u>Acutifolia</u> type leaves. Many thin unbranched leafless stems up to 2 cm long (unidentified).
112 - 114	Disintegrating <u>Acutifolia</u> type leaves.
114 - 292	No recognisable <u>Sphagnum</u> . Varying amounts of disintegrating <u>Eriophorum</u> leaves and <u>Calluna</u> twigs.

* Denotes regions which are highly humified.

5. Radiocarbon dates

The radiocarbon dates, for seven samples, determined by Dr. V. R. Switsur and corrections (Switsur 1973) are shown in Table 3.3.

Table 3.3 Radiocarbon dates and corrected dates

Depth cm	^{14}C years bp	Uncertainty \pm	Corrections BP
44 - 48	1470	50	1392
82 - 86	2035	50	1993
110 - 114	2429	50	2483
144 - 148	3130	50	3323
188 - 192	4900	50	5447
230 - 234	6120	50	6780
286 - 290	8010	75	-

Table 3.4 Radiocarbon dates and associated changes in peat

Level cm	Changes in peat	¹⁴ C years bp	Corrected years BP
44 - 48	Fall in <u>Plantago</u> and Gramineae. Increase in <u>Betula</u> . <u>S. imbricatum</u> maximum. High growth. Low humification.	1470 ±50	1392
82 - 86	Marked rise in <u>Plantago</u> , Gramineae.	2035 ±50	1993
110 - 114	Changes in <u>Ulmus</u> , <u>Betula</u> , Gramineae. Lower humification. First recognisable <u>Sphagnum</u> .	2429 ±50	2483
144 - 148	Small increase in <u>Betula</u> , <u>Ulmus</u> , Gramineae, herbs. Decrease in <u>Quercus</u> , <u>Corylus</u> . Lower humification. Growth low.	3130 ±50	3323
188 - 192	Low <u>Ulmus</u> (decline?). Beginning continuous <u>Fraxinus</u> . Very high humification.	4900 ±50	5447
230 - 234	<u>Alnus</u> steady increase. <u>Pinus</u> falling. 2nd <u>Melampyrum</u> maximum. Growth and humification increasing together.	6120 ±50	6780
286 - 290	Lowest true peat sample.	8010 ±75	

DISCUSSION1. Comparison of two methods for measuring peat growth

In this and following sections the statistical methods and tables used for comparison of data are as described by Siegel (1956). Values of probability ≤ 0.05 are taken as being significant.

Using the corrected radiocarbon dates (Table 3.3), except for the deepest sample, the time span of the profile was divided into seven periods and the mean peat growth rate ($\text{Growth}({}^{14}\text{C})$) was calculated for each. The periods 1-7 and their corresponding growth rates are shown in Table 4.1.

From the experimental results of the Lycopodium method (Fig. 3.4), mean growth values ($\text{Growth}(\text{Lyc})$) were obtained for the periods 1-7 and they are given in Table 4.2.

$\text{Growth}(\text{Lyc})$ was plotted against $\text{Growth}({}^{14}\text{C})$ to check for agreement between the results of two different methods for evaluating growth (Fig. 4.1). The scatter of points in Fig. 4.1 suggests a probable positive correlation between $\text{Growth}(\text{Lyc})$ and $\text{Growth}({}^{14}\text{C})$. The correlation is confirmed by calculating the Spearman rank correlation coefficient (r_s) which has a value 0.85 and an associated probability between 0.05 and 0.01. This significant level of agreement between the results of the two methods suggests that the Lycopodium method is a suitable alternative to a series of radiocarbon dates for determining peat growth rate, at least when the time periods are large. The above correlation applies to peat from Quick Moss but it is possible that the

Table 4.1

Mean peat growth rates from radiocarbon dates

Period	Depth (cm)	¹⁴ C years (bp)	Corrected (BP)	Duration (years)	Peat thickness (cm)	Peat Growth (cm/yr)
1	46	1470	1392	1392	46	0.033
2	84	2035	1993	601	38	0.063
3	112	2429	2483	490	28	0.057
4	146	3130	3323	840	34	0.040
5	190	4900	5447	2124	44	0.020
6	232	6120	6780	1333	42	0.032
7	288	8010	-	1890	56	0.030

Table 4.2

Mean peat growth rates from Lycopodium method

Period	Peat Growth(Lyc) (arbitrary units)
1	2.75
2	5.30
3	3.56
4	1.98
5	1.15
6	0.85
7	0.43

Table 4.3

Mean % humification for ¹⁴C periods

Period	% Humification
1	35.8
2	34.0
3	50.3
4	58.0
5	79.0
6	81.0
7	63.0

Fig. 4.1

Scatter diagram to show the relationship between Growth(^{14}C)
and Growth(Lyc)

Growth(^{14}C) calculated from radiocarbon dates (Table 4.1)

Growth(Lyc) calculated from the values in Fig. 3.4 (Table 4.2)

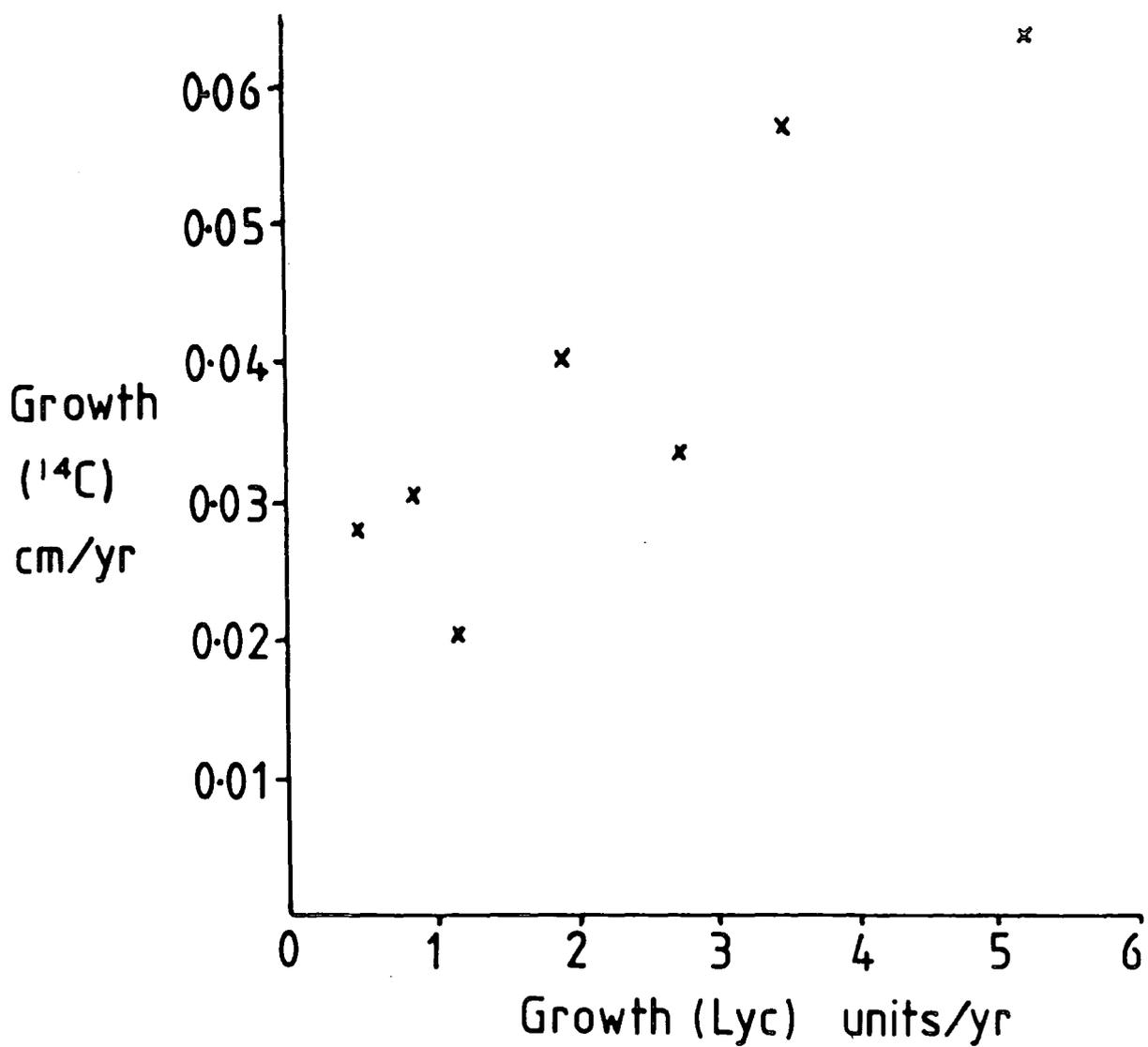


Fig. 4.1

same principle might also apply at other sites of a similar nature.

The use of the Lycopodium method for peat growth

The addition of a known number of exotic grains (e.g. Lycopodium spores) to a known volume of sediment can be used to measure pollen influx (grains/cm²/yr) if the rate of sediment accumulation throughout the profile is known or to measure the growth rate of a sediment if pollen influx is known to have been constant. An example of the former is found in the work of Davis (1967) who, using a series of radiocarbon dated levels, calculated the rate of accumulation of the lake sediment throughout the last 14,000 years. She was then able to use exotic pollen grains to show how pollen influx had varied during this period.

Quick Moss peat shows horizontal bands of colour variation which suggests that, unlike the lake sediment which normally accumulates at a constant rate over long periods of time, the peat accumulation rates have fluctuated rapidly. The Tree:Shrub:Herb pollen ratios (Fig. 3.1), however, remain fairly constant throughout the 5,500 years of growth of the lower peat and this is likely to mean that pollen influx did not vary much so, in this case, addition of Lycopodium spores can be used to estimate rates of peat accumulation. As argued on p. 6 of the Introduction, changes in pollen concentration should reflect the changes in growth rates in the peat and this is confirmed at Quick Moss by the correlation of Growth(Lyc) with Growth(¹⁴C).

The assumption of constant pollen influx appears to be valid even when one considers small scale changes on the pollen diagram (Figs. 3.1 and 3.2) and short term changes in the growth rate shown by the Lycopodium method (Fig. 3.4). The pollen diagram indicates that, from time to time,

prehistoric man was removing trees from somewhere in the pollen catchment area, possibly resulting in a temporary reduction in tree pollen. An associated reduction in tree pollen concentration in the peat at this time would result in an increase in the Lycopodium: Tree pollen ratio, indicating an apparent increase in peat growth. Although the second peak of the Melampyrum curve (232 cm) coincides with a peat growth increase, there are at least two levels where man's activity coincides with reduced peat growth, e.g. the first Melampyrum peak (256 cm) and the small Bronze Age clearance (144 cm). There are also two levels in the lower peat with high growth rates which do not correspond with recorded human activity. The first of these, at 208 cm, occurs at the point where wood remains disappear from the peat and the pollen of Calluna and Cyperaceae begins to rise. This marks the level at which the bog finally became established and it is likely that the recorded peat growth increase was a real one, perhaps caused by a wetter climate. A second level showing increased growth is at 160 cm at a time when the forest cover of the area around the bog was almost complete, in the period preceding the Bronze Age clearance. There is therefore little evidence from the lower peat that the pollen influx, and hence the apparent growth rates, have been significantly changed by man.

Large scale interference with the natural vegetation took place during the growth of the upper peat. Although there are also some very high growth values in this region they do not coincide with the clearance maxima. The largest clearance on the diagram (Fig. 3.2) reaches a maximum at approximately 64 cm and very high growth rates occur before and after, but not coinciding with, this level. Towards the end of the major clearance, when one would expect a high concentration of tree pollen in the peat as the forests regenerated, two high values for

growth are seen at 40 cm and 48 cm. These are unlikely to be the result of reduced pollen influx. Two levels in the upper peat, however, do show increased growth which corresponds with minor clearances: 24 cm and 104 cm, but it seems probable that, in view of the evidence from the larger clearances, man's activity was not an important factor in these increases.

It may be noted that, whilst not coinciding exactly with human activity, the very high growth rates, between 24 and 74 cm, are from peat largely composed of Sphagnum imbricatum. This species was a rapid peat former in the past, although it is rare today, and its response to a wetter climate could have produced some very rapid peat growth.

It can be concluded that at Quick Moss the Growth(Lyc) values (Fig. 3.4) reflect the growth rates of the bog throughout its development and that there has been little or no modification of the results due to man's clearance activities. The rates of growth are consistent with those obtained from radiocarbon dates so, if this is also valid at other upland sites, the Lycopodium method, carried out during routine pollen analysis, appears to be a quick alternative method for indicating the changes in peat growth throughout a profile when radiocarbon dates are not available.

2. Relationship between Growth(¹⁴C) and % Humification

Mean values for % Humification were calculated for the periods 1-7 using the results of the chemical assay (Fig. 3.5) and they are shown in Table 4.3. The values were plotted against Growth(¹⁴C) in Fig. 4.2. A significant level of negative correlation between the two is indicated

Fig. 4.2

Scatter diagram to show the relationship between Growth(¹⁴C)
and % Humification

Growth(¹⁴C) calculated from radiocarbon dates (Table 4.1)

% Humification calculated from the values in Fig. 3.5 (Table 4.3)

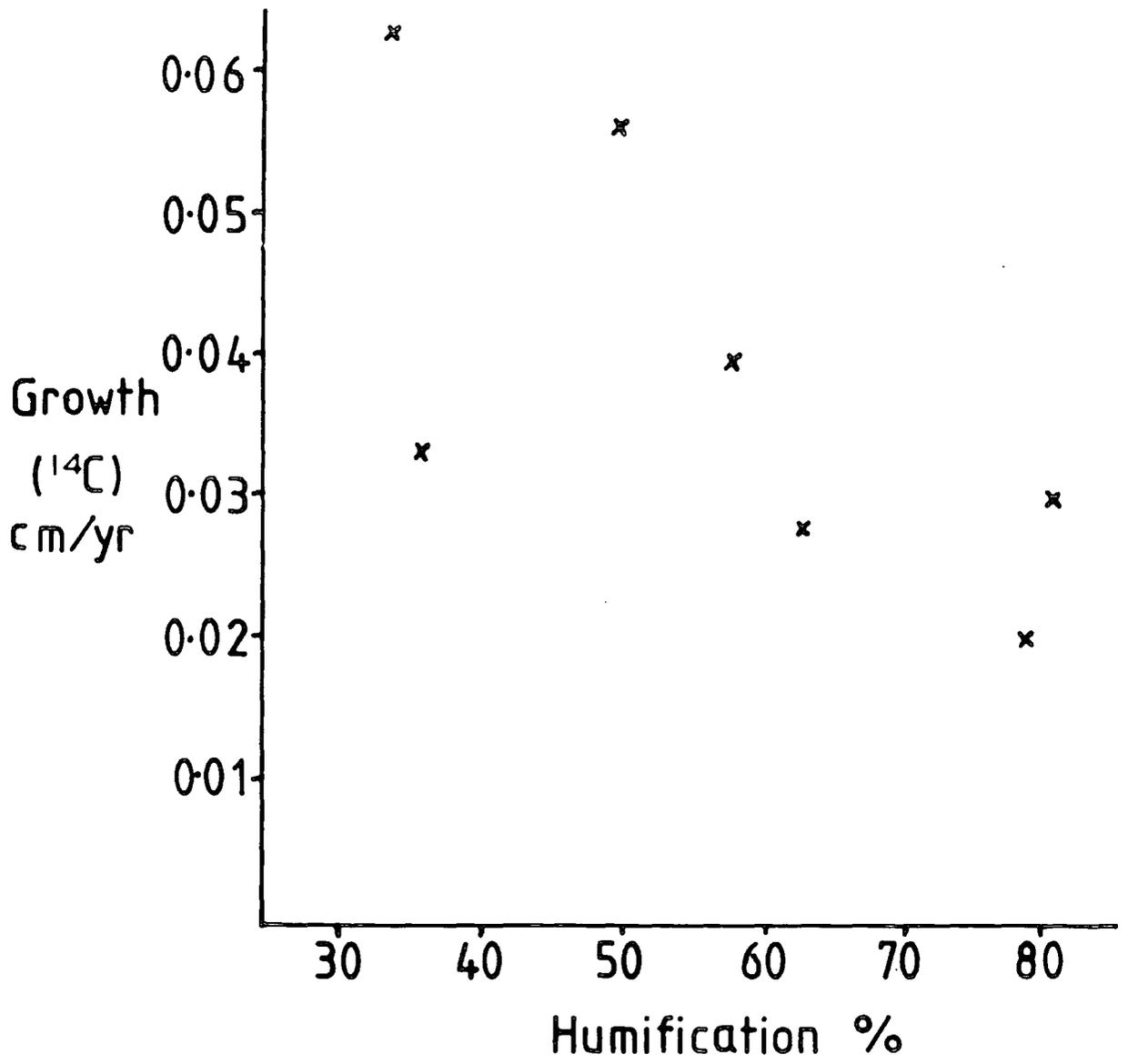


Fig. 4.2

by the Spearman rank correlation coefficient (r_s) which has a value 0.79 with an associated probability between 0.05 and 0.01. On this general level, therefore, Growth(^{14}C) and % Humification are found to be negatively related in the Quick Moss peat.

In Fig. 4.1 and Fig. 4.2 the comparisons are limited to seven groups of results by the radiocarbon dates so only general conclusions have been drawn. Larger numbers of values have been obtained experimentally for Growth(Lyc) and % Humification. The relationship between these two has therefore been investigated more fully throughout the profile.

3. Relationship between Growth(Lyc) and % Humification

A scatter diagram for the whole profile with values for Growth(Lyc) and % Humification at 8 cm intervals from Figs. 3.4 and 3.5 is given in Fig. 4.3. In the field there are visible physical changes in the peat at about 114 cm so the points representing peat from above this level have been marked differently from those below 114 cm. Each point is also identified by depth. Points from above 114 cm are well distributed across the graph and those from below 114 cm are mostly collected within a small area but, over all, there is a suggestion of a negative correlation between % Humification and Growth(Lyc). To test the significance of this possible correlation, the Spearman rank correlation coefficient was calculated for

- (a) the whole profile
- (b) the peat above 114 cm
- (c) the peat below 114 cm.

Since a negative correlation was suspected the Humification values were

Fig. 4.3

Scatter diagram to show the relationship between Growth(Lyc)
and % Humification

Growth values from Fig. 3.4

% Humification values from Fig. 3.5

Depth of each sample given and samples above 114 cm marked
differently from those below 114 cm

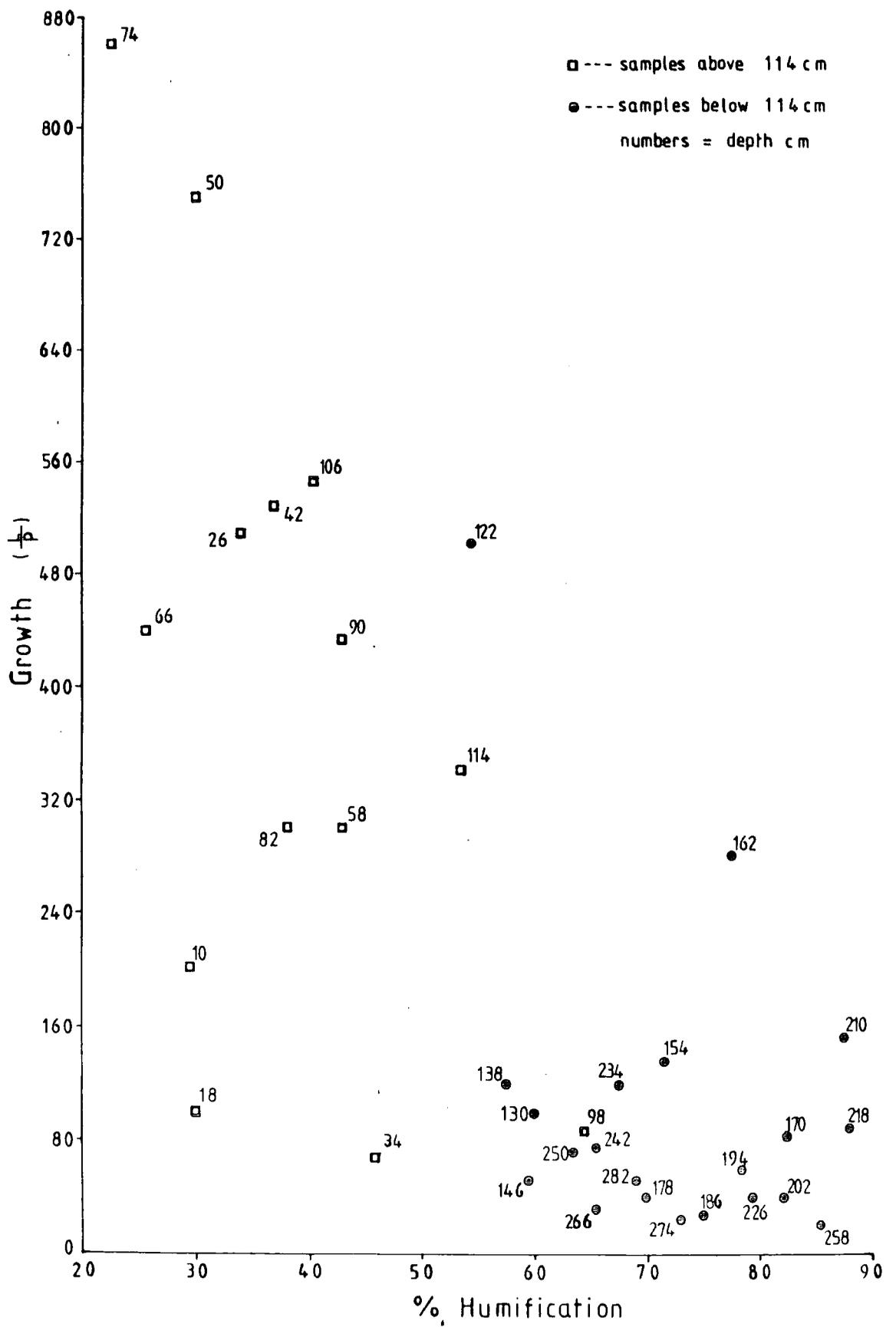


Fig. 4.3

ranked in reverse order.

Values for the top and bottom samples of the profile were omitted from the calculations as it was felt that the peat might be atypical. The bottom sample (288 - 290 cm) was almost mineral soil and a misleading colorimeter reading could have resulted from reflection of light by suspended mineral particles. It is also possible that the peat in the top sample (0 - 2 cm) could have been modified through its exposure at the bog surface.

The Spearman rank correlation coefficient (r_s) - summary of results

- (a) Whole profile (35 samples from 8 to 282 cm)

$$r_s = 0.68$$

$$p < 0.001$$

There is a significant negative correlation between Growth(Lyc) and % Humification at the 0.001 level over the whole profile.

- (b) Above 114 cm (14 samples from 8 to 114 cm)

$$r_s = 0.47$$

$$P < 0.05$$

There is a significant negative correlation between Growth(Lyc) and Humification at the 0.05 level in peat above 114 cm.

- (c) Below 114 cm (21 samples from 120 to 282 cm)

$$r_s = 0.101$$

$$p > 0.1$$

There is no significant correlation between Growth(Lyc) and % Humification at the 0.05 level in peat below 114 cm.

This test shows a negative correlation between Growth(Lyc) and % Humification in the whole profile (a) and within the upper peat (b) but no correlation can be demonstrated in the lower peat (c).

During the r_s test, experimental results from Figs. 3.4 and 3.5 were examined as series of values arranged in order of magnitude, regardless of spatial distribution in the profile. It may be, however, that increases and decreases in growth and humification which take place from one sample to the next are also important. To clarify this point, 2 x 2 contingency tables were constructed for the same sections of peat as were tested for r_s . Experimental results for each section of peat were examined systematically and the change in growth and humification from one sample to the next was recorded as an increase or a decrease. The Fisher exact probability test was used to analyse the data from the contingency tables. This test appeared the most suitable in this case as some values in the tables were quite low.

2 x 2 contingency tables and the Fisher exact probability test
- summary of results

(a) Whole profile (35 samples from 8 to 282 cm)

$$p = 0.046, \quad p < 0.05$$

There is a significant negative correlation over the whole profile.

(b) Above 114 cm (14 samples from 8 to 114 cm)

$$p = 0.021, \quad p < 0.05$$

There is a significant negative correlation in peat above 114 cm.

(c) Below 114 cm (21 samples from 120 to 282 cm)

$p > 0.31$

There is no significant correlation in peat below 114 cm.

At the 0.05 level of significance a negative relationship is shown between growth and humification in (a) and (b) but not in (c) by the 2 x 2 tables and the Fisher exact probability test. The same results were given by the r_s test.

Over the whole profile (a) a closer negative correlation between growth and humification was shown by the r_s test than by the 2 x 2 tables. The sample by sample examination used to construct the 2 x 2 tables revealed a stronger negative correlation in (b), the upper peat, than was shown by r_s . Both tests failed to establish any relationship between the two variables in (c), the lower peat.

4. Discussion of the Relationship between Peat Growth and % Humification

It is interesting to compare these results with those obtained by Aaby and Tauber (1974) for there are both similarities and differences. Aaby and Tauber found a negative correlation in their upper peat, resembling the one found at Quick Moss. They also found an intermediate layer with no clear relationship between peat growth and humification. In the lower peat there was a positive relationship between the two. In contrast, at Quick Moss, no intermediate layer was found and there is no correlation within the lower peat. When the lower peat results were included in the whole profile a negative, rather than positive, relationship was suggested. The two bogs, however, have developed under different physical conditions: the Danish site used by Aaby and Tauber is a lowland raised bog and Quick Moss is an upland blanket bog.

The development of peat in the two distinct regions identified in the Quick Moss profile are considered separately.

Upper Peat (above 114 cm)

The presence of a negative correlation between growth and humification in Quick Moss upper peat suggests that the response of this peat to surface humidity has been similar to the response described by Aaby and Tauber (1974) in their upper peat, i.e. an increase in humidity, resulting in a wet bog surface, stimulated Sphagnum growth and retarded humification and vice versa.

Aaby and Tauber were able to show this negative relationship by using the numbers of resistant Rhizopods in the peat to indicate surface humidity (see p. 10). Unfortunately this could not be done at Quick Moss due to the absence of Rhizopods. It has been shown by Heale (1961), from work on fens and bogs in northern England, that the species of Rhizopods which produce resistant tests occur more frequently in fens than in mineral deficient blanket bogs. Probably Quick Moss is an unsuitable habitat for decay resistant Rhizopods due to the absence of minerals needed for test formation.

It seems reasonable to suppose however, despite this lack of direct evidence, that surface humidity has been an important controlling factor in peat development at Quick Moss. Since surface humidity is, in turn, mainly controlled by climate then changes in climate are likely to have played a significant part in controlling the growth and the subsequent humification of the Quick Moss peat. Varying rainfall would seem to be the most likely factor affecting surface wetness, and hence the rate of development of the ombrogenous peat, although fluctuations in wind and temperature might also have been important in controlling the

water lost by evaporation.

Increases and decreases in humification (Fig. 1.3) in the Quick Moss upper peat appear to follow a fairly regular pattern which coincides, in part, with the climatic rhythm proposed by Aaby (1976). From his work on humification changes in samples of peat removed from an area between hummocks in a raised bog, Aaby was able to show that surface wetness had increased and decreased following an approximately 260 year cycle for 5,500 years and this was found to correlate well with other available evidence for climate changes. Using estimated dates (Fig. 3.3) for levels at Quick Moss, the time intervals between wet periods of low humification are about 260 years with some intervals rather longer and others shorter. It is possible that more precise dating may reveal an even closer agreement with Aaby's rhythm. Three of the levels of low humification (112 cm, 46 cm, 26 cm) have estimated dates which also correspond with the dates of Granlund's recurrence surfaces RY III, RY II and RY I (see p. 2) but it is not possible to speculate on recurrence surfaces at Quick Moss using evidence from one monolith alone.

Agreement between changes in bog stratigraphy and recorded climate changes was found by Barber (1981) at Bolton Fell Moss, a lowland raised bog about 46km N.W. of Quick Moss. A series of wet 'phase shifts', shown by periods of renewed growth of some species of Sphagnum and the presence of pond mud in peat profiles, correlated well with wet periods in Lamb's climatic curves (Lamb 1977). This helps to confirm that surface humidity can control the growth of peat plants and the stratigraphy of the bog. The many commercially cut surfaces used in Barber's study revealed peat of an age equivalent to Quick Moss upper peat where a similar relationship has been shown to exist. There is, as yet, unfortunately, no information from the

deeper peat at Bolton Fell Moss which could be compared with the rather different results from Quick Moss lower peat.

Lower Peat (below 114 cm)

In accounting for the lack of relationship between growth and humification in the lower peat, three possible causes are considered: firstly, that the experimental method may have failed to detect an existing relationship; secondly, that secondary change in the peat has obscured a real relationship; and thirdly, that there was no direct relationship between the rate of peat growth and the degree of humification when the lower peat was forming probably because of the prevailing environmental conditions.

a) Limitation of the experimental method

The experimental methods used for determining growth and humification may have their limitations in that different sized samples were used. A relatively large volume of peat (32 cm³) was needed for the humification assay and only 0.25 cm³ for growth and pollen analysis. In the former a piece of peat was cut from the whole thickness of the 2 cm slice and in the latter a small pellet, 0.32 cm long, was cut from the middle of the 2 cm thickness. The pellet was assumed to represent growth in the whole 2 cm slice but it is possible there were variations even within the slice, with each growth result actually referring only to a small section in the middle of the 2 cm. The humification percentage, however, does represent a mean result for 2 cm growth of peat, thus like was not, strictly speaking, compared with like.

It is also possible that the Lycopodium method may have failed

to detect small, but real, changes in growth rate since the variations from sample to sample are not very marked.

Smaller sampling intervals might have overcome these limitations in the methods but this seems unlikely in view of the results obtained with similar sampling intervals in the upper peat.

b) Secondary change

This was considered by Aaby and Tauber (1974) to be responsible for the development of a positive correlation in their lower peat. The principal agent was thought to have been autocompaction, due to pressure from the overlying layers, with creep and continued anaerobic decomposition as possible contributory factors. Aaby and Tauber were able to demonstrate how samples of peat with similar Sphagnum remains and the same % humification showed a progressive decrease in growth rate as depth increased. Since depth measurements were used to calculate growth rates, it appeared that compression of the lower layers may have distorted the results.

Quick Moss lower peat is too humified to contain recognisable Sphagnum remains but there are peat samples with approximately the same degree of humification in which growth rates can be compared. In these samples growth rate does not increase with depth. There is also a distinct change in the relationship between growth and humification at the boundary between the upper and lower peat and no intermediate zone has been detected in which the peat may have begun to be modified by compression, as was found by Aaby and Tauber. The evidence suggests therefore that autocompaction is unlikely to have taken place at Quick Moss.

Lateral movement, or creep, in accumulating peat is not fully

understood, having mostly been studied in the laboratory. This and anaerobic humification were considered to be less important than autocompaction by Aaby and Tauber so, since there is no evidence for either from Quick Moss, it seems unlikely that they caused much modification of the peat.

It might be thought that the drainage channels, described on p. 17, could have changed the nature of the bog as the streams cut down through the peat. Tallis (1973) however has shown, at a similar site in the southern Pennines, that the channels are probably of recent origin, initiated about 250 years ago by drying or burning of the surface vegetation, and that the lateral drainage of water into the channels is largely through the upper peat. It seems the colloidal nature of the humified lower peat impedes water movement and if this is also the case at Quick Moss, it is unlikely that the channels have had any modifying effect on the nature of the lower peat.

Therefore, the evidence obtained from Quick Moss lacks features which would indicate secondary change in the lower peat and it seems most likely that the lack of correlation between growth and humification is a primary phenomenon linked with the growth of the bog. This means that the bog surface conditions in the past must have been different from those of today with respect to flora, climate or probably both.

c) Environment during growth

The advanced humification of the lower peat makes identification of all but a few resistant plants impossible and the pollen record does not help with identification at the species level. Consequently the exact nature of the bog flora is not known although the many fragments of Eriophorum and Calluna in the lower peat, with increasing

amounts of Betula wood towards the bottom of the profile, suggest a flora suited to drier conditions than those prevailing during the upper peat growth.

As explained on p. 12, Clymo (1965) has shown that, under the same conditions, some bog plants decay more rapidly than others and so temporal variations in the bog flora may have contributed to varying degrees of humification. A later investigation by Clymo (1970) showed that the growth rate (net production) of living Sphagnum varies with the species as well as with temperature and local wetness. At Quick Moss the highest growth rates in the upper peat are in the section dominated by S. imbricatum (18 - 74 cm). At a different Pennine site another species, S. rubellum, has been shown to have a secondary effect on the growth of the bog flora in prolonging the life of Calluna plants. The upward growth of S. rubellum round the Calluna stems provides suitable conditions for continuous development of new adventitious roots (Clymo and Reddaway (1974) after Rawes and Welch (1969)). The bog flora may also, from time to time, have been modified by fire leading to an increase in Eriophorum and high levels of humification until the vegetation recovered (see p. 16). Since, however, the principal factor controlling the flora itself is likely to have been surface humidity, the climatic factors affecting humidity were probably crucial. It has been suggested by Barber (1981) that the dominance of S. imbricatum mentioned above, and also common in other bogs at this time, was terminated in fact by the onset of a wetter climate producing too high surface humidity.

5. Climate

Radiocarbon dates show that most of the growth of the lower peat at Quick Moss took place during the Atlantic and Sub-Boreal

periods, at a time when, following the formation of the North Sea, it is thought a moderately wet and warm oceanic climate prevailed (Lamb 1977). Towards the end of the Sub-Boreal period the climate appears to have deteriorated markedly and this corresponds with the time when the lower peat gave way to the upper peat and a new relationship between growth and humification became established.

Peat growth values from the lower peat are much smaller than those of the upper peat and this suggests that the bog surface was drier in lower peat times, possibly due to a high rate of evaporation from the bog surface caused by the warm climate. The dry, warm conditions at the bog surface, as well as retarding peat growth, could have favoured humification of the peat, producing the generally high humification percentages obtained from the lower peat. This explanation may account for the general pattern of slower accumulation rates and higher humification values in the lower peat although it does not offer any reasons for the absence of a relationship between the two at the sample to sample level, the reasons for which one can only speculate upon.

The climatic cycles detected by Aaby (1976) (see p. 81) lead one to suppose that, in addition to the general cooling of the climate during the last 5,000 years or so, there have also been many smaller scale fluctuations and it is probably these that produced a variety of responses in the growing peat which led to the apparently unrelated growth and humification patterns.

The responses of peat to a changing climate are very complex and depend on three inter-related aspects: surface humidity, growth of peat plants and humification of dead plants. All three are controlled in some way by precipitation and temperature.

i) Humidity at bog surface $\propto \frac{\text{precipitation}}{\text{evaporation}}$

A high precipitation/evaporation ratio produces a wet bog surface and vice versa.

ii) Growth of peat plants \propto humidity and temperature

Given adequate humidity, an increase in temperature also increases growth.

iii) Humification of dead plants $\propto \frac{\text{temperature}}{\text{humidity}}$

Humification increases with a higher temperature but decreases with increased humidity.

It can be seen that temperature is involved in the growth of peat plants in two ways. An increase in temperature will cause increased growth of bog plants but only if there is adequate humidity at the bog surface (as in ii). Surface humidity is, in turn, reduced by an increase in temperature due to increased evaporation (as in i).

Thus during periods of moderate rainfall in lower peat times, the temperature may, very often, have been high enough to evaporate most of the surface water producing conditions which would have retarded Sphagnum growth and only when the rainfall was very heavy would the precipitation/evaporation ratio have been high enough to increase the surface humidity sufficiently to increase growth. It could be argued that, in the warmer climate of the lower peat times, changes in the generally slow growth rate were probably largely due to fluctuations in rainfall (and snowfall) causing variations in the precipitation/evaporation ratio.

The humification process (as in iii), on the other hand, requires

very little water and is accelerated by warmth. Except when rainfall was very heavy, humification was probably regulated by temperature fluctuations since the humidity levels are likely to have been too low, for much of the time, to have had a significant retarding effect.

If growth and humification had responded differently to rain and temperature in the ways suggested then one can see that, in a short period of comparatively dry and cool weather, growth would have been slow because of a low precipitation/evaporation ratio and humification would also have been slow, retarded by a low temperature. A subsequent increase in temperature might have increased humification but not growth, and an increase in rainfall, growth but not humification. Thus, if growth and humification had at many times varied independently of each other in this way, it might go some way towards accounting for the lack of correlation that was actually found.

In contrast, during the generally cooler, wetter climate of the upper peat times the fluctuating, but high, precipitation/evaporation values and the resulting high levels of humidity would have promoted Sphagnum growth and would also have been more significant than temperature in controlling humification. This climate regime would therefore have allowed a more direct relationship between growth and humification; a possible reason why Quick Moss upper peat shows a negative correlation between the two.

Although the problem is complex, it appears that, of the factors considered, the climate at the time the plants were alive is the most likely to have caused the unrelated growth and humification patterns in Quick Moss lower peat.

There are several conclusions which may be drawn from this study.

It can be seen from the pollen diagram that the vegetational record shows similarities with evidence from other upland sites in the area and other features which are specific to Quick Moss. There is also evidence from the pollen diagram and associated growth and humification curves that pollen influx has been fairly constant throughout the life of the bog, suggesting that the Lycopodium method is a reliable one for indicating growth fluctuations in the peat. The correlation between Growth(Lyc) and Growth(^{14}C) confirms the reliability of the method. An inverse relationship between growth and humification has been shown in the upper peat, to a lesser degree over the whole profile but not in the lower peat. A possible explanation of this difference seems to lie with the climate, particularly the temperature and rainfall at the time the peat forming plants were alive. Varying rainfall appears to have been the most important factor in controlling peat growth and peat humification in cool conditions, but in warmer weather it is probable that increased evaporation from the bog surface modified the effects of varying rainfall.

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