A study of the vegetational history of Widdybank Fell, in Upper Teesdale

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THE VEGETATIONAL HISTORY OF WIDDYBANK FELL, IN UPPER TEESDALE.

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ABSTRACT

A study was made of the vegetational history of Widdybank Fell, Upper Teesdale, using the techniques of macrofossil, stratigraphic and pollen analysis. The study was designed to investigate (a) the Post-glacial history of the vegetation; (b) the relationship of this history with the survival of the present day Teesdale flora; (c) the age of the blanket peat which now covers a large area of the Fell.

Peat growth began in hollows at the end of zone III and continued throughout the Boreal period. Evidence from the pollen diagrams shows that the Fell was covered by open woodland during zones VI and VIIa. Throughout the Post-glacial period, herbaceous species, including many characteristic of open grassland habitats, maintain high values, equalling the values for tree species.

The Atlantic period is characterised by very slow peat growth with oak, elm and alder as the dominant tree species. Radio-carbon dates taken from Tinkler's Sike suggest that peat growth became more rapid and widespread during the Sub-boreal period, about 1440 BC. The major development of blanket peat took place towards the end of zone VIIb and during the following Sub-Atlantic period. The increase in herbaceous pollen types began towards the end of zone VIIb with a major rise at about 620 BC. Evidence from the pollen data suggests that the increase in open habitats and deforestation of the Fell was directly connected with an increase in human utilization of the land.

The relict species of the Teesdale flora survived the Post-glacial forest maximum in an open woodland condition and spread on to their present grassland habitats from the end of zone VIIb onwards as human activity and climatic deterioration created tracts of open grassland and peat areas.

INDEX

DIAGRAMS AND PLATES.

Diagrams:

Plates.

CHAPTER 1

INTRODUCTION.

Towards the end of the nineteenth century, a considerable amount of work was carried out particularly in Scandinavian on the climatic changes which had taken place since the last glaciation of northern Europe. At about the same time, work was beginning in Britain chiefly by C. Reid and later by E. M. Reid and Chandler, not only investigating pleistocene deposits but also analysing tertiary deposits for plant remains.

In Scandinavia, Blytt (1893) and Sernander analysed the stratigraphy of peat bogs and postulated that differences in peat stratigraphy were related to changes in climate. The Blytt-Sernander scheme recognised five major climatic divisions of the post-glacial period:-

Sub-Atlantic	Cold and wet. Oceanic
Sub-Boreal	Warm and dry. Continental
Atlantic	Warm and wet. Oceanic
Boreal	Warmer than before and dry.
Pre-Boreal	Sub-Arctic.

This was followed by work in other parts of Europe particularly central Europe and the Alps (Gams and Nordhagen 1923) which demonstrated that throughout Europe changes similar to those found by Blytt and Sernander in Scandinavian peat bogs could be traced.

In the early part of this century Lennart Von Post (1924, 1946) evolved the technique of pollen analysis and used it to reconstruct the history of vegetation during the Post-glacial period in Sweden. He correlated this work with the earlier climatic divisions of this period and proposed a three-fold division:-

1. A period of climatic amelioration characterised by the appearance of thermophilous tree species.

2. The climatic optimum period.

3. A period of decreasing warmth during which the tree species characteristic of the warm period declined and the present day forest constituents returned.

This broad general classification of the post-glacial has been supported by evidence from all parts of Northern Europe and indeed many other parts of the world.

The theory of pollen analysis depends basically on the following factors:-

(a) The pollen of most trees and many shrubs and herbs (i.e. chiefly those which are wind pollinated but also some which are zoogamous) is produced in large quantities dispersed in the area and distributed regularly over a wide area.

(b) Pollen grains have an outer layer or exine which is not only complex in structure but extremely resistent to decay. Thus pollen deposited in anaerobic conditions are preserved for an indefinite period of time.

(c) Pollen grains of different plant families, genera and in many cases species are characteristic and may be identified from each other.

Following these three factors in the technique of pollen-analysis much work has been carried out throughout this century on the distribution structure and identification of pollen and spores. Wodehouse (1935) and Erdtman (1943) and later Iversen together with Troels-Smith (1950) and Faegri (1963) have carried out detailed investigations into the structure and morphology of pollen grains allowing a very large number of grains to be identified as far as specific level. Many investigations on the dispersal and subsequent distribution of pollen grains have been carried out (in particular by Erdtman (1937) and more recently by Tauber (1967) These investigations into long distance transport of pollen, relative contribution of different species to the pollen rain, the effect of wind, difference in flowering time, relative position of trees, shrubs and herbs to others and many other factors have contributed greatly to modern pollen analysis.

By 1940 sufficient work had been carried out in the British Isles to enable Godwin (1940) to draw up a post-glacial pollen zonation scheme for England and Wales which later was extended to Ireland (Jessen 1949). Using evidence provided from a large number of sites both on the European mainland and in Britain, he divided the post-glacial epoch into five major zones following on from the three-fold division of the period immediately following the Full-glacial period i.e. the late Glacial period, as follows:-

	Zones.	Climatic zone	Vegetation
Late Glacial	I		Park-Tundra type of vegetation dominated by herbaceous species including many arctic species and some tree birches.
	II		Milder Allerød period of open vegetation dominated by Pine, birch and willow with many herbaceous species.
	III		Post Allerød cold period of open herbaceous vegetation.
Post-Glacial	IV	Pre-Boreal	Dominated by pine and birch with rapidly diminishing values for herbaceous, particularly, arctic species.
	V	Boreal	Hazel - Birch - Pine period
	VI		(a) Hazel - Pine period with increasing Elm values.

Zones	Climatic zone	Vegetation
		(b) Increase in oak and elm values. (c) Decline of hazel and pine and appearance of Lime and Alder.
VII	Atlantic	(a) Alder - mixed oak forest period. Decline of pine and birch.
	Sub-Boreal	(b) Decline of Elm, lime and pine. Increase in hazel.
VIII	Sub-Atlantic	Alder - birch - oak (beech) period. Increase in herbaceous species.

This zonation scheme although broadly applicable to the whole British Isles, nevertheless shows regional variations. In the North and West of England the frequency of birch was generally higher than in the south and east and Pine showed much higher values in Zone IV in the south - eastern sites. Also during the Zone VI there is most Pine during the early part of this period in the south-east whilst in the north and west the pine maximum occurs rather later during the latter part of the period-zone VIc (Pennington 1964; Oldfield 1965).

Pennington (1969) summarizes evidence for a period of damp conditions in the north-west of England preceding the rise in Alder values which characterizes the opening of the Atlantic period in Britain. Conway (1954) in her work on the Southern Pennine blanket peats gives evidence for damper conditions at the Boreal-Atlantic transition and suggests that on the Southern Pennines Peaks, conditions deteriorated throughout not only the succeeding Atlantic period when peat formation was relatively slow but also the period following the elm decline when the accelerated growth of peat suggests a wetter rather than a drier climate. During the Sub-Atlantic period too, species such as *Fagus* and *Carpinus* were in the main restricted to south-eastern localities.

With the advent of radio-carbon dating techniques (Libby 1955) a further aid to the investigations of post-glacial vegetational history became available. Dates were obtained from sites throughout Northern Europe and Britain particularly across pollen zone and climatic boundaries. The climatic and vegetational changes in the post-glacial period were found to be more or less synchronous and Godwin (1960) summarizes these dates as follows:-

Zone Boundaries

VIIb/VIII	500	BC
VIIa/VIIb	3000	BC
VI/VII	5000	BC
IV/V	7500	BC
III/IV	8,300	BC
II/III	8,800	BC
I/II	10,000	BC

Thus using this technique it is possible to investigate the vegetational history of an area with greater precision and compare one site with another with much greater accuracy.

Contributing to this detailed picture of post-glacial vegetational history are a vast number of investigations into both lowland and upland sites in the north of England. In particular, the Southern Pennines have been investigated by Conway (1954) and Tallis (1964;1965); The English Lake District by Pennington; the lowlands of Lancashire and Westmoreland by Oldfield (1960); Walker (1955); Smith (1958) and Birks (1964); The North

York Moors by Dimbleby (1952) and Clarke (1954); and the lowlands of County Durham and the Northern Pennines by Blackburn (1951), Bellamy et al (1966) and Johnson and Dunham (1963).

In view of these numerous and detailed investigations of sites in Northern England it is rather surprising that no detailed work has been carried out in Upper Teesdale.

Upper Teesdale is an area of major botanical importance because within this area grow an assemblage of plant species, most of which are found at only a very few other stations in Britain and a few of which are found only in Teesdale. This flora shows striking similarities to that of the late glacial period and has been interpreted as a relict flora which has survived the post-glacial forest maximum in a variety of habitats in the area. Pigott (1956) sets out a detailed description of the communities in the Upper Teesdale area in which these relict species occur, among them the sugar limestone grasslands and flushes occurring on Cronkley and Widdybank Fells. The survival of these relict species in this area has been attributed to the peculiar conditions of climate and geology which combined with altitude have provided favourable habitats for the growth of Arctic and Sub-Arctic species.

Pigott and others have carried out detailed ecological and taxonomic investigations of these species but although remains of a forest layer had been discovered beneath the blanket peat on both Cronkley (Blackburn unpublished) and Widdybank Fells (Pigott 1956) there has been no previous investigation of the vegetational history of Upper Teesdale using pollen-analytical, macro-fossil and stratigraphic techniques.

During 1966 and 1967 the proposal by the Tees Valley and

Cleveland Water Board to build a reservoir immediately above Cauldron Snout became known. This caused an unprecedented threat to many of the unique Teesdale communities including the riverside habitats of Potentilla fruticosa and the upland communities including such species as Minuartia stricta, Plantago maritima, and Armeria maritima in the calcareous flushes and Sesleria caerulia, Gentiana verna and Primula farinosa on the limestone grasslands either by an alteration in the river-level itself or by a change in the local climate of the area by the presence of a large body of open water.

Thus the need for a thorough investigation into the vegetational history of the area in addition to further detailed work on the ecological and taxonomic aspects of the flora was clear.

On both Cronkley and Widdybank Fells and also in the Cow Green reservoir basin to the West of Widdybank Fell, there are a large number of peat deposits of varying depth, far more than could be investigated in the two years available. A choice had to be made, therefore, at the outset between a detailed investigation on one of these areas e.g. Widdybank Fell, and a more general investigation taking for example one deposit in each of the three areas. The former method was chosen because it was thought that it might be more fruitful in its bearing on the history of the Teesdale rareties and local vegetation changes which were taking place during the post-glacialperiod. At the same time, Mr. R. Squires was interested in carrying out a comparative study of the peat deposits at differing altitudes from 2000' O D on Mickle Fell to about 1200' O D at Dufton Moss on the valley floor. Within a year of beginning this work on Widdybank Fell, the Cow Green reservoir scheme was adopted and work began in the summer of 1967. When, at about this time I.C.I. set up a grants scheme making funds available for furtherresearch in the area, Dr. J. Turner and others began a study of the peats in the reservoir basin itself.

The small area of Widdybank Fell seemed to offer an ideal situation for a detailed study. Within the area of the Fell itself many of the most interesting Teesdale communities are present, in particular, calcareous flushes, sugar limestone outcrops and grasslands and unaltered limestone grasslands in addition to a complex of mire communities. Pigott (1956) had discovered a layer of Birch wood below the peat on Widdybank Fell and Hutchinson (1966) had discovered a new record of Betula nana and found remains of it in the peat below, on this Fell also. Not least, the Fell is covered by vast tracts of peat of two main types, a shallow blanket peat covering leached acid soils or outcrops of Whin Sill, and areas of Deeper Sphagnum peat filling hollows in the irregular topography, both of which offered the opportunity for an intensive study of the history of the vegetation of the Fell.

The initial aims of choosing Widdybank Fell were :-

1. By taking a large number of sites within this small area to investigate thoroughly the stratigraphic pollen analytical and macro-fossil evidence of the vegetational history of the Fell.

2. By taking sites which varied (a) in depth and structure of peat (b) in altitude and (c) in proximity to sugar limestone outcrops to build up a detailed picture of local vegetation and the changes which took place in it throughout the post-glacial period.

3. By building up a detailed picture of vegetational change through the post-glacial period on the Fell, to substantiate ecological evidence for the origins and development of the Teesdale Flora.

CHAPTER 2

INTRODUCTION TO WIDDYBANK FELL.

Topography

Widdybank Fell is situated on the North side of the Tees Valley, (Fig.1), on the Eastern watershed of the North Pennine ridge, at 54° 40'N Lat., about nine miles W.N.W. of Middleton-in-Teesdale, and two miles above Langdon Beck hamlet. The Tees takes it source from the drainage waters of little Dun and Cross Fells and from Great Dun and Knock Fells, where the tributary, Trout Beck, rises. The Tees flows down from the high ground of the summit range between Backside Fell and Meldon Hill and then into the wider valley of the Weel, before Cauldron Snout waterfall. Below this fall, the Tees is joined by the Maize Beck, which originates in Great Rundale Tarn, about 2000' on Dufton Fell. Below this confluence, the river runs between the high dolerite cliffs of Falcon Clints on the North and Cronkley Scar on the South side.

Widdybank Fell is a plateau of high land between 2 - 3 sq.m. in area, rising steeply above the river at Falcon Clints from 1450' OD to 1500' OD. Widdybank is of much lower altitude than many of the surrounding Fells. Its highest point is 1717' OD whereas many of the fells comprising the summit range of the Northern Pennines reach 2000' OD or more. Cronkley Fell is also a relatively low plateau by comparison, reaching a height of 1793' OD although the land rises above 2000' OD towards Mickle Fell.

Widdybank Fell is bounded on the south, east and west sides by a loop in the river Tees and on the north side by the road from Langdon Beck to Cow Green mine, (Fig.2). The area to the East side of the Fell, gradually sloping downhill from 1500' OD to 1250' OD is known as Widdybank

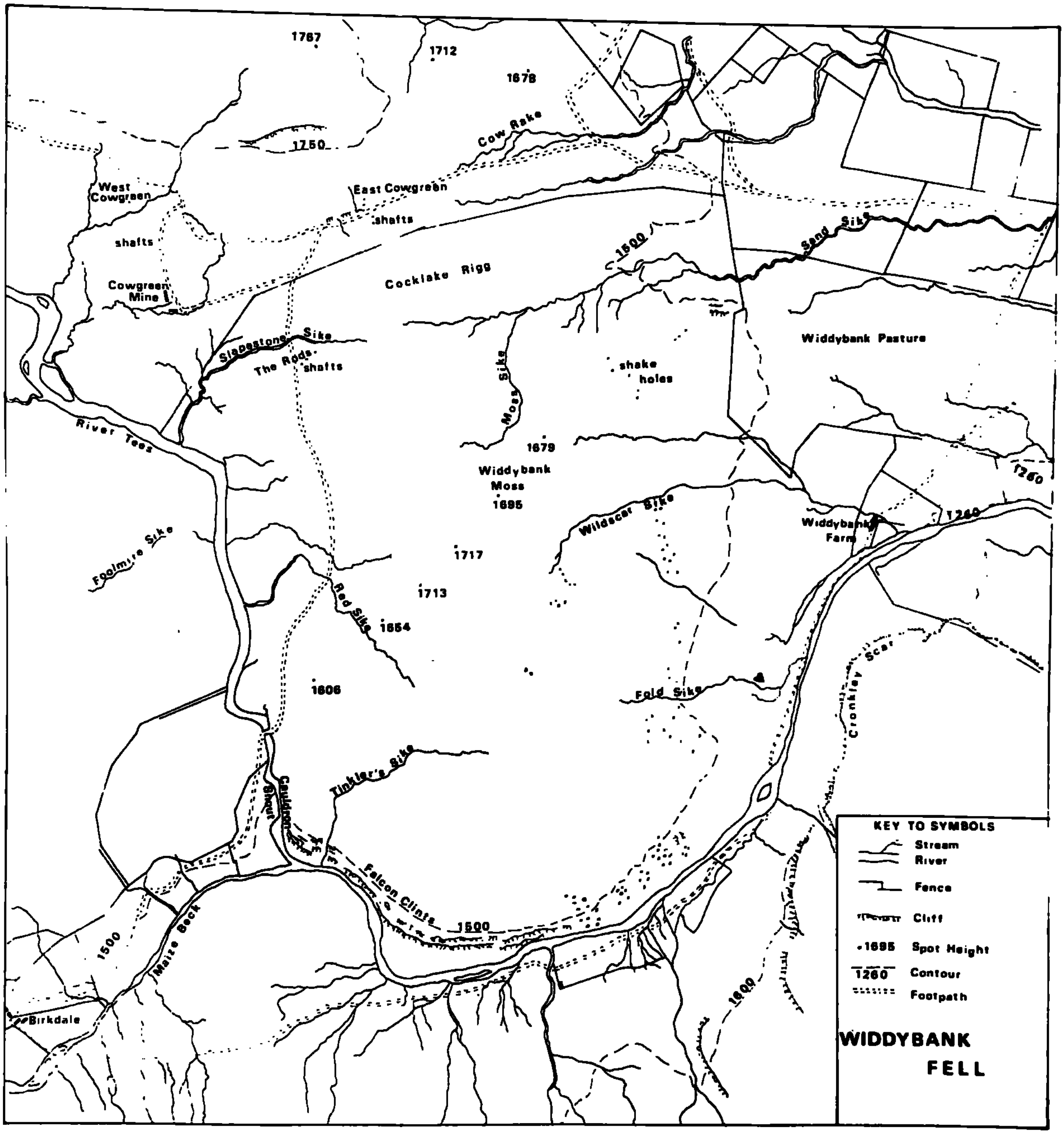

1787
1712
1678
1750
Cow Rake
West Cowgreen
East Cowgreen
shafts
shafts
Cowgreen Mine
1500
Sand Sike
Cocklake Rigg
Slapestone Sike
The Rods
shafts
Moss Sike
shake holes
Widdybank Pasture
River Tees
1679
Widdybank Moss
1695
1260
Widdybank Farm
1260
Wildacer Sike
Foolmire Sike
1717
1713
Red Sike
1654
1606
Fold Sike
Cronkley Scar
Tinkler's Sike
Cauldron Snout
Falcon Clints
1500
1500
Maize Beck
Birkdale
1600
KEY TO SYMBOLS
Stream
River
Fence
Cliff
•1695 Spot Height
1260 Contour
Footpath
WIDDYBANK
FELL

Fig. 1.

Pastures and is fenced off from the higher ground to the West. Within this area, near the south-eastern margin of the Fell lies Widdybank Farm. On the western side a bridle path running north-south from East Cow Green (Fig.1) to Birkdale Farm, separates the valley now designated for the Cow Green reservoir, from the main part of the Fell. The area which I have taken to examine is the area enclosed by the road to the North; Falcon Clints to the South; Widdybank Pasture to the East and the reservoir road to the West.

The plateau of the Fell is dissected by a number of streams or sikes: Slapestone, Red, and Tinkler's Sikes, together with three minor unnamed streams flow westwards, draining into the Tees at the Weel, whilst the other sikes drain eastwards: Wildscar, Fold and Holmwath Sikes flowing into the Tees below Falcon Clints and Sand Sike into the Harwood Beck, which joins the Tees below Langdon Beck.

Geology

The Northern Pennine region as a whole consists basically of a block tilted towards the east and faulted to the north, west and south. The rocks of this block are chiefly of Carboniferous age, although small outcrops of rocks of older age occur. Below Cronkley Scar the Carboniferous basement group lies unconformably over the Lower Palaeozoic rocks, which are but poorly exposed there. They consist of highly cleaved slates with some fossils - the Skiddaw Slates, and lavas belonging to the Borrowdale Volcanic Series. The Carboniferous basement group is exposed at Falcon Clints and consists of conglomerates upon which lie bands of limestone, shale and sandstone. The lower limestone group as exposed at Cow Greem, consists of the Melmerby Scar Limestone overlying the basement group and above this lie the Robinson, Peghorn and Lower Smiddy Limestones interbedded with shales and sandstones. Widdybank Fell is chiefly composed of the lower Carboniferous limestone group whilst the Middle and Upper limestone groups are exposed elsewhere in the region. The middle Limestone groups shows cyclothemic depositions of limestones, shales and sandstones and is exposed over large areas of Upper Teesdale though not at Widdybank Fell (2). The Upper Limestone group is not exposed over the region under consideration, although it is exposed on the high fells to the north, south and west of the Tees valley (Johnson and Dunham 1963).

Into the Carboniferous limestone series was intruded the Great Whin Sill and its associated system of dykes, during post-carboniferous time about 196 million years ago At Widdybank Fell the Whin Sill is intruded into the Lower Limestone group, although eastwards it was intruded into the Middle Limestone group. The whin consists of quartz dolerite, which differs in texture according to its position relative to the country rock and therefore the rate at which it cooled. The country rocks adjacent to the Whin Sill have been strongly metamorphosed by the heat of the intrusion, producing rocks quite different from the original. Hence the limestone in contact with it has been altered to a coarse-grained, easily eroded rock, termed " sugar " limestone.

Within the Carboniferous rocks of the Northern Pennines, mineral deposits are found, and these have been mined since ancient times. Mineral deposits occur in the Widdybank area and a number of mines have been worked for long periods of time although all are now abandoned (1). The Cow Green mines were formerly worked extensively, first for lead ore and later for barytes from about 1895 until 1952 when the mine was closed.

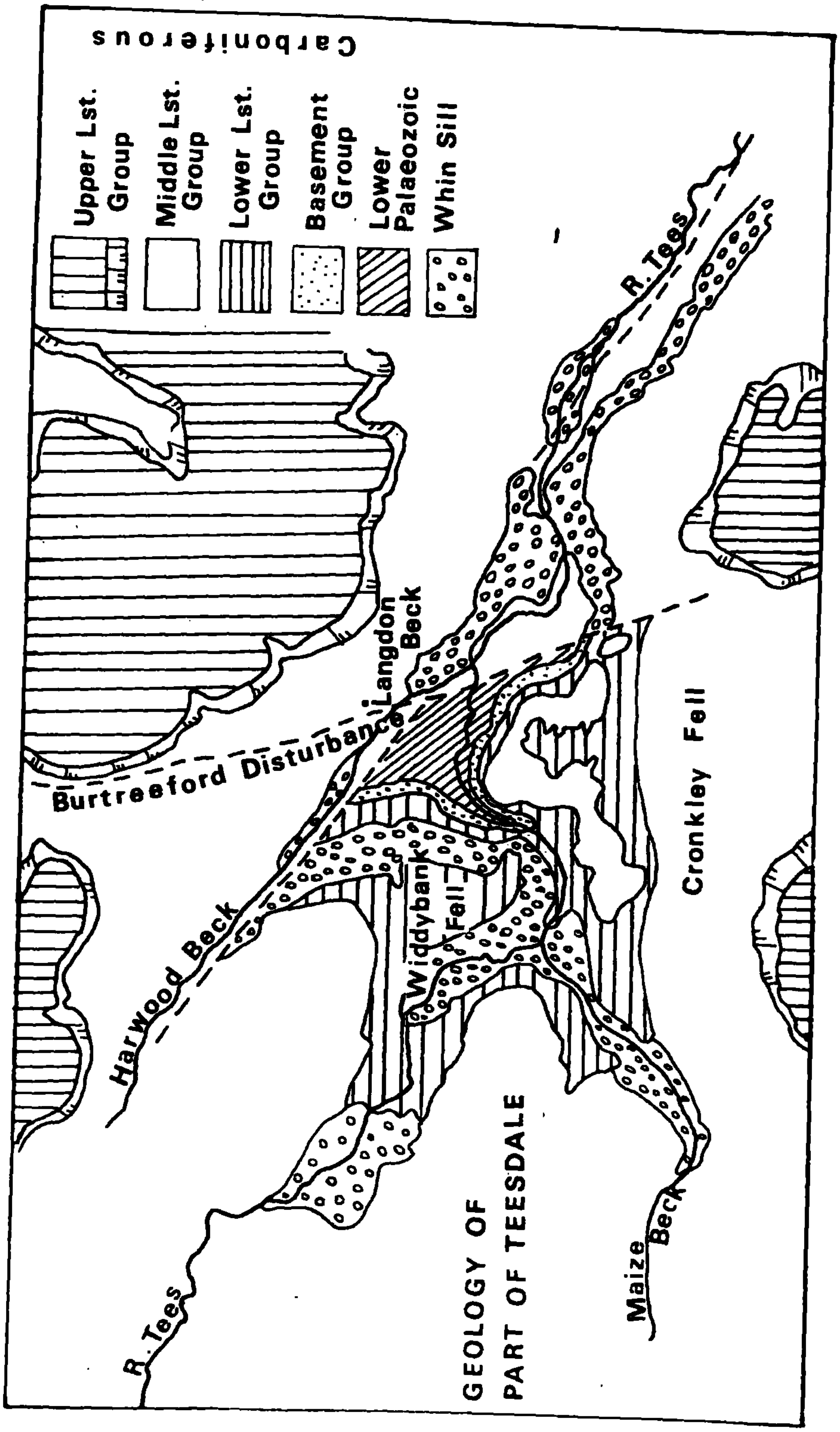

Carboniferous
Upper Lst. Group
Middle Lst. Group
Lower Lst. Group
Basement Group
Lower Palaeozoic
Whin Sill
R. Tees
Langdon Beck
Burtreeford Disturbance
Cronkley Fell
Widdybank Fell
Harwood Beck
R. Tees
Maize Beck
GEOLOGY OF PART OF TEESDALE

Fig. 2.

Barytes was obtained from the old lead workings which were opened along veins in the Melmerby Scar limestone, in close proximity to the Whin Sill. Veins were worked from Cow Green and East Cow Green mines in a north-south direction and from the Rods (Fig.1) in a north-east-south west direction and also in parallel veins at Slapestone Sike. The barytes mined at Cow Green and other adjacent mines was conveyed along tramways to Cow Rake (Fig. 1) and then by aerial ropeway to Langden Beck. Thus during the last century, mining concerns in the immediate area of Widdybank Fell were a thriving and important part of the Teesdale economy and they clearly had a considerable bearing on the recent history of the Fell.

Superficial Geology

There is much evidence of glacial activity to be found in Upper Teesdale. A series of drumlins occur on the floor of the Upper Tees valley and there is a ridge of lateral moraine below Cronkley Scar. Dwerryhouse (1902) mentions the occurrence of eratic dolerite boulders on Widdybank and Cronkley Fells lying above the limestones. He also found striae on the rocks which suggested that ice had passed over the fells. In the valley of the Tees at the Weel, there is a hummock of morainic material across the valley on both sides of the river. The boulder clay is stiff and blue-grey in colour weathering to a greyish-brown. There is, therefore, ample evidence for the glaciation of the Upper Tees valley. The actual number of glaciations, their duration and extent is the subject of several conflicting hypotheses. In Britain as a whole there is evidence from till and drift material to suggest at least three major glacial periods, corresponding with those of the Scandinavian periods. In Scandinavia there were at least 3 major glacial periods, the Elster, Saale, and Weichsel whilst there were four periods of glaciation in the Alps: the Gunz, Mindel, Riss and Wurm. The correlation between the Scandinavian and Alpine periods is not proven but it is thought that the Elster corresponds with the Mindel and with the Lowestoft glaciation in Britain; the Saale with the Riss period (Gipping Glaciation in Britain) and the Weichsel with the Wurm. The last glaciation in Britain seems to be most closely correlated with Weichselian.

Trotter (1929) and Wells (1957) have provided evidence for at least two major glaciations in East Edenside and Stainmore thus supporting the evidence from other parts of Britain for three major glacial periods. Other workers consider the various deposits to have originated from a single complex glaciation and have suggested that this single glacial period corresponds with the Saale or Riss glaciation, which on the continent laid down a series of clays, sands and gravels (Raistrick 1951; Carruthers 1948). Other work has suggested that although there were a number of glaciations, the Northern Pennines or parts of them may have been ice-free during the last or Full-glacial period. (Raistrick and Blackburn 1932). Both these hypotheses would mean that a considerable length of time has elapsed since the ice covered the region.

There is much evidence on the summit range of the Northern Pennines for glacial activity. Trotter (1929) showed that ice was present on the Pennine escarpment at 2200' by the discovery of a Lake District erratic. Raistrick (1931) suggested that the area above this height was an ice-free zone or nunatak during the maximum glaciation as no erratics were found above 2200' or in the Tees valley. More recent evidence (Johnson and Dunham 1963) suggests that there may have been glacial activity far above

2200" on Knock Ridge and Cross Fell. Therefore it is possible that at the maximum period of glaciation, ice was present over the entire Pennine ridge.

Johnson and Dunham (1963) set out an account of glacial evidence from the Moorhouse Reserve and the areas adjacent to it, but indicate that the evidence available is not sufficient to shed further light on these problems. They also describe widespread evidence for cryoturbation during the Late-glacial and early Post-glacial periods on the Moorhouse Reserve. Manley (1959) provides evidence for corrie glaciation during the post-Allerd recession period in the Lake District and suggests that small moraines in the Northern Pennines may also date from this period. Rowell and Turner (1952) also describe similar moraines in the Mallerstang area of Edenside.

There is, therefore, much evidence for a very cold, periglacial climate following the recession of the ice, during which solifluxion and frost action were widespread and Johnson and Dunham (1963) suggest that this period persisted into Post-glacial times.

Climate

Glasspoole (1931) gives the average annual rainfall for the Tees valley as 35" at Middleton-in-Teesdale, 50-60" at Widdybank Fell and reaching 70" over Cross and Mickle Fells. Manley (1936;1942) records from meteriological data at Moorhouse, that the climate is one of prolonged winter with persistent snow cover; a cold late spring and short summer giving way to a stormy autumn.

Present Vegetation

In order to provide a complete picture of the Widdybank Fell area, it is essential that the present vegetation cover should be described

PLATE 1

GENERAL VIEW OF WIDDYBANK FELL FROM THE RODS LOOKING TOWARDS THE SOUTH-WEST.

in brief, together with the other background information already set out. Much work is at present in progress in Upper Teesdale and a considerable amount of work has already been published both on the general ecology (Piggott, 1956) and on specific species in the Teesdale flora (Elkington 1963; Valentine (1965).

Much of the Fell is covered by wet mire communities and these may be divided into two categories - the acidophilous and the base-rich types.

The larger part of the area is covered by blanket bog, dominated by Calluna Vulgaris and Eriophorum vaginatum, some of which is still growing although much is in various stages of degeneration. Locally the bog surface is still dominated by Sphagnum species. Some transition associations exist as wet heather e.g. Juncus squarrosus heath. In the springs and flushes, where the sugar limestone outcrops, bryophyte-sedge communities occur.

Parts of the fell are not covered by the encroaching blanket peat and these dry communities may also be divided into several distinct types. The dry sugar limestone grassland, which supports a particularly rich interesting and varied flora; Unaltered limestone grassland which supports a rich flora on the brown earth soils derived from the limestone parent material and a species - poor grassland where the soils have become dry and acidic. On the deeper mature soils where drift is present a species - rich heather moor occurs and this grades into dry heather moor, where the soils are podsolized and wholly dominated by Calluna vulgaris.

A list of communities is set out in Appendix 1.

Human Occupation

There is no evidence of pre-historic human occupation of Widdybank Fell. However, there is some evidence from the surrounding area.

The earliest human occupation of the area is Mesolithic. Microlithic flint and chert tools together with the horn-sheaths of Bos have been found in the peat at Moorhouse. (Johnson and Dunham 1963). Trechman (1913) records that at Blackton Beck near Eggleston, arrowheads of mesolithic age and pigmy implements of Mesolithic or Neolithic age have been found in the peat together with scrapers, flakes and flint saws of Neolithic age. The flints almost certainly came from the Yorkshire Wolds. Neolithic stone axes have also been found on Holwick Fell (Raistrick 1933).

The remains of Bronze age people are even more scarce than those earlier cultures. A Beaker fragment of Early Bronze age was found on Holwick Fell (Raistrick 1931) and south-east of Middleton a megalith though now destroyed dates from late Bronze age time.

The Iron Age and the Romano-British periods are poorly represented although a number of remains have been found in lowland regions of Edenside and Durham. The Danish and Viking periods had a considerable effect upon the coastal regions but there is little evidence of their presence in Teesdale, although many of the place-names of Teesdale are derived from Scandinavian roots (Hull 1920). Following the Norman conquest, the forest of Teesdale was held by a succession of lords and for two periods in the 15th and 16th centuries by the crown. In the 18th century part of the lands were leased for mining and much of the land enclosed (Raistrick 1938).

CHAPTER 3.

Field and laboratory techniques.

Investigations into the vegetational history of the fell were carried out using the following field and laboratory techniques.

1. Field.

(a) Peat Blocks. Where extensive erosion into the peat has taken place, it was possible to collect blocks of peat from the cleaned peat face. The surface of the face was cleaned horizontally with a sharp knife and cuts made back into the face. Blocks about 1 ft. square were taken con-concurrently from top to base. The collection of Peat blocks, rather than cores of peat collected in liners from a borer, allows a larger quantity of uncontaminated peat to be removed thus allowing exactly corresponding samples to be used for the recording of stratigraphy, identification of macroremains, pollen analysis and radio-carbon dating. There is however some disturbance and contamination at the surface and base of each block cut. This is eliminated from samples collected in liners by using two bore holes, close to one another, alternately.

(b) Stratigraphy. At each of the major sites selected for investigation an extensive survey of the stratigraphy of the bog was carried out. Transects were laid out across the bog surface with stakes, 10, 20 or 40 metres apart, in two or more directions. Compass bearings were taken on each transect. The surface of the bog along each transect was levelled, using a Dumpy level and staff. At each stake, cores were taken using a Hiller borer, and the stratigraphy of the peat recorded in the field. Samples from each level were also taken to the laboratory for macro-fossil analysis.

(c) Samples for pollen analysis. After recording the stratigraphy, cores for pollen analysis were collected from one or more points including the deepest point along the transects. As access to the area was restricted in the main to the winter months of each year because of the grouse breeding season during the late spring and early summer and the shooting season in late summer it was not always possible to collect in this way. Thus, in Slapestone Sike SLI was collected before the stratigraphy was completed and a further basal sample was collected from the deepest point of the bog to supplement this.

All samples for analysis were collected using a Hiller borer with liners inserted. Each liner was removed from the borer in the field, and wrapped in clean polythene before being transported back to the laboratory. One sample, TS1 was collected in the form of peat blocks, and these were wrapped in polythene before being taken back to the laboratory.

2. Laboratory

(a) Macro-remain analysis. Samples for macro-remain analysis were collected from each core to supplement stratigraphic data obtained in the field.

Each sample was broken down by heating in a basin with 10°/o potassium hydroxide for about 15 minutes. The sample was then placed on a fine sieve, after any seeds which had floated to the surface had been removed with a camel hair brush, and washed with a spray of water. The remains were then transferred to a small dish and examined under a binocular dissecting microscope for recognisable plant or animal remains. These were stored in tubes containing a mixture of glycerol, alchohol and formaldehyde. Leaf fragments found in the peat were mounted on slides in gum chloral. Wood fragments were embedded in wax and sections cut on a microtome.

During the first winter of this work, two weeks were spent in the Sub-Department of Quaternary Ecology, Cambridge, identifying macro-remains using the Cambridge seed collection. Further macro analysis was subsequently carried out using the smaller Durham seed collection. Seeds were identified as far as possible, down to specific level although in many cases it was not possible to identify further than generic level. Bryophytes were identified using the Durham type collection and wood fragments were identified with the aid of Clifford's key to the wood anatomy of British trees and shrubs (Godwin 1956).

(b) Pollen analysis. In the laboratory, samples were taken from the cores in the liners and placed in tubes. Care was taken to exclude all the outer edges of the core, to avoid contamination. 1 cm 3 samples were taken at 2.5 or 5 cm intervals along the core. Where the peat was very fibrous, it was necessary to take samples at 10 cm intervals. The tubed samples were kept in a cold room until they were ready to be analysed.

Preparation of samples.

The technique used for the preparation of samples for analysis was based on that of Faegri and Iversen (1964), using KOH and acetolysis:

(a) 1 cm was placed in a boiling tube with 10 ml 10% KOH and heated in a water bath until the peat had broken down.

(b) The sample was then passed through a sieve so that the macro-remains were caught in the sieve. The residue was washed through with a little water. This was then centrifuged and the supernatent poured away. The residue was examined for silica. If none was present, then the treatment proceeded without HF treatment.

(c) The remaining sediment was washed and centrifuged until the supernatent was clear.

(d) The sediment was then washed with a few mls of glacial acetic acid, and broken up with a clean, dry rod, so that all water was removed. This was centrifuged and the supernatent poured off.

(e) 10 mls Acetic anhydride were added to the sediment and then stirring with a clean glass rod, 1 ml conc. H_2SO_4 was added slowly down the side of the tube. This was then boiled in a water bath for exactly 1 minute, in a fume cupboard. This was centrifuged and the supernatent poured off carefully.

(f) A few drops of glacial acetic acid were added to the sediment and stirred, and the tube filled up with distilled water and centrifuged. Glacial acetic acid was found to bring down the sediment during centrifuging if the acetic anhydride mixture had not done so properly.

(g) The sediment was then washed with water and centrifuged. It was then washed again in distilled water with a few drops of 10% KOH and a drop of detergent added to floculate any floating sediment. This was centrifuged and the last washings drained away. Keeping the tube turned upside down, the inside of the tube was dried with filter paper and a mixture of hot glycerine jelly + saffranin equalling twice the volume of sediment added, stirred and mixed.

(h) The glycerine jelly + sediment was heated in a water bath and a drop smeared on a slide. This was then carefully covered by a 50 × 22 mm coverslip and warmed so that the jelly spread out evenly under the whole coverslip. The slide was then labelled and counted.

HF Techniques

If silica was found to be present, the sample was treated after boiling in KOH but before acetolysis, as follows:

(a) A little water was added to the sample, which was then poured into a Pt bucket, standing on a clay tripod in a fume cupboard. With extreme care, HF was added until the Pt bucket was about ½ full and was then heated to boiling, and allowed to boil for 3 mins.

(b) This mixture was poured into a beaker containing 10% HCl. This was then poured into a centrifuge tube and centrifuged, balanced against water. The supernatent was poured carefully away into a sink of running water. All utensils used with HF were put immediately into a beaker of water to dilute.

(c) The sample was then heated with 10% HCl to dissolve the white precipitate, and then centrifuged.

The whole process was repeated if silica was still found to be present before continuing with acetolysis.

Counting.

Long cover slips, 3 x 1 cm were used throughout and the density of pollen was taken into account before counting, so that representative traverses could be taken. If the pollen was dense, some traverses were made at the ends and some towards the centre of the slide. If the pollen was more sparse then the traverses were equally spaced across the whole slide. Traverses were made in one direction only at right angles to the long edge of the slide, and every grain counted, under x 400 magnification on a Reichert microscope.

A total of 150 tree pollen grains were counted on each slide.

At some levels where tree pollen grains were sparse in relation to non-tree pollen grains, a count of only 100 total tree pollen was reached.

Identification.

Where grains were unidentifyable by reason of their poor preservation, they were noted as destroyed pollen and not included in the total count but used as a measure of pollen preservation.

All grains were identified using the Durham Botany Department type collection and the pollen key of Faegri and Iversen (1964).

Special grains.

Identification of certain pollen types required special attention:

(a) Betula nana

An attempt was made to separate B. nana from the tree Betula species. All Betula grains were measured in terms of grain diameter and pore depth, according to the ratio given by Walker (1955). Photographs were taken of grains showing a high ratio and also showing low ratios (Appendix II). Following Terasmae (1951) and Birks (1968) grains showing a high ratio and very small pore depth were classed as B, nana . Grains with intermediate ratios which were not separable morphologically from the tree birches, were not classed separately from the tree birches, as it is known from type slide show considerable variations in the size of the ratio. Therefore only grains showing a high (11.5) ratio and the characteristic shallow pores were classed as B. nana.

The % of B. nana may not, therefore, be truly representative of the amount actually present in the pollen rain but it does indicate when *B. nana* was a relatively important constituent of the vegetation.

(b) Cereals

Cereal grains were identified using a Zeiss phase-contrast microscope with the aid of Faegri and Iversen's key (1964) and modern reference material. Some cereal grains were found to be so destroyed that identification was impossible.

The precise measurements required for cereal grain identification are based on standard measurements of Corylus grains. Thus from each slide containing a cereal grain the diameters of between ten and fifty *Corylus* grains were measured. Faegri and Iversen's key is based on material mounted in silicone oil and the measurements given are standard size: *Corylus* = 25 μ.

Thus $\frac{C}{25}$ (average diameter of *Corylus*) = k.

Measurements of the cereal grains were therefore divided by the factor k to obtain standard measurements for identification using the key.

Presentation of Data

At each level the count for each pollen type is expressed as a percentage of the total tree pollen count. Species included in the total tree pollen count were *Betula*, *Pinus*, *Ulmus*, *Quercus*, *Tilia*, *Alnus*, *Fagus* and *Fraxinus*. Also at each level the total counts for tree, shrub and herb species were expressed as a percentage of the total pollen count. *Sphagnum* was omitted from this total because of the fluctuations shown in its curve.

The results of these analyses were expressed in the form of pollen diagrams.

CHAPTER 4.

DESCRIPTION OF SITES

The first consideration in a study of the vegetational history of an area must be the choice of sites suitable for such an investigation.

The major part of Widdybank Fell is overlain by blanket peat, which varies in thickness from a few cms on the steeper slopes to a depth of several metres in the cols or hollows. Where the sugar limestone is exposed, especially on the west and southern parts of the Fell, the blanket peat has not encroached and the rock is covered by thin soils. Extensive erosion of the peat has taken place wherever streams drain the Fell. The soils which support species-rich grassland (Appendix I) over unaltered limestone are brown earth soils showing some mottling probably due to impeded drainage. Soils associated with species-poor Calluna grassland are slightly podsolized brown earths.

Several aspects of the history of the Widdybank Fell flora seemed to be of particular interest. Firstly the period during which the earliest peat began to form on the fell and the changes which have taken place from this period to the present day, both regional and local. Secondly, the time at which blanket peat began to develop and the factors which influenced its spread. Thirdly the local differences and changes in the flora associated with sugar limestone outcrops throughout the post glacial period.

In order to investigate these, sites for analysis were chosen with the following factors in mind:-

1. Proximity or distance from present day outcrops of sugar limestone, limestone grasslands or flushes.

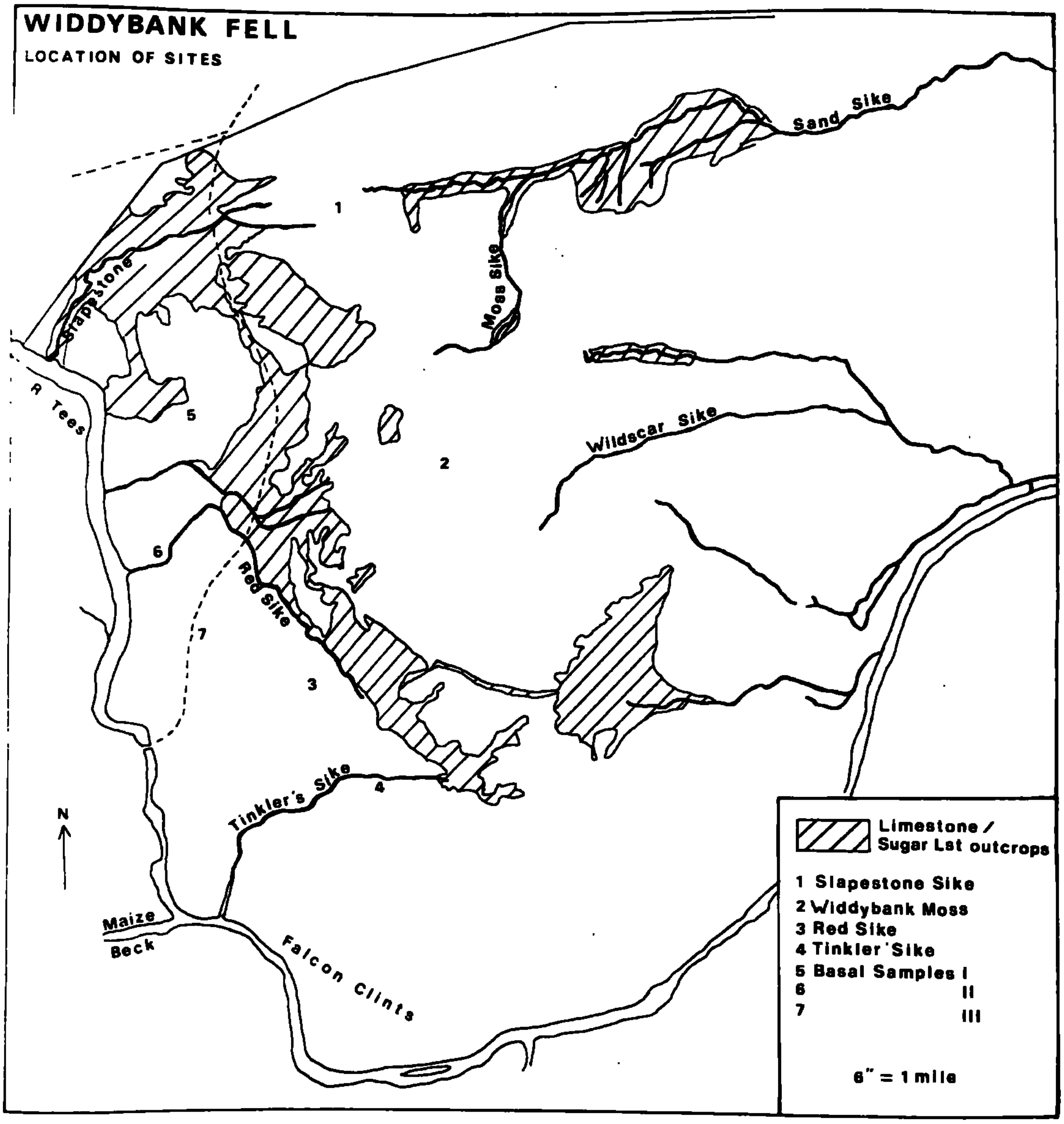

WIDDYBANK FELL
LOCATION OF SITES
Sand Sike
1
Moss Sike
Slapestone
R Tees
5
Wildscar Sike
2
6
Red Sike
7
3
Tinkler's Sike
4
N
Maize
Beck
Falcon Clints
Limestone / Sugar Lst outcrops
1 Slapestone Sike
2 Widdybank Moss
3 Red Sike
4 Tinkler 'Sike
5 Basal Samples I
6 II
7 III
6" = 1 mile

Fig. 3.

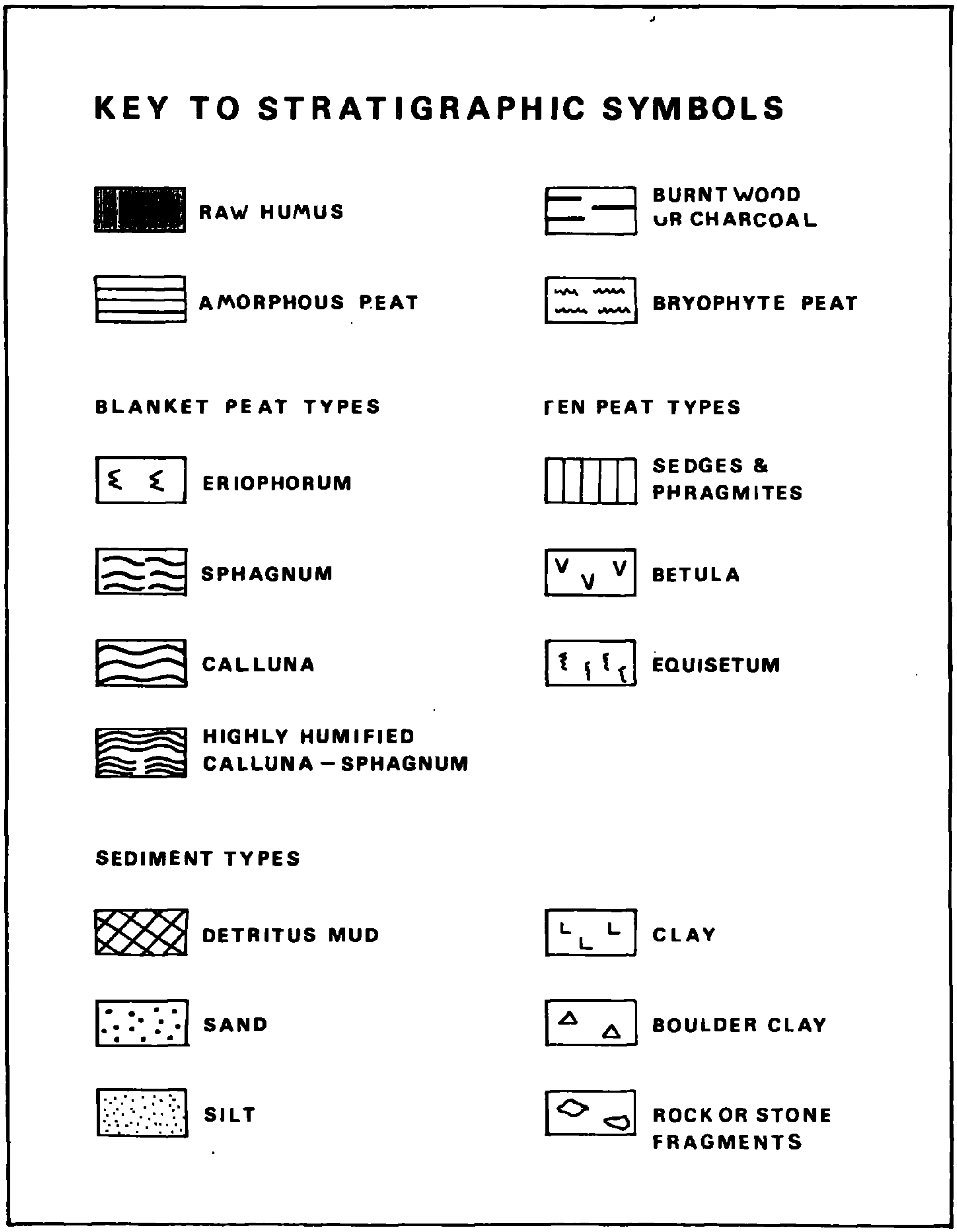

KEY TO STRATIGRAPHIC SYMBOLS
RAW HUMUS
BURNT WOOD OR CHARCOAL
AMORPHOUS PEAT
BRYOPHYTE PEAT
BLANKET PEAT TYPES
FEN PEAT TYPES
ERIOPHORUM
SEDGES & PHRAGMITES
SPHAGNUM
BETULA
CALLUNA
EQUISETUM
HIGHLY HUMIFIED CALLUNA – SPHAGNUM
SEDIMENT TYPES
DETRITUS MUD
CLAY
SAND
BOULDER CLAY
SILT
ROCK OR STONE FRAGMENTS

Fig. 4.

2. Areas where there has been extensive peat development over a long period of time. For instance, over some areas of the Fell, where conditions have been favourable for peat formation, there has been mire growth since early post-glacial times. (Fig.3).

1. Red Sike / Tinkler's Sike bog. (Diagrams 3,5)

Between Red Sike and Tinkler's Sike there has been extensive peat development and here the bog is still actively growing. The bog surface is characterized by various species of Sphagnum, in particular S. papillosum, S. cuspidatum, S. rubellum together with Calluna vulgaris and Eriophorum vaginatum. Other species present include Erica tetralix, Eriophorum angustifolium, Narthecium ossifragum, Drosera rotundifolia and many species of Carex.

The western end of the bog is more eroded and dissected by water channels and the surface is dominated by Calluna vulgaris and Eriophorum vaginatum. East of Tinkler's Sike, the bog surface is again drier and dominated by Calluna and Eriophorum vaginatum together with some Sphagnum and lichens, particularly Cladonia spp. It is in this area that Betula nana exists in association with the above species. This record was made by Hutchinson (1965) and a preliminary investigation of macro-remains in the peat had been carried out by him.

Initially, a profile TSI was taken for analysis from a peat face about 10 metres from the area where 7 plants of B. nana are growing. Blocks of peat were taken from the cleaned peat face and subsequently used for pollen and macro-analysis and also for radio-carbon dating.

Three transects were laid across the surface of Red Sike bog. Transects A and B being in a SW_NE direction and transect C in an

E-W direction. Transect A was continued down the steep scarp slope south of the bog to link up with BM 1512.5' at Cauldron Snout. (Plate 2)

Samples for analysis were also taken from RS1 and RS11 (Diagram 4). The position of RS1 was selected for two reasons:

1. This point was only 50 m distant from the extensive outcrop of sugar limestone surrounding Red Sike.
2. At this point there was a considerable depth of peat overlying a basal, gravelly silt which showed a positive reaction with 10% HCl.

   RS2 was selected for its depth of peat and for its position in the centre of the mire but to the west of both RS1 and TS1.

Stratigraphy (Diagrams 5,7,8).

The depth of peat varies from about 100 cms at the margin to a maximum depth of 400 cms in the centre. At the northern margin of transects A and B, there is a thin basal layer of grey silt containing pebbles and sand, which overlies bed rock. This stratum never exceeds a thickness of 10 cms and does not continue into the central part of the basin. At two points on Transect B the grey silt band grades into a stiff, blue clay of 5 - 10 cms depth above bed rock. Above this layer of silt and clay at the northern edge of the mire, there is a thin layer of detritus mud, 5 - 10 cms deep. Patches of detritus mud overlie bed rock on the steep slope south of the mire on Transect A, and at the eastern edge of transect C at the side of an artificial drainage channel.

Towards the northern margin of the bog this layer of detritus mud is overlain by a layer of moderately humified Sphagnum peat including remains of sedges and Calluna, which forms the main thickness of peat. Above this there is a transition into Eriophorum - Sphagnum - Calluna peat

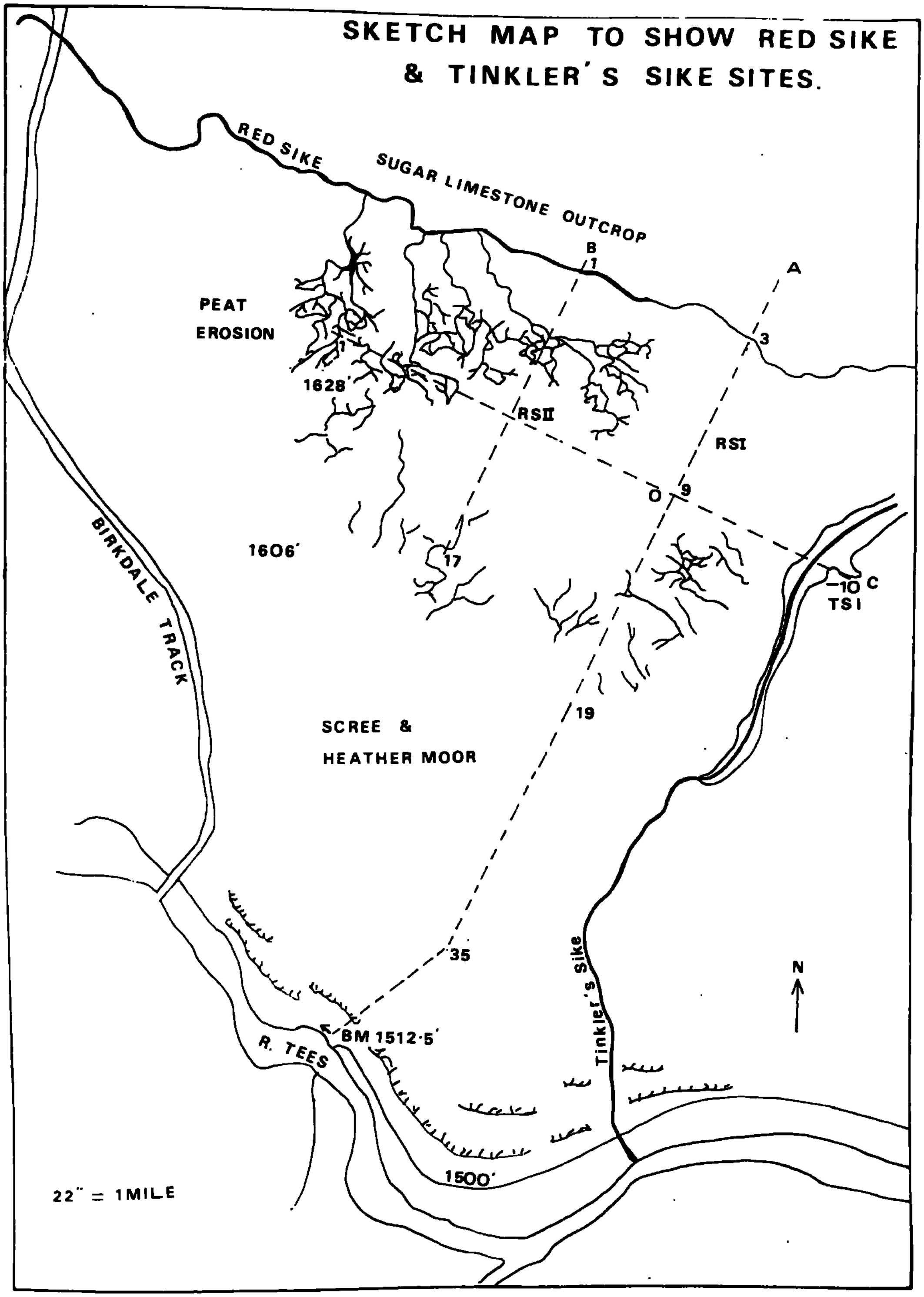

SKETCH MAP TO SHOW RED SIKE
& TINKLER'S SIKE SITES.
RED SIKE
SUGAR LIMESTONE OUTCROP
PEAT
EROSION
1628'
RSII
RSI
A
B
1
3
O
9
17
1606'
10
C
TSI
BIRKDALE TRACK
19
SCREE &
HEATHER MOOR
35
BM 1512·5'
R. TEES
Tinkler's Sike
N
1500'
22" = 1MILE

Fig. 5.

which becomes fresh towards the surface.

The stratigraphy of the central area of the bog shows a layer of Phragmites - sedge peat directly overlying bed rock. This layer is readily recognisable as it is usually light brown in colour, stiff in texture and containing birch wood and bark, Menyanthes seeds, Carex seeds as well as fresh Phragmites remains. Wood fragments were analysed in the laboratory and proved to be birch in all cases. No pine wood remains were found. Towards the edges of the bog this layer was represented by a well - humified sedge peat containing few macro-remains. The depth of this layer varies from a few cms at the margins to a maximum of 130 cms in the centre. Above the Phragmites - sedge layer, Sphagnum peat containing remains of Calluna and sedges grades into Eriophorum - Calluna - Sphagnum peat which continues to the surface of the bog.

Transect C at the eastern edge links site TS1 with the Red Sike bog. The stratigraphy here proved to be essentially similar to that found in the central area of Red Sike bog:

0 - 12 cms	Dark brown crumbly Calluna peat containing Eriophorum remains; Juncus seeds; Selaginella selaginoides macrospores and Carex seeds.
12 - 25 cms	Lighter brown, wetter Calluna - Eriophorum peat containing sedge remains and Selaginella macrospores.
25 - 40 cms	Dark brown peat containing burnt Calluna wood.
40 - 112 cms	Dry, moderately humified, light brown Phragmites peat with burnt Calluna, remains; Carex seeds; occasional Menyanthes seeds and Selaginella megaspores.

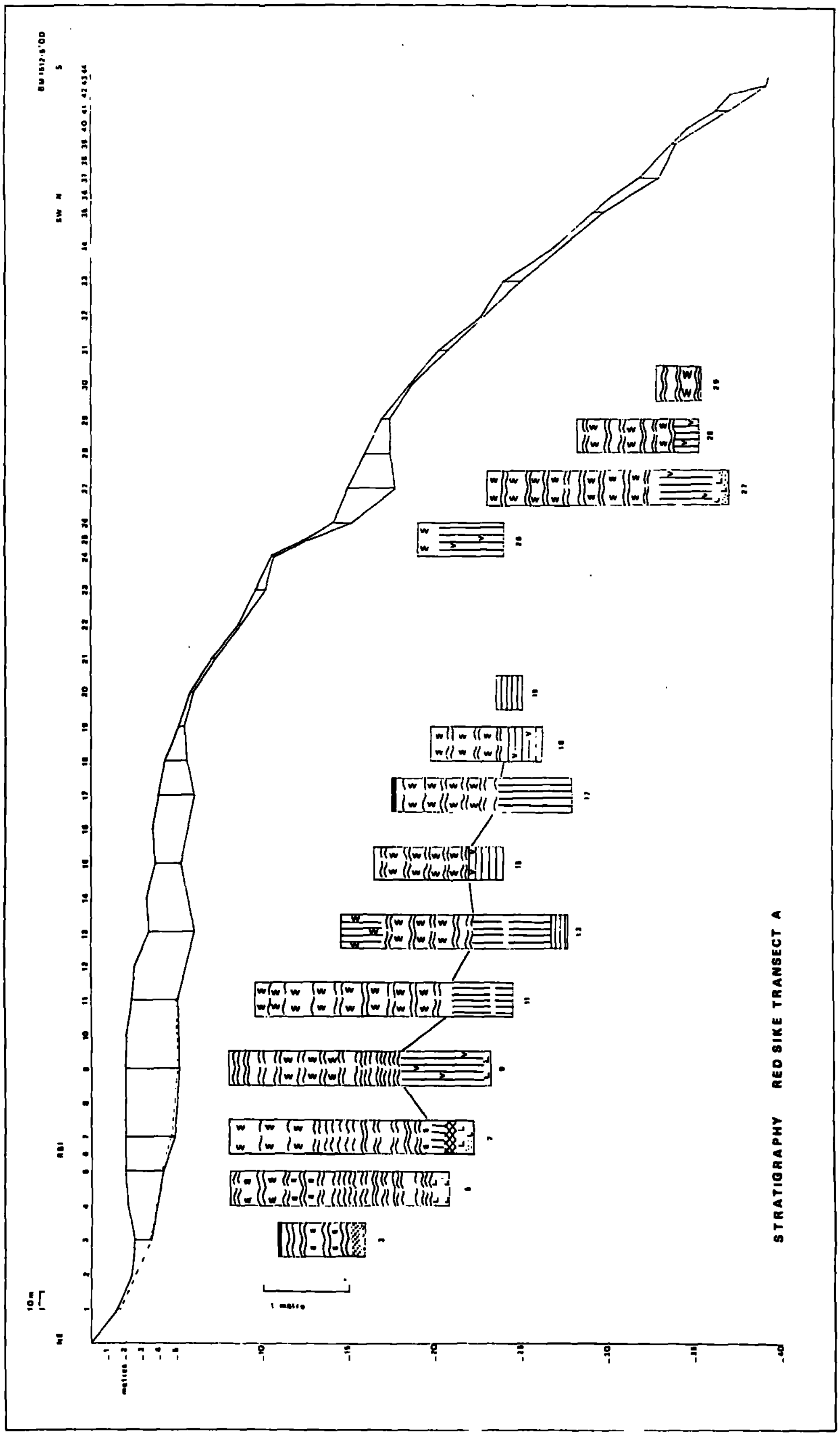


Fig. 6.

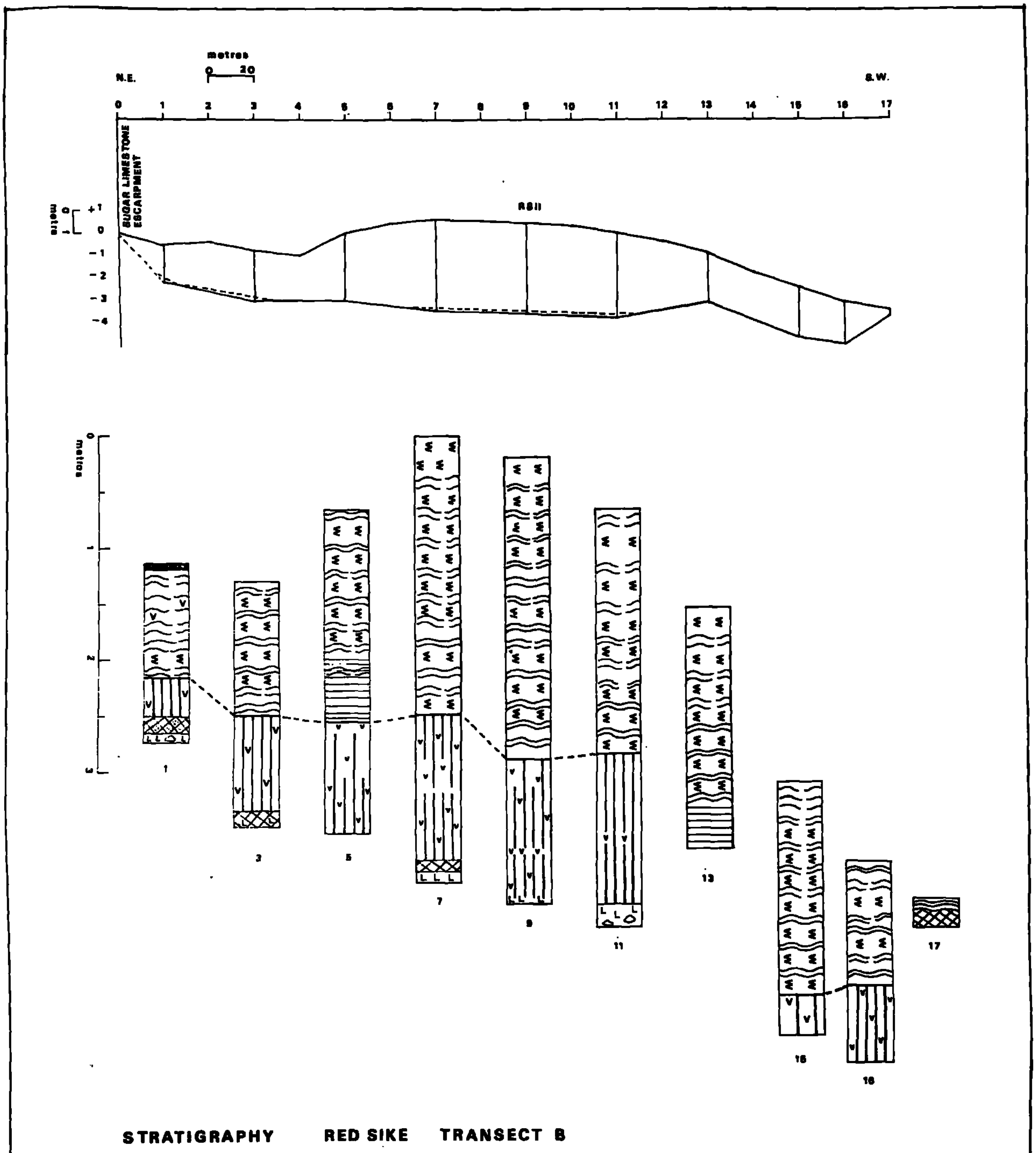

metres
0 20
N.E.
S.W.
0 1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 16 17
SUGAR LIMESTONE ESCARPMENT
RS11
metre
+1
0
-1
-2
-3
-4
metres
1 3 5 7 9 11 13 15 16 17
STRATIGRAPHY RED SIKE TRANSECT B

Fig. 7.

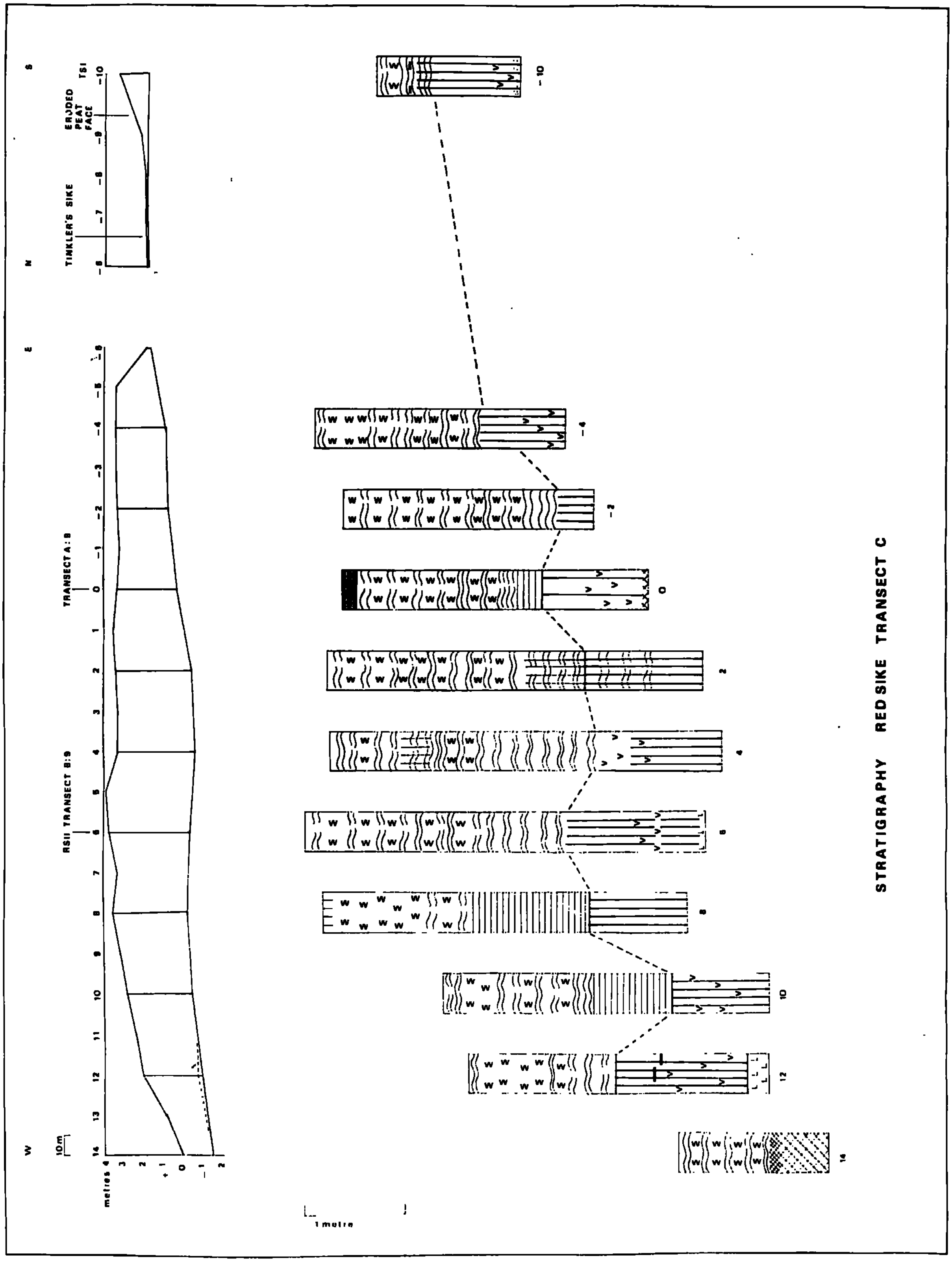

STRATIGRAPHY RED SIKE TRANSECT C
TINKLER'S SIKE
ERODED PEAT FACE
TS1
TRANSECT A:8
RSII TRANSECT B:9
10m
metres
1 metre

Fig. 8.

112 - 135 cms	Light brown *Phragmites* peat containing *Betula* twigs; *B. nana* leaves and seeds; *Menyanthes* seeds; *Chara* oospores; *Selaginella* megaspores; *Carex* seeds and a single seed of *Lychnis flos - cuculi*.
135 - 143 cms	*Phragmites* peat with few *Betula* fragments, no leaves or seeds; seeds of *Carex*, *Carduus* / *Cirsium*, *Viola*, and *Lychnis flos - cuculi*, and *Selaginella* megaspores.

The detailed stratigraphy for RS2 is as follows:

0 - 50 cms	Fresh, reddish brown *Eriophorum - Sphagnum* peat.
50 - 100 cms	Well humified *Eriophorum - Sphagnum* peat
100 - 200 cms	Wet, well humified *Calluna - Eriophorum - Sphagnum* peat.
200 - 270 cms	Drier *Calluna* peat containing many rootlets.
270 - 295 cms	Dark brown sedge peat.
295 - 350 cms	Light brown Phragmites peat containing sedge and *Betula* wood remains.
350 - 355 cms	Layer of *Betula* wood.
355 - 395 cms	Light brown sedge peat containing *Phragmites*.
395 - 400 cms	Greyish clay + pebbles to base rock.

Widdybank Moss.

This site was selected because it occupies a position close to the centre of the Fell at the relatively high altitude of 1650' OD. The area is one of extensive peat erosion with deeply cut erosion channels draining to the north east and eventually draining into tributary channels of Moss Sike. To the South and north of the area the ground rises steeply

PLATE 2.

RED SIKE, TRANSECT B, LOOKING TOWARDS THE NORTH.

about 30 - 40' above the level of the Moss. To the west the surface slopes gently away for about 200 metres before dropping away to Wildscar Sike. This area is dissected by shallow, artificial drainage cuttings. At the sourthern margin of the Moss below a scarp slope, there are a number of *Sphagnum* filled shake holes and a pool partially filled with actively growing S. *cuspidatum*.

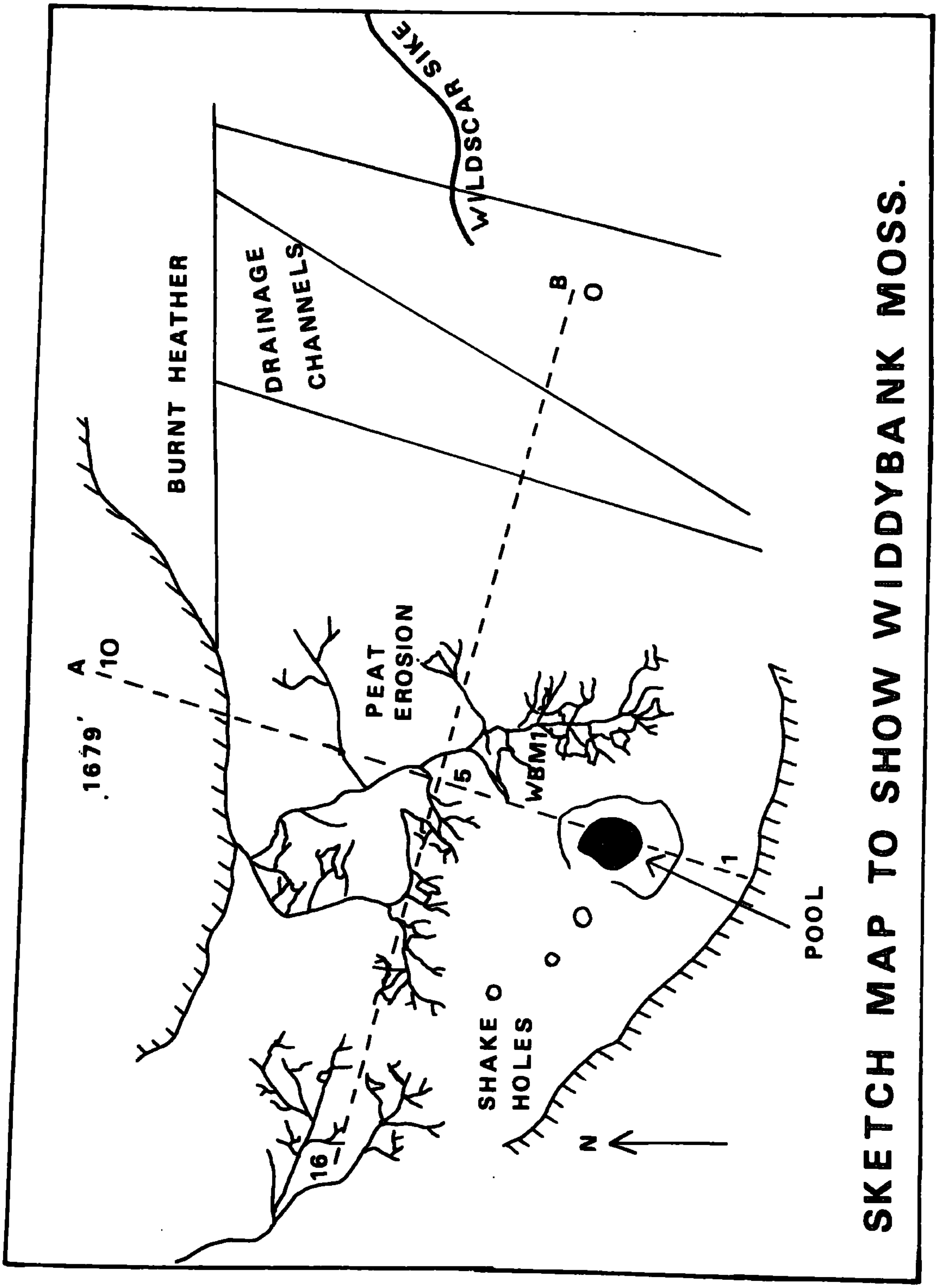
Two transects were laid out across the Moss surface at right angles to each other, transect A in a NW-SE direction and transect B running from SW-NE. (Diagram 9). A sample for analysis was taken from WBM1. Since access to the area was necessarily restricted to the winter months, the analysis core was collected before the stratigraphy of the Moss had been completed.

The surface vegetation of the Moss is largely of the blanket bog type, dominated by *Calluna vulgaris*, *Eriophorum vaginatum* with local areas of *Trichophorum caespitosum*. (Plate 4).

The depth of peat in this area varies from a maximum 350 cms at WBM1 and 200 - 300 cms in the centre of the Moss to thinner peat 100 - 150 cms at the edges.

Stratigraphy. (Diagrams 10 and 11.)

Rotten limestone or sandstone at the base is overlain by a thin layer of blue - grey or light grey clay which contains angular stones and sand lenses. In some places, this layer of clay is iron stained. This layer grades into a layer of detritus mud containing sedge remains. In the central area of the Moss, this is overlain by a stratum of stiff dryish *Sphagnum* peat with many sedge remains and occasional seeds of



SKETCH MAP TO SHOW WIDDYBANK MOSS.

Fig. 9.

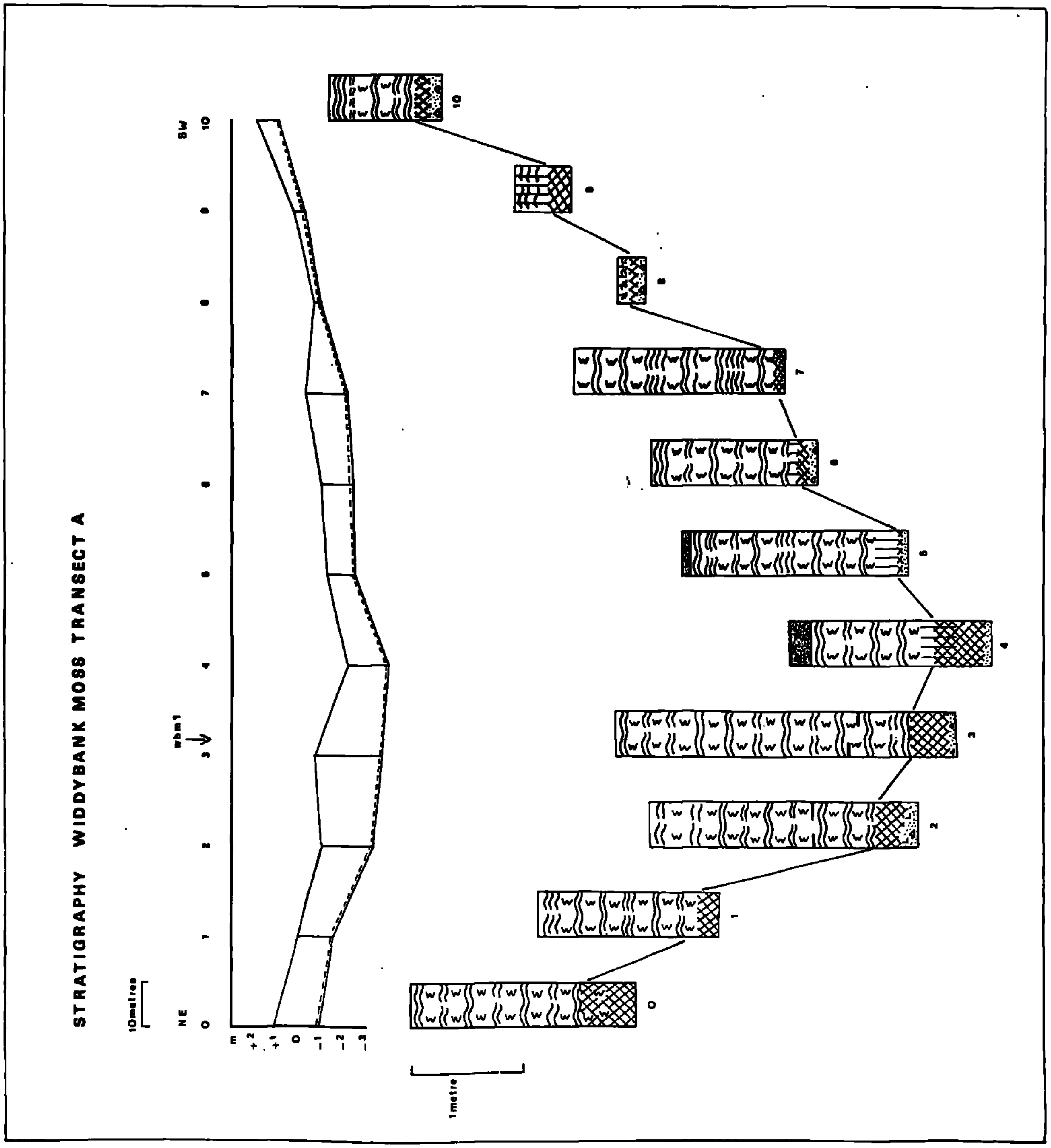

STRATIGRAPHY WIDDYBANK MOSS TRANSECT A
10metres
1metre
m
+2
+1
0
-1
-2
-3
NE
SW
wbm1
0
1
2
3
4
5
6
7
8
9
10

Fig. 10.

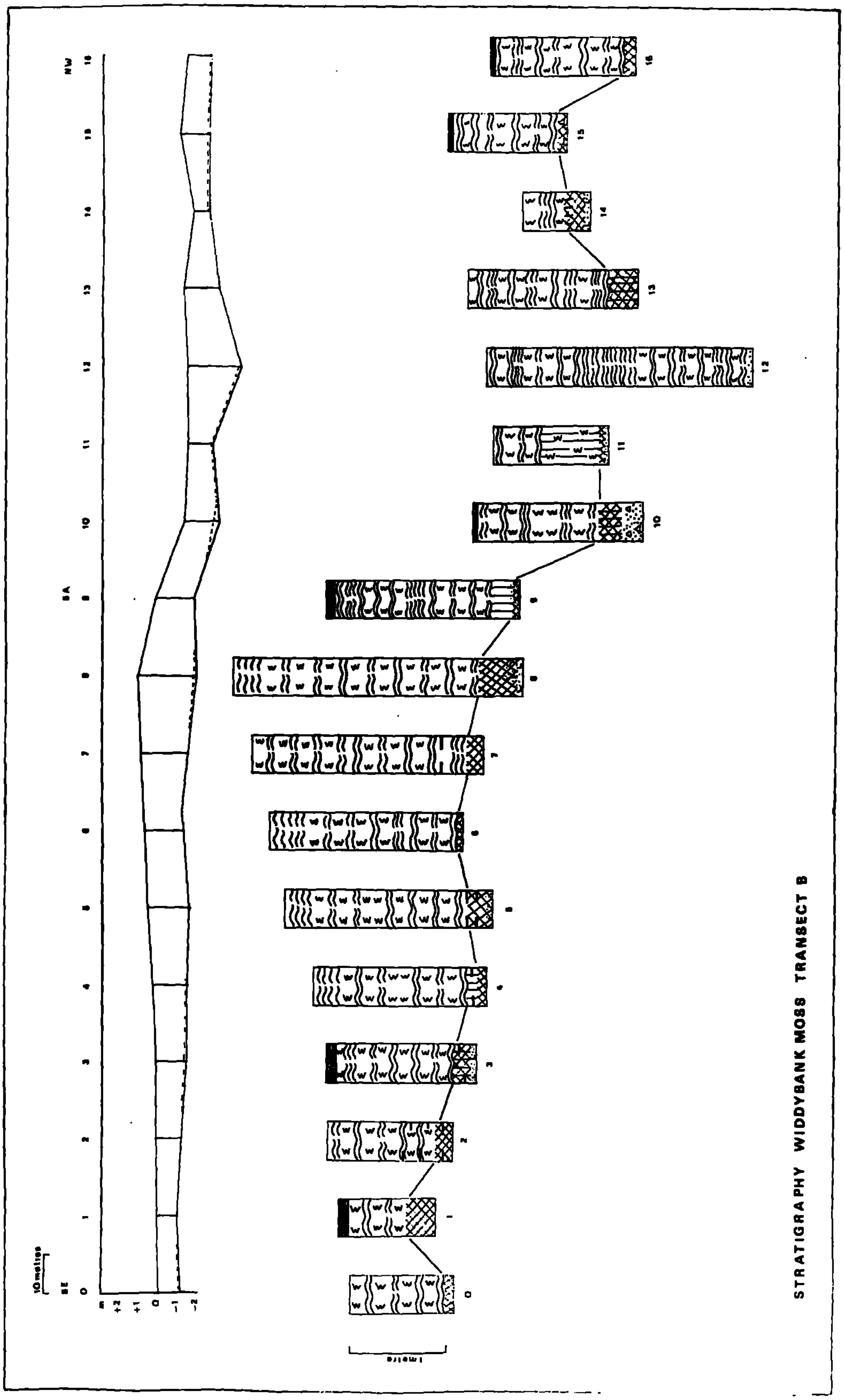

STRATIGRAPHY WIDDYBANK MOSS TRANSECT B
10 metres
1 metre
SE
NW
8A
m
+2
+1
0
-1
-2

Fig.11.

Chenopodium. Within this layer, thin bands of carbonised material occur in places along transect B. Above this dryish _Sphagnum_ peat grades into a well humified _Eriophorum_- _Sphagnum_ - _Calluna_ peat. This becomes fresher towards the surface and contains bands of _Sphagnum_. On peat hags, the surface peat is a dry, crumbly _Calluna_ peat.

The detailed stratigraphy for WBM 1 is:

0 - 20 cms	Very dry, crumbly _Calluna_ - _Eriophorum_ peat.
20 - 50 cms	Well humified, dark brown, wet _Eriophorum_ - _Sphagnum_ peat.
50 - 150 cms	Mid brown, moderately humified _Sphagnum_ - _Eriophorum_ _Calluna_ peat.
150 - 230 cms	Dark brown, well humified _Eriophorum_ - _Calluna_ peat containing _Sphagnum_ and patches of carbonised material.
230 - 295 cms	Stiff, dark brown peat with _Sphagnum_, _Calluna_ and sedge remains.
295 - 325 cms	Very stiff detritus mud containing angular pebbles.
325 - 330 cms	Orange - grey stoney clay with blue-grey and grey pebbles.

Slapestone Sike bog (Diagram 12).

This site lies on the watershed between Slapestone Sike and Sand Sike in the northern part of Widdybank Fell. To the North, Cocklake Rigg rises steeply and to the south there is an escarpment of Peghorn limestone at the base of which are mine workings linking up with the Rods to the east (Diagram 1). The area at the head of Slapestone Sike is one of extensive peat erosion with deep erosion channels draining into a central eroded area which is water filled throughout the year.

Drainage water drains away to the east into Slapestone Sike. An artificial peat bank prevents drainage of the water into Sand Sike. At the head of Sand Sike there area a number of small spoil heaps and in the centre of the bog stands a boundary stone of the Teesdale Mining Company.

Two transects were laid out across the bog at right angles to each other, transect A running from north to south across the area of open water and transect B running from east to west immediately to the south of the open water (Plate 3). Sample SL1 was collected during the first winter of the work before the stratigraphy had been completed and basal sample SL2 was collected during the spring of 1968 .

The surface vegetation consists mainly of _Calluna vulgaris_ and _Eriophorum vaginatum_ with local areas of actively growing _Sphagnum papillosum_ and _S. rubellum_ with S. _cuspidatum_ in the pools. _Eriophorum angustifolium_ grows in the erosion channels.

Stratigraphy. (Diagrams 13 and 14).

Peat is deposited up to a maximum depth of 345 cms in the central area, thinning out towards the margins north and south, where the basin abuts onto limestone escarpments. The rock surface slopes very gradually down from east to west. Investigation of the stratigraphy showed that there is a basal deposit of blue-grey or greenish-grey clay containing angular pebbles and sand lenses. This deposit is about 20 cms thick at the margins of the bog and in the centre the borer penetrated into the clay to depths of up to 50 cms. The deposit was very stiff and sticky and at most points it was not possible to push the borer down below this clay stratum. At 97m on transect A 50 cms of blue-grey clay was found to overlie the bed rock.

PLATE 3.

SLAPESTONE SIKE, TRANSECT B, LOOKING TOWARDS THE NORTH-WEST.

The surface of the clay deposit was found to contain abundant Juncus effusus and J. squarrosus seeds and Chara oospores. Above the basal clay deposit is a layer of detritus mud between 10 - 30 cms thick. Hylocomium splendens remains occur in the mud, together with root fragments and occassionally burnt wood.

In the central part of transect A and throughout transect B the mud layer is overlain by light brown sedge peat. Locally Sphagnum papillosum bands occur within this layer. Moss remains collected from the sedge peat were Hylocomium splendens; Mnium punctatum; Aulocomium palustre; Rhytidiadelphus squarrosus and Drepanocladus sp. A number of seeds were also found: Ranunculus flammula; Lychnis flos - cuculi; Empetrum nigrum; Menyanthes trifoliatum; Betula sp; Violasp.; Luzula sylvatica; Carex sp. and Selaginella megaspores, Chara oospores, Birch bark and cone scales and fragments of Phragmites.

Above, the light brown sedge peat changes abruptly to a well humified Sphagnum - Eriophorum - Calluna peat containing bands of fresh S. papillosum and S. cuspidatum. Other moss remains were Hylocmium splendens; Rhytidiadelphus squarrosus and Rhacomitrium lanuginosum. Burnt Calluna remains were found through out the peat. At the surface on peat hags, the peat became dry and crumbly, containing Calluna remains, whilst in the hollows and erosion channels it became a wet fresh Sphagnum - Eriophorum angustifolium peat.

From 0 - 80 metres on transect A at the northern margin of the bog, no sedge peat layer was recorded. The detritus mud layer grades immediately into a blanket peat containing occasional birch fragments and Sphagnum bands. Towards the surface the peat becomes a fresh, fibrous

Eriophorum peat with *Sphagnum imbricatum* and burnt *Calluna* wood.

The detailed stratigraphy of SL1 is as follows:

0 - 50 cms	Dark brown, fibrous *Eriophorum* peat with *Calluna* and *Sphagnum* remains.
50 - 85 cms	Mid brown, well humified *Sphagnum* - *Eriophorum* *Calluna* peat,
85 - 150 cms	Light brown *Sphagnum* - *Eriophorum* peat, with birch twigs at 150 cms and *S. cuspidatum* at 90 cms.
150 - 210 cms	Highly humified, light brown fibrous *Eriophorum* - *Sphagnum* peat containing birch fragments.
210 - 240 cms	Well humified, *Sphagnum* - *Eriophorum* peat containing *Calluna* wood, *Hylocomium splendens*, *Rhaeomitrium lanuginosum*, *Sphagnum papillosum*, and *S. cuspidatum*.
240 - 245 cms	Peat / clay transition: detritus mud containing roots
245 - 255 cms	Light grey clay with sand lenses and *Juncus effusus* seeds at the surface
255 - 275 cms	Blue grey clay with sand lenses and pebbles.
275 - 300 cms	Greenish grey clay with sand lenses and pebbles.

SL 2. Only the basal 60 cms of this were used for analysis.

0 - 30 cms	Dark brown, fresh *Calluna* - *Eriophorum* peat.
30 - 90 cms	Mid brown, well humified *Sphagnum* - *Eriophorum* - *Calluna* peat, with charcoal fragments at 90 cms.
90 - 130 cms	Light brown *Sphagnum* - sedge peat with red rootlets at 125 cms
130 - 150 cms	Stiff yellow brown sedge peat.
150 - 170 cms	Light brown sedge peat with *Betula* fragments.

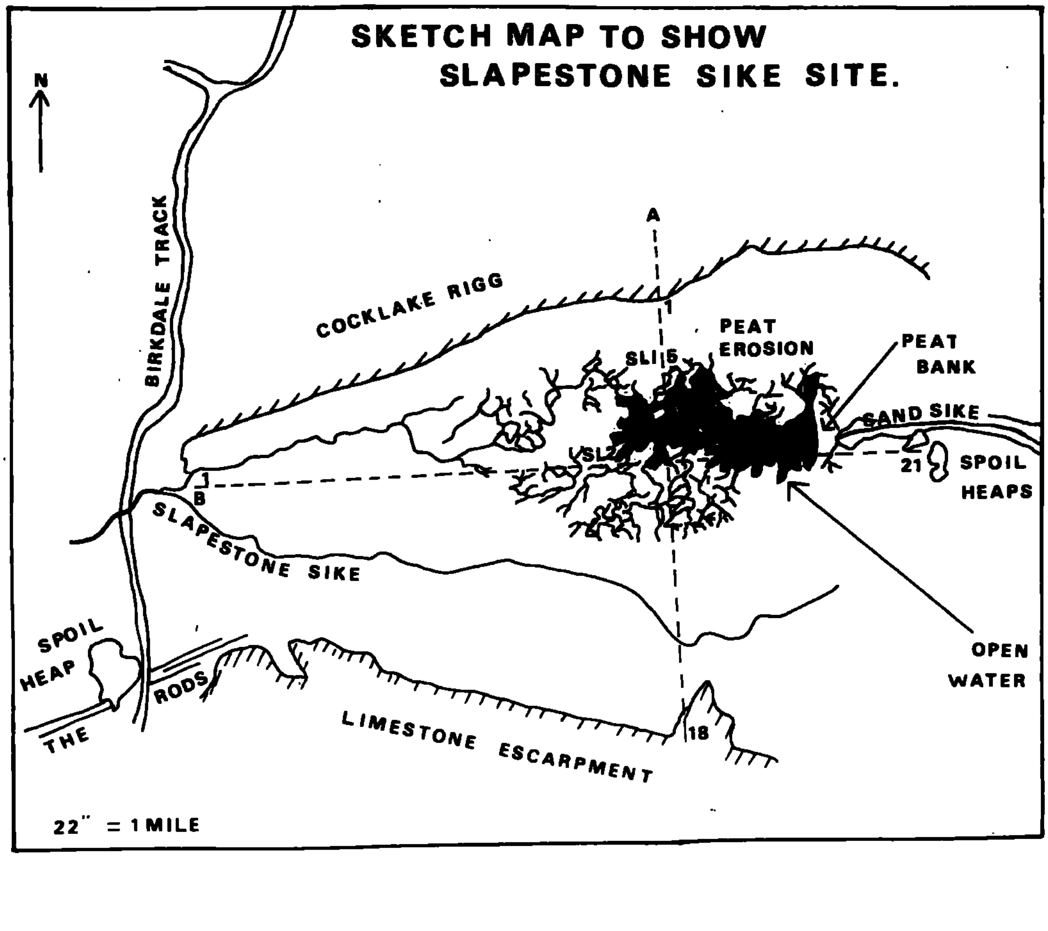

SKETCH MAP TO SHOW
SLAPESTONE SIKE SITE.
N
BIRKDALE TRACK
COCKLAKE RIGG
A
B
SL1
5
SL2
PEAT
EROSION
PEAT
BANK
SAND SIKE
21
SPOIL
HEAPS
SLAPESTONE SIKE
OPEN
WATER
SPOIL
HEAP
THE
RODS
LIMESTONE ESCARPMENT
18
22" = 1 MILE

Fig. 12.

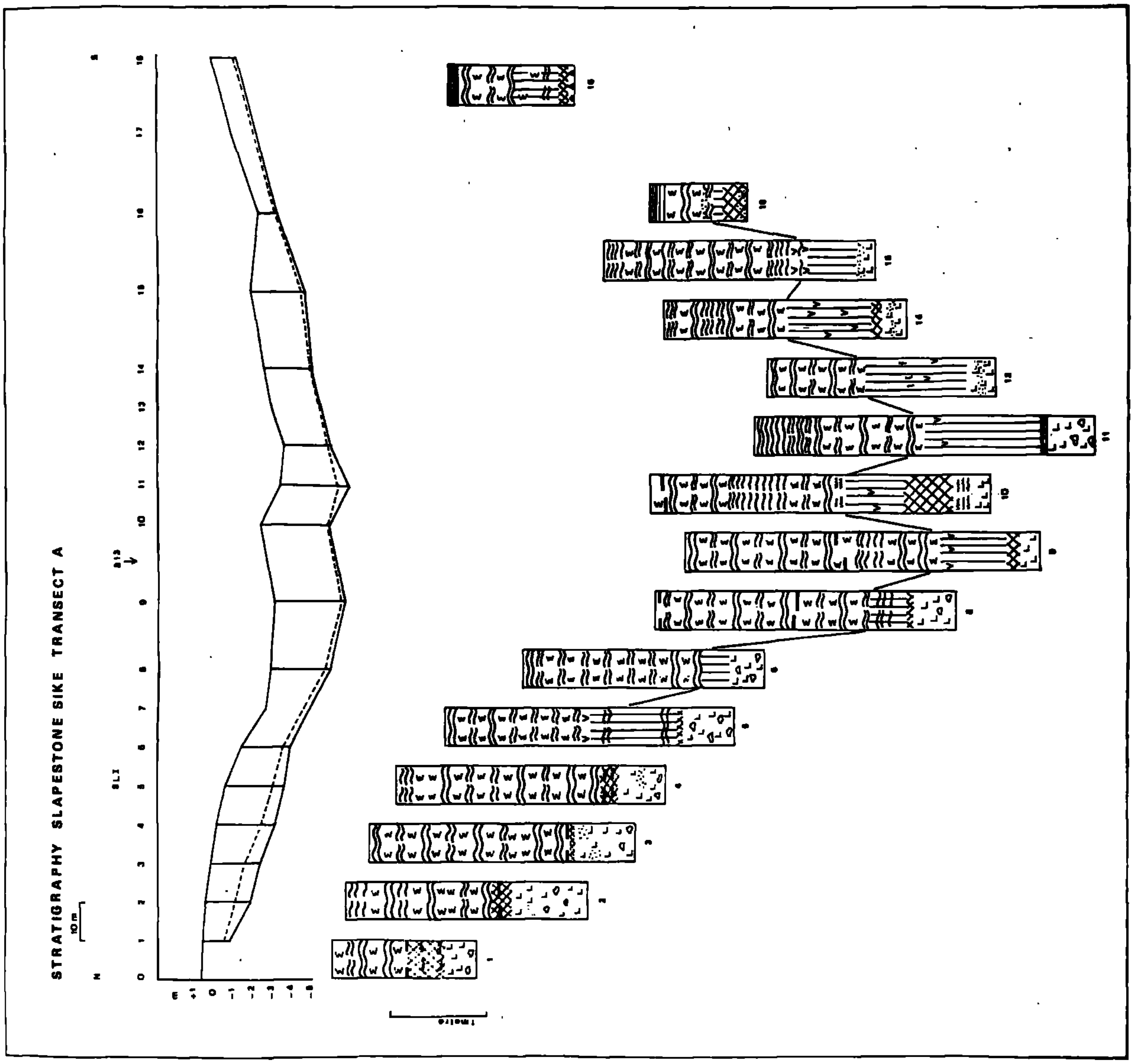
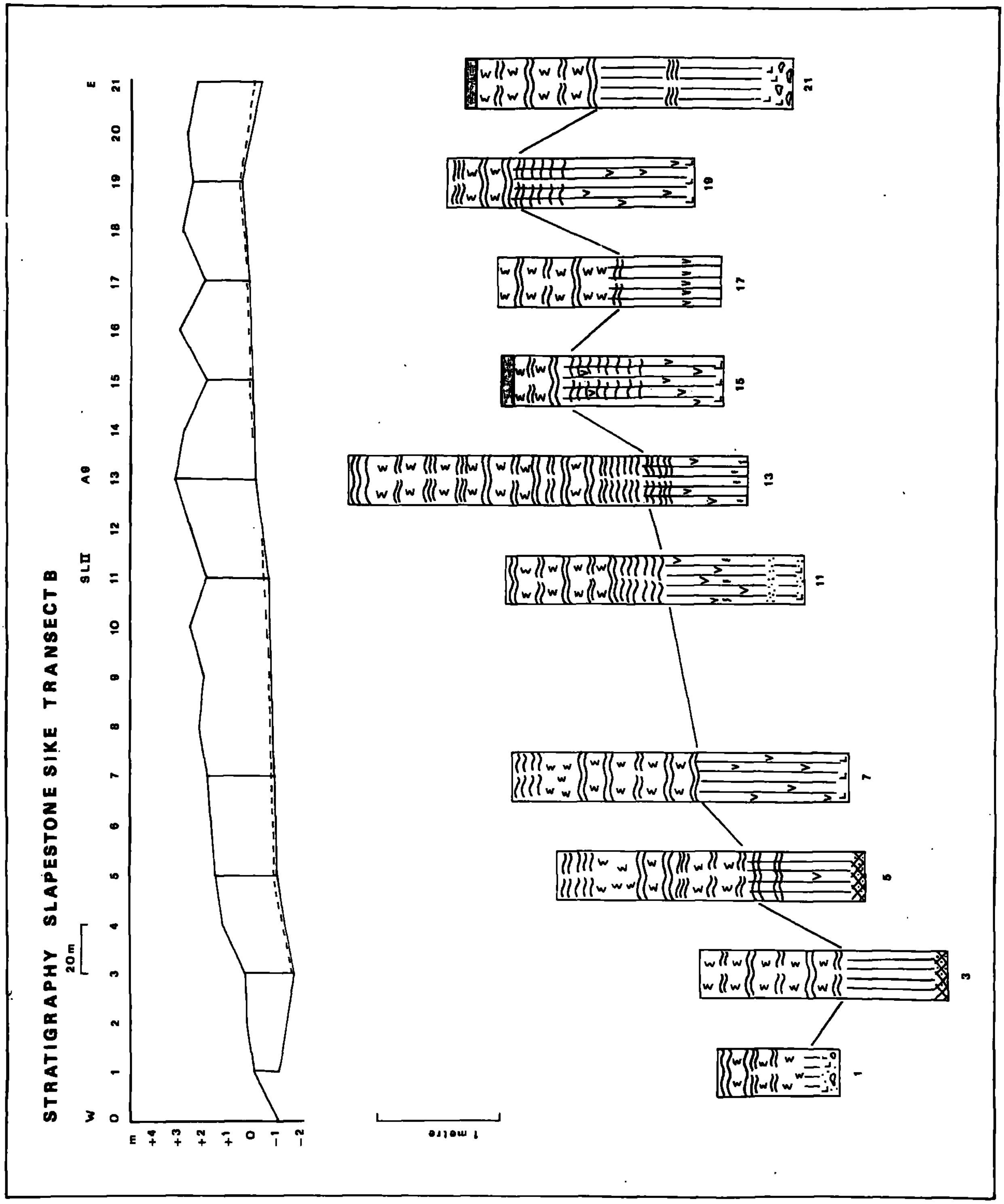


Fig. 13.



STRATIGRAPHY SLAPESTONE SIKE TRANSECT B
20m
W
E
0 1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 16 17 18 19 20 21
SL II
A9
m
+4
+3
+2
+1
0
-1
-2
1 metre
1
3
5
7
11
13
15
17
19
21

Fig. 14.

	At 170 cms there is a band of cf. Equisetum rhizomes.
170 - 200 cms	Light brown sedge peat with Menyanthes seeds.
200 - 240 cms	Stiff, light brown sedge peat with a silt band at 225 cms.
240 - 245 cms	Silty, sedge peat.
245 - 250 cms	Greenish grey silty clay.

Basal Samples

In addition to the three main sites chosen for investigation on Widdybank Fell, three basal samples were taken from the blanket peat on the west side of the Fell to establish the period when the major spread of peat over the Fell began.

Basal Sample 1 was collected from the western slope of the fell between Slapestone Sike and Red Sike above the reservoir access road (Diagram 3), Grid ref. 814303. A 50 cm sample for analysis was collected across the peat / clay boundary, where there was blanket peat to a depth of 90 cms overlying 10 cms of greyish, stony clay.

Basal Sample 2 was collected from the lower slopes of the fell, below the reservoir access road on the northern bank of Red Sike about 100 metres before the sike joins the Tees. Here blanket peat to a depth of 100 cms overlies 10 cms of grey stony clay. A sample for analysis was collected across the peat / clay boundary.

Basal Sample 3 . A block of peat was taken from the cuttings made during the building of the reservoir site huts, immediately to the south - east of the Birkdale track where it crosses the access road (Diagram 3). Here the depth of blanket peat is barely 50 cms in thickness overlying

10 cms of boulder clay, which rests on limestone rock.

Pollen analytical data.

1. Red Sike / Tinkler's Sike.

Two complete profiles were collected for pollen analysis from this site together with one basal sample.

TS1 Samples for analysis were cut from a series of peat blocks at a distance of 5 cms. apart and 2 cms apart in the basal 10 cms. At each level 150 tree pollen grains were counted and each pollen type expressed as a percentage of total tree pollen. Particular attention was given to the identification of Betula pollen grains and herbaceous pollen. This data is presented as a pollen diagram - Tinkler's Site I. (Diagrams 15 and 16).

The Basal 8 cms of peat, which consist of Phragmites peat containing scattered fragments of Birch Wood and B. nana leaves, show a consistently high percentage of Pinus - between 60 - 90%, the remainder of the tree pollen being Betula spp. The counts for Tree Betulas and Betula nana are represented on the diagram as separate parts of the same total percentage. The method for identification of the Betula is dealt with in Appendix II. At the base of the diagram there is no Ulmus or Quercus present and Corylus is represented by very low counts - 3 - 6% of total tree pollen. Salix is relatively high - 10% and Juniperus shows exceptionally high values in this basal 8 cms. The AP/NAP ratio is very low - 10% AP to 90% NAP.

The high non-tree pollen count consists chiefly of Cyperaceae pollen, which the large number of sedge macro-remains in the peat supports, with high values of Gramineae, Filicales spores and Selaginella Spores

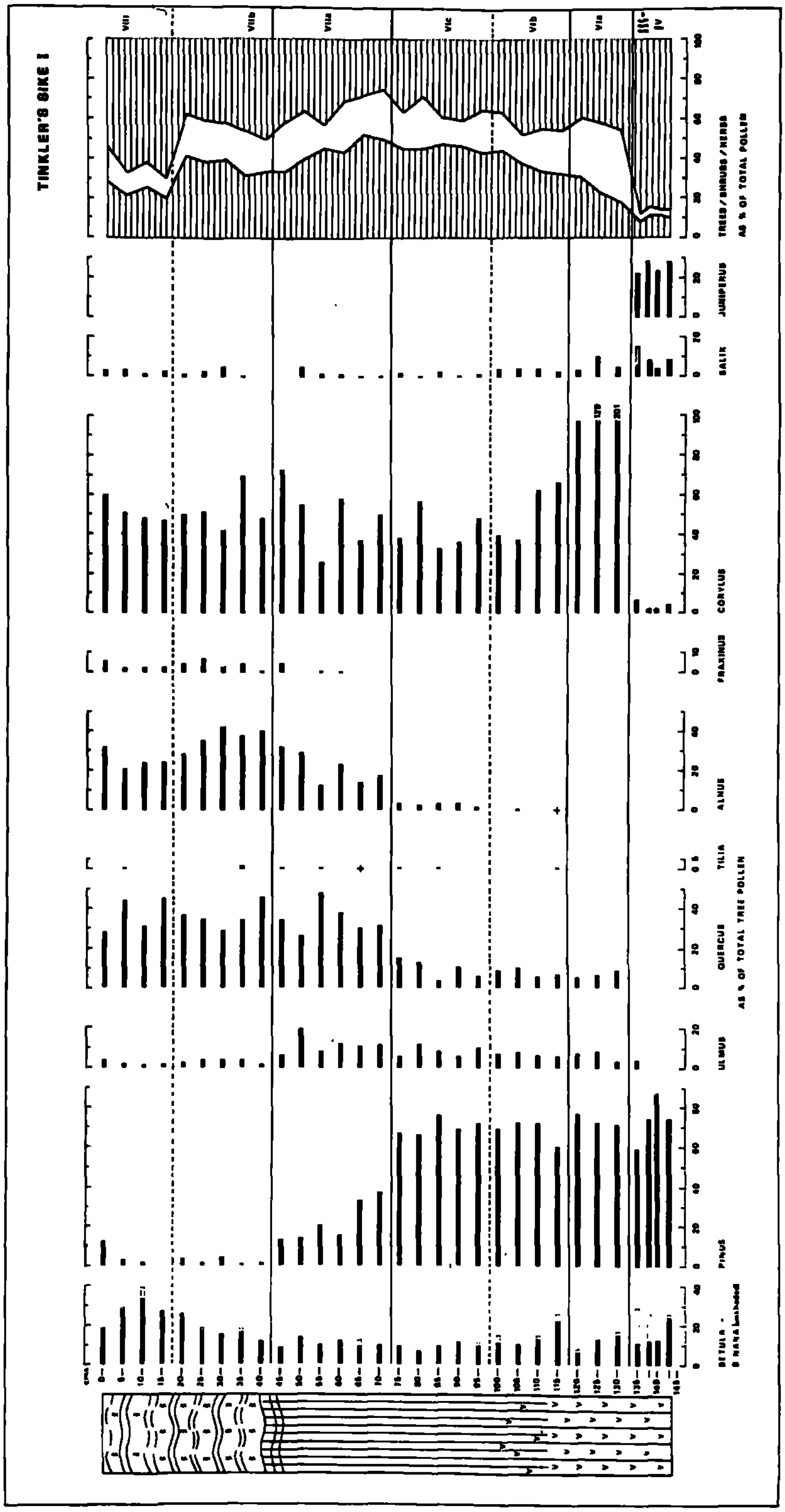

TINKLER'S SIKE I
BETULA + B NANA hatched
PINUS
ULMUS
QUERCUS
TILIA
AS % OF TOTAL TREE POLLEN
ALNUS
FRAXINUS
CORYLUS
SALIX
JUNIPERUS
TREES / SHRUBS / HERBS
AS % OF TOTAL POLLEN
VIII
VIIb
VIIa
VIc
VIb
VIa
IV

Fig. 15.

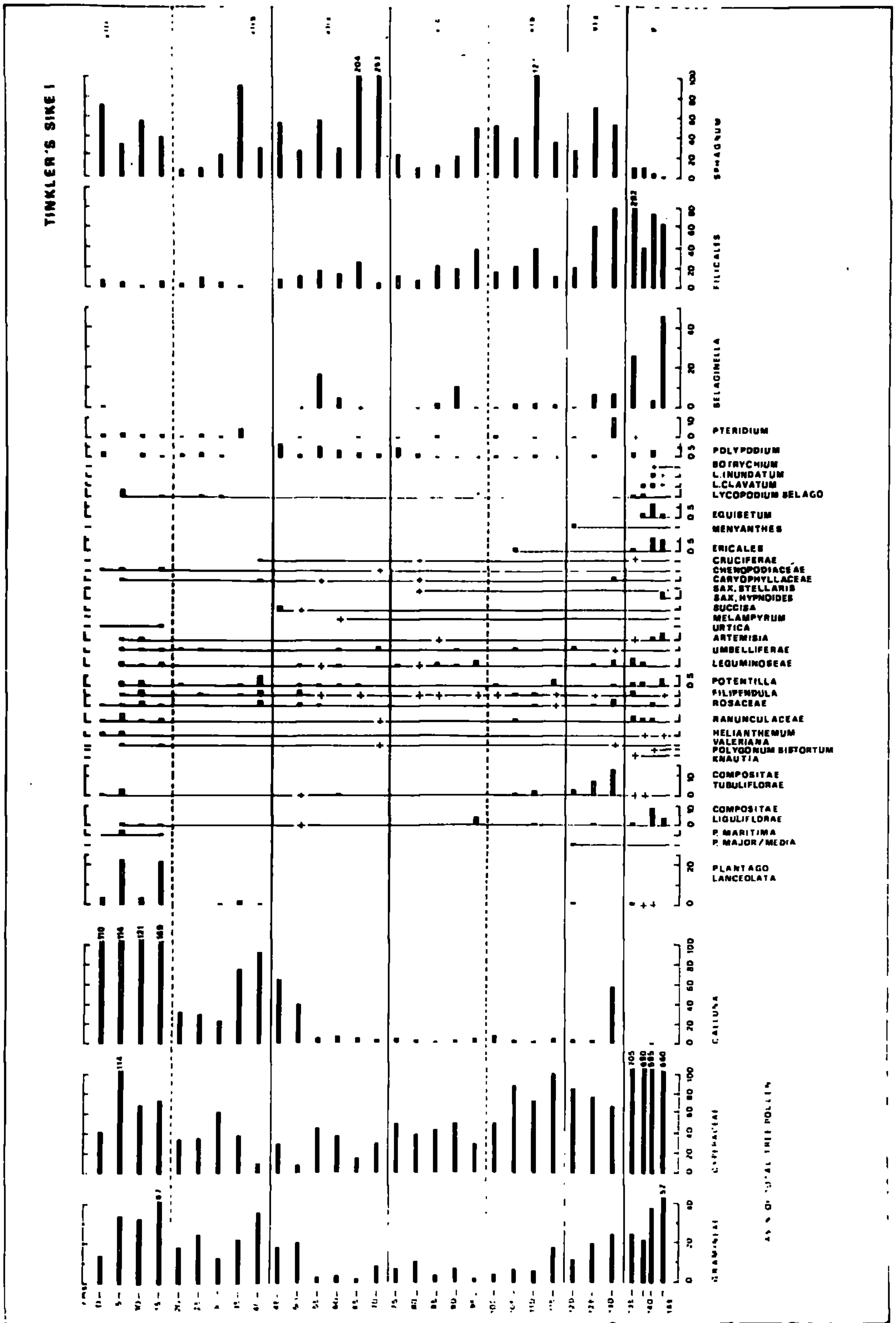

TINKLER'S SIKE I
SPHAGNUM
FILICALES
SELAGINELLA
PTERIDIUM
POLYPODIUM
BOTRYCHIUM
L.INUNDATUM
L.CLAVATUM
LYCOPODIUM SELAGO
EQUISETUM
MENYANTHES
ERICALES
CRUCIFERAE
CHENOPODIACEAE
CARYOPHYLLACEAE
SAX. STELLARIS
SAX. HYPNOIDES
SUCCISA
MELAMPYRUM
URTICA
ARTEMISIA
UMBELLIFERAE
LEGUMINOSEAE
POTENTILLA
FILIPENDULA
ROSACEAE
RANUNCULACEAE
HELIANTHEMUM
VALERIANA
POLYGONUM BISTORTUM
KNAUTIA
COMPOSITAE
TUBULIFLORAE
COMPOSITAE
LIGULIFLORAE
P. MARITIMA
P. MAJOR / MEDIA
PLANTAGO
LANCEOLATA
CALLUNA
GRAMINEAE

Fig. 16.

again borne out by the macro-spores found in the peat. The values for Sphagnum are very low but present throughout. A large number of other herbaceous species are also represented in the basal 8 cms. of peat including peaks of Equisetum. Ericales (including Empetrum)Artemisia, Lycopodium spp. Saxifraga type hypnoides, Plantago lanceolata, Compositae type liguliflorae, Filipendula, Potentilla.

A Radio-carbon date GAK 2031 from 135 cm gives a date of 9900 ± 190 B.P or 7950 ± 190 B.C.

This information suggests that peat began to form towards the end of late glacial times in a slight hollow in the limestone rock which underlies the Red Sike / Tinkler's Sike bog. The climate must have been one of very cold Arctic or sub-arctic conditions during which tree growth was limited and an essentially open vegetation was predominant. Tree pollen constitutes only 10% of the pollen record and this is confined to Pinus , Betula and Betula nana. Corylus values are very low, characteristic of the end of the late glacial or pre-boreal time. Juniperus pollen values are very high, disappearing abruptly at 130 cms This suggests a correlation with the high Juniper period at the commencement of Zone IV. However the high percentages of Gramineae, Cyperaceae and other herb pollen remain high until 130 cms i.e. the fall of herb pollen percentages coincides exactly with the disappearance of Juniperus pollen. This suggests a late zone III type of vegetation. The radio carbon date obtained from 135 cms suggests a date corresponding approximately with the Scaleby Moss dates for the III/IV boundary (Q151) (Godwin, Walker and Willis 1957). It is worth noting that the geographic factors which combine to make Upper Teesdale what it is today must have existed throughout the post glacial period, hence the transition from Zone III to Zone IV type of vegetation and climate may have taken place rather later than elsewhere in the British Isles.

Above 135 cms is a sudden and abrupt change in the pollen spectra. Pinus and Betula percentages remain but Corylus reaches values of 100 - 200% total tree pollen. Ulmus and Quercus both appear at 135 cms as about 10% of the total tree pollen. Salix declines and Juniperus disappears completely and no further records were found. There is a decline in Gramineae, Cyperaceae pollen and Selanginella spores, from the high values of the previous 8 cms. and generally lower values for herbaceous pollen, although there are peaks of Compositae Tubuliflorae and Pteridium. Sphagnum expands from the very low values of the previous zone. Other herbaceous species represented include Plantago spp, Rosacaae Valeriana, Leguminoseae, Umbelliferae, Cruciferae and Menyanthes and a single level of high Calluna at 130 cms.

The sudden changes in the pollen spectra at this level, particularly the abrupt disappearance of Juniper and rise of Ulmus, Quercus and Corylus, suggests a gap in peat formation and therefore in the pollen sequence followed by the onset of acid peat development. This is supported by the Calluna peak at 130 cms and also by the rise in Sphagnum although there is no evidence from the peat stratigraphy, except that on drying out layers of non-calcareous sandy material appeared in the peat around this level. During the period when this section of peat was laid down conditions must have been rather less severe. There is evidence of the slow spread of tree species through the region and the proportion of tree to non-tree species begins to rise slowly. Mixed oak forest species are beginning to reach the region, spreading northwards from the south-east. Corylus reaches its post glacial maximum during this period. These factors suggest a correlation with Zone VIa/VIb of the regional pollen zonation scheme, during which time the climate was more continental although the pollen spectra suggest a still predominantly open vegetation on Widdybank Fell with Pine and Birch being the chief tree pollen contributors.

Within the following 15 cms of peat the changes in the pollen spectra are rather less dramatic but nevertheless significant. Corylus falls from the exceptionally high values of the preceding zone to between 40 - 60% Total Tree pollen and this value is maintained throughout the succeeding zones of the diagram. Scattered grains of Alnus are found at 115 cm and 105 cm. There is a single grain of Tilia at 115 cms. The tree pollen ratio continues to rise slowly. Pinus shows consistently high values and Betula remains about 20% Total Tree pollen including a small but persistent percentage for B. nana.

Gramineae values decline steadily to 5% at 100 cms and herbaceous pollen values generally show a slight decline although they are still represented by Filipendula Potentilla, Rosaceae, Ranunculaceae and Compositae. Sphagnum values are erratic but are always 30% Total Tree pollen.

This zone coincides with a change in stratigraphy when Phragmites and wood fragments become scarce and Sphagnum becomes more common. A radio-carbon date GaK 2030 taken at 120 cms. immediately below this zone gives a date of 6300 BC± 280 which fits in with other dates obtained for Zone VI (Godwin 1957).

The changes in *Corylus* percentages together with those for *Quercus* and *Ulmus* suggest Zone VIb of the regional pollen zonation scheme.
Above 100 cms *Alnus* makes its first consistent appearance with values of 3 - 5 %. *Ulmus* and *Quercus* maintain values of 10 - 25% and there are scattered occurences of *Tilia*. The Tree pollen ratio continues to increase but does not reach more than 40% Total pollen count. *Pinus* continues to maintain very high values although *Betula* declines during this period. The non-tree pollen count is still represented by a wide variety of herbaceous species including Caryophyllaceae, *Artemisia*, Umbelliferae, Cruciferae, *Filipendula*, Leguminoseae and *Selaginella* and *Lycopodium* spores making up 30 - 40% of the total pollen rain.

The climate during this late Boreal period VIc is recognised as being warm and dry throughout the British Isles although it is probable that isolated areas of moderately high altitude such as Widdybank Fell may have remained cool and therefore retained a predominantly open vegetation throughout the boreal period. The Boreal/Atlantic Transition takes place at 70 cms. At and above this level *Alnus* rises steadily, replacing *Pinus* which declines steadily throughout the following 25 cms. *Ulmus* maintains values of 15 - 20% throughout this period and *Quercus* expands to reach its maximum values of 30 - 40%. *Tilia* is present in small quantities in this zone and *Fraxinus* appears for the first time. The Tree pollen ratio reaches its maximum at 65 cms of 40% Total pollen.

Gramineae pollen shows low values during the first part of this zone but expands at 50 cms. At the same level *Calluna Vulgaris* expands sharply from very low values to values in excess of 40%.

The Cyperaceae curve does not expand at this time. Early in the zone Sphagnum shows a pronounced rise but this falls off towards the end of the zone. Polypodium shows values between 2 - 5% throughout this zone and there is a peak of Selaginella at 55 cms. The herb flora is still rich and varies including Succisa, Potentilla, Filipendula, Rosaceae, Caryophyllaceae, Chenopodium, Melampyrum, Leguminoseae and Umbelliferae.

The increasing oceanity of the climate during zone VIIa is seen in the rise of Alnus and also to some extent by the increase in peat forming species. There is no visible change in peat stratigraphy during this zone and there is no evidence to suggest more rapid peat growth during this period. Thermophilous tree species reach their maximum during this period as Quercus and Ulmus expand. Tilia is never represented by more than 2 - 3%. Despite this forest maximum, the AP/NAP ratio never exceeds 40% which strongly suggests that whilst Widdybank Fell may have been able to support tree cover at this time, the cover was light enough to maintain a rich herb flora.

The rise of Gramineae and Calluna curves before the end of Zone VIIa together with a decline in the tree pollen ratio suggests that the Fell may have been returning to a more open vegetation type even before the onset of the climatic deterioration which is marked by the beginning of blanket peat development above the 40 cms level. A radio-carbon date GaK 2029 at 70 cms - the point at which Pinus values fall and Alnus values rise gives a date of 4200 BC ± 160. This is rather late for the Boreal/Atlantic Transition, which is usually dated to around 5000 BC (Godwin 1957). However it is interesting to note that Oldfield (1965) and Walker (1955) both suggest that pine may have persisted into Zone VIIa in the N.W. i.e.

that its decline commences rather later than over the remainder of the country. If this is the case then the VI/VIIa boundary for this diagram is not entirely synchronous with the accepted BAT. Thus the radio-carbon date for this boundary will be rather younger than other dates for the B/A Transition. This problem is referred to in Godwin (1960) in connection with Irish diagrams.

At 40 cms the stratigraphy of the peat makes an abrupt and characteristic change from Sedgepeat to Blanket peat consisting of Eriophorum Vaginatum, Calluna vulgaris and Sphagnum spp. The onset of this widespread development of blanket peat seems to commence rather later than in the Southern Pennines (Conway 1954) which takes place together with the rise of Alnus at the beginning of Zone VIIa. The commencement of blanket peat development at Tinkler's Sike coincides with a rise in Betula pollen at the expense of Pinus and the decline of Ulmus. Alnus continues to expand reaching maximum values between 40 - 30 cms. Fraxinus is now present consistently at values of 5 - 10% Total Tree pollen. Tilia is represented at 35 cms only. The tree pollen ratio declines very slightly during this period. Gramineae, Calluna and also Sphagnum pollen shows peaks at 40 cms and the values then decline. Cyperaceae also shows a peak slightly later at 30 cms. Potentilla Filipendula and other Rosaceae pollen types all show small peaks at 40 cms and Pteridium, Polypodium and Lycopodium, together with Plantago lanceolata show small peaks above 35 cms.

The abrupt change in peat stratigraphy at 40 cms suggests a change in conditions which lead to the widespread growth of blanket peat over the Fell. Alnus was also favoured by this change in conditions as it continued to expand. At the same time the decline of Ulmus and the rise of herbaceous species, especially Gramineae, suggest that some utilization of the land was being made by Neolithic Settlers. Neither Pinus nor Ulmus recover after the decline in pollen values at 40 cms although the values for Calluna and to a lesser extent Gramineae fall off and at the same time Pteridium and other fern spores increase.

A further radio-carbon date GaK 2028 at 44 cms at the point at which Pine declines completely and at which Ulmus also declines gives a date of 1440 BC ± 90. This date shows no correlation with other dates for the Ulmus decline which is usually held to have occurred around 3000 BC. This raises several problems which will be discussed in a later chapter.

The final phase in the diagram above 20 cms shows little change in the relative tree pollen frequencies. Betula expands to its highest values but declines towards the surface and small but consistent records of B. nana occur throughout. However the AP/ NAP ratio falls steeply at 20 cms to about 20% Tree pollen. The NAP diagrams shows the major changes which separate this phase from the preceding one. There is a second expansion of Gramineae and Calluna and Cyperaceae above 20 cms together with a sudden rise in Plantago lanceolata and other Plantago spp. Sphagnum increases also during this last phase. Many other herbaceous species are well represented including Compositae, Valeriana, Polygonum, Helianthenum, Ranunculaceae, Filipendula, Potentilla, Artemisia, Urticae, Melampyrum, Chenopodium, Cruciferae. A radio-carbon date GaK 2027 taken at 14 cms at the beginning of this rise in Herbaceous pollen types gives a date of 620 BC ± 80. This date falls approximately in line with other dates for the Sub-boreal - Sub-Atlantic Transition period (Godwin 1960).

The pollen spectra of the 15 cms of peat immediately below the surface then suggest a return to open Tree-less vegetation on the fell with the more rapid growth of blanket peat over the slopes of the Fell commencing with the onset of the Sub-Boreal climatic deterioration. The nature of these changes and their probable causes are discussed in Chapter 5.

The change in stratigraphy at 40 cms which suggests a deterioration in climate leading to blanket peat development and the apparently synchonous fall of Ulmus at this level together with the exceptionally young date of 1440 BC for this, raise several problems. First of all it would be impossible to dismiss the possibility of contamination of the sample by modern rootlets. However if there is contamination of this sample and the 14 cms sample near to the surface then the date for the expansion of herbaceous pollen would be altered considerably. If, however, the date is accepted as reasonably accurate, then it must be considered whether the elm decline is really related to climatic change or whether it is an anthropogenic effect. If the decline of Ulmus is related to climate then was the onset of Sub-boreal conditions later or missing from this area of Irish diagrams (Mitchell 1965). If the Ulmus decline is a fact linked with the activity of man, then was the settlement of these fells later than elsewhere? A further possibility, which would provide an explanation for the date 1440 BC is a further gap in peat formation from the end of the Boreal Period or mid-Atlantic to 1440 BC $\pm$ 90 when peat growth recommenced. The sample for radio-carbon dating which gave this date was the first sample containing low elm values and may therefore represent the middle of zone VIIb rather than the beginning. Sandy layers similar to those at the 130 cm horizon add some support to this theory. Granlund's recurrence surface RY IV at 1200 BC when peat growth was renewed at a large number of sites in Britain and N. Europe could possibly correspond with this renewal of peat growth.

Red Sike II (Diagrams 17 and 18)

At the base of the diagram *Pinus* values are high, between 60 - 80% and *Betula* shows values between 20 and 40% total tree pollen. *Corylus* is already present in increasing amounts. *Ulmus*, *Quercus* and *Alnus* are present but their values are rather erratic through the first few levels. This may be due to a mixing of the pollen across the peat/clay boundary. There is 10% *Juniperus* pollen at the opening of the diagram but this declines steadily and disappears after 6 cms.

Ilex is also present at 410 cms but only as 2 - 3 grains and it is not found again until the Sub-Atlantic period. However its presence in the region does suggest that minimum winter temperatures cannot have been far below freezing point (Iversen 1944).

At the opening of the diagram, herb pollen represents 60 - 70% total pollen count consisting of high values for Cyperaceae, *Selaginella* and Filicales and there are also peaks of Compositae, *Filipendula* and Ericales. Gramineae and *Calluna* pollen show low values and *Artemisia*, *Saxifraga stellaris*, *Valeriana*, Ranunculaceae and *Lycopodium* spp are also represented.

At this time then, the vegetation was open, tree species contributing only 20% to the total pollen rain. This area to the south of Red Sike must have been sufficiently waterlogged for the growth of a mire consisting chiefly of sedge species together with *Phragmites* and *Filipendula*. The community may have been a transitional one supporting tree birches and associated with this more stable community may

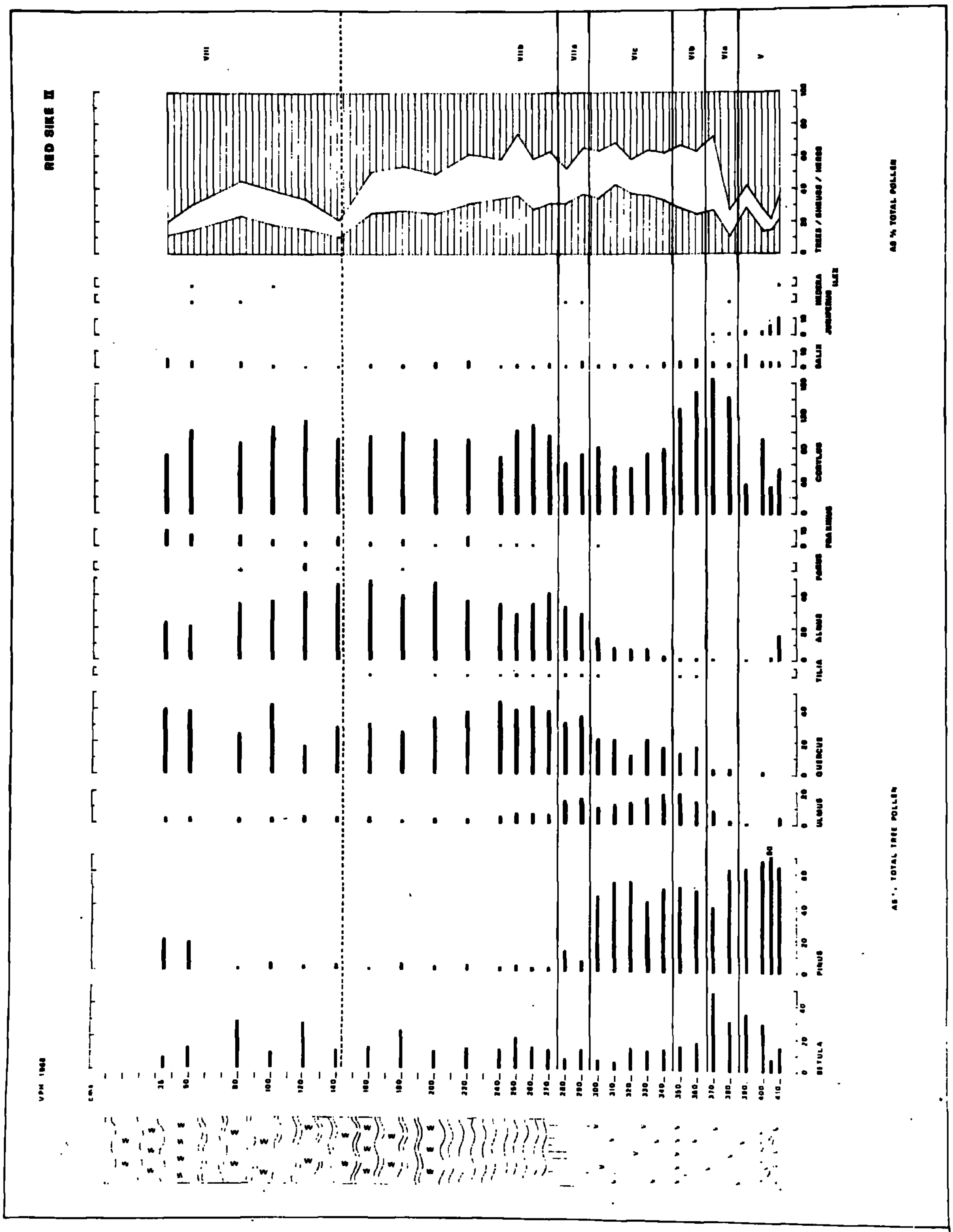

RED SIKE II
BETULA
PINUS
ULMUS
QUERCUS
TILIA
ALNUS
FAGUS
FRAXINUS
CORYLUS
SALIX
JUNIPERUS
HEDERA
ILEX
TREES / SHRUBS / HERBS
AS % TOTAL POLLEN
AS % TOTAL TREE POLLEN

Fig. 17.

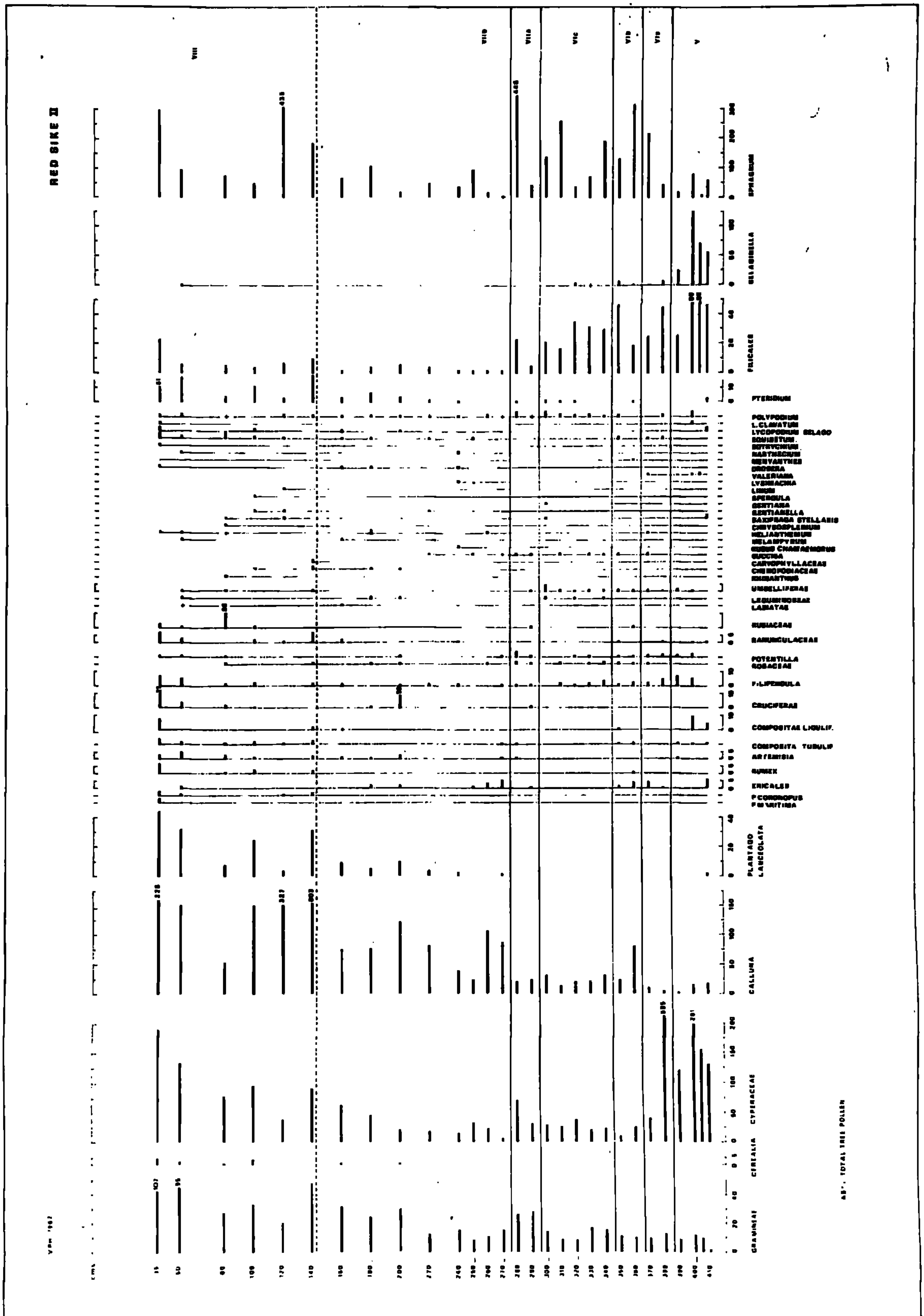

RED SIKE II
SPHAGNUM
SELAGINELLA
FILICALES
PTERIDIUM
PLANTAGO LANCEOLATA
CALLUNA
CEREALIA
CYPERACEAE
GRAMINEAE
AP % TOTAL TREE POLLEN

Fig. 18.

have been marsh dwelling species of Compositae and Filicales.

Oak and Elm are both present in the area, therefore the climate must have been ameliorating and becoming increasingly drier and warmer. Hence, perhaps, the development of the drier Birch fen community. Juniper is declining rapidly which suggests a correlation with its general decline towards the end of the Pre-Boreal period - Zone IV/V.

During the following 80 cms. Ulmus and Quercus rise replacing Betula and to a much lesser extent Pinus. Corylus rises sharply at 380 cms to values exceeding 140% total tree pollen and declines to values of about 80% total tree pollen above 350 cms. - Zone VIa and VIb respectively. Quercus expands to values of up to 20% during mid-Boreal time whereas, in the diagrams for Tinkler's Sike less than 300 metres to the East, Quercus is not represented by values greater than 10% until the decline of Pinus at the end of Boreal time. Also Pinus never exceeds values of 60% after the rise of Corylus, differing from the values of 70 - 80% maintained throughout the Boreal period at Tinkler's Sike.

At the opening of Zone VI, Cyperaceae pollen is still very high but declines rapidly to 30 - 40% throughout the remainder of the Boreal period. Gramineae remains low, although both Calluna and Sphagnum rise briefly during VIb. Filicales values remain high throughout Zone VI although Selaginella declines sharply at the end of Zone V.

The tree pollen ratio rises during Zone VI to 40% total pollen count at 310 cms but there is still a rich herb flora including such pollen types as Ericales, Rumex, Compositae, Filipendula, Rosaceae, Potentilla, Rubiaceae, Leguminoseae, Umbelliferae, Succisa, Helianthemum, Gentianella, Menyanthes and Equisetum.

Above 300 cms *Pinus* values decline sharply to about 10% total tree pollen. At the same time, *Quercus* and *Alnus* expand considerably, and *Tilia* is present consistently and *Hedera* also occurs at 290 and 280 cms. Gramineae also rises briefly although rather fewer herbaceous species are represented. Above 280 cms *Pinus* declines away to values of less than 5% and does not recover throughout the remainder of the post-glacial until the present day. At the same level Ulmus declines from values up to 20% to about 5% total tree pollen. Both *Quercus* and *Alnus* continues to expand and *Fraxinus* also rises.

The Atlantic period seems only to be represented in this diagram by the two levels - 290 and 280 cms and that above this the pollen spectra are of Sub-boreal age. The peat stratigraphy changes abruptly at 270 cms from a dryish sedge - *Sphagnum* peat to a much fresher *Sphagnum* peat which grades into *Sphagnum* - *Eriophorum* - *Calluna* blanket peat mid-way through Zone VIIb. Thus, as in TSI there is no marked change in peat development at the onset of Atlantic times, and it seems probable that much of Zone VIIa is missing. Possibly the growth of peat was very slow during this period.

During the 120 cms of peat which represent VIIb, peat accumulation must have been much more rapid that hitherto :- *Calluna* expands at the beginning of the zone and *Plantago lanceolata* is also represented to values up to 10% throughout the zone. Grass and Cyperaceae both rise before the end of VIIb. *Sphagnum*, on the other hand, shows low values. Herbaceous species are represented by Ericales, *Artimisia*, Cruciferae, *Filipendula*, *Potentilla* and other Rosaceae, Ranunculaceae, Labiatae, *Succisa*, *Helianthemum*, *Gentiana* and many mire and heath species:-

Rubus chamaemorus, *Drosera*, *Narthecium*, and *Equisetum*. The AP/NAP ratio does not alter appreciably during this period although this range of herbaceous species suggests a spread of blanket peat communities and also an expansion of true grassland species.

At 140 cms the AP/NAP ratio falls to 10% total pollen, *Betula*, rises, *Quercus* and *Alnus* decline. *Tilia* which was present throughout the early part of VIIb has disappeared from the pollen record. *Fagus* reaches a peak at 120 cms and *Fraxinus* continues to expand.

There is a general rise in values of almost all herbaceous species, particularly *Calluna* and *Plantago lanceolata* and to a lesser extent, Gramineae, Cyperaceae, *Pteridium* and other ferns. Species associated with an opening out of the vegetation such as *Plantago coronopus*, *Rumex* and *Artemisia* are also well represented.

There is a slight decline in herb pollen values between 100 - 50 cms but a rapid and sustained rise from this level to the surface.

Comparison of RSII with TS I.

Both these diagrams show the sequence of changes in vegetation both local and regional throughout the post-glacial period from early Boreal times. There has been a much greater development of peat in the central area of the bog than at Tinkler's Sike where the peat has been considerably eroded and the water drained into the stream. There may have been a drying out of the peat here or there may have been very slow development of peat throughout as a very long period of time is represented by 143 cms of peat. At RSII peat seems to have accumulated more rapidly during the Sub-boreal and Sub-Atlantic periods than during the earlier Atlantic period which is represented by only 20 cms of peat.

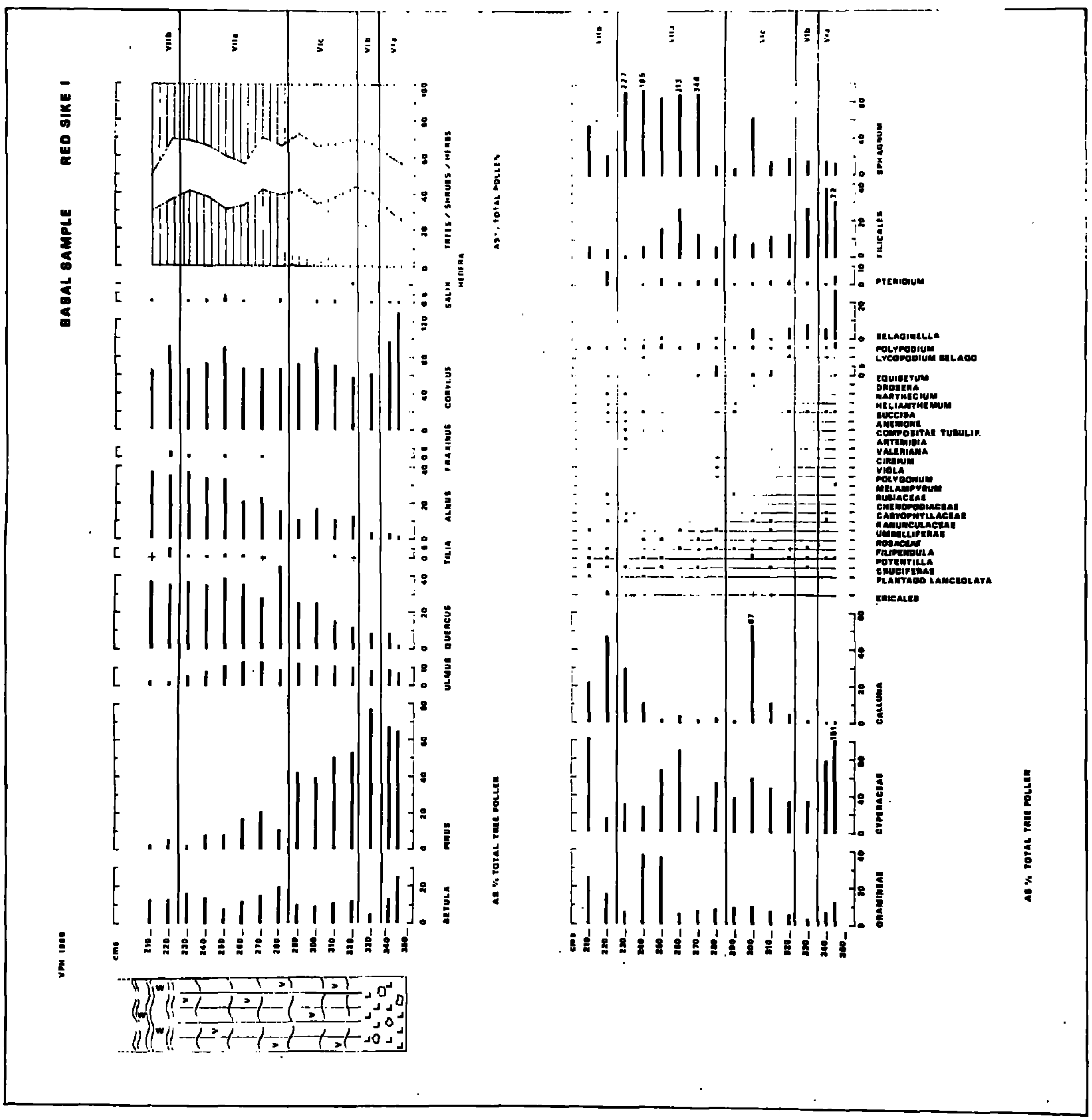

BASAL SAMPLE
RED SIKE I
BETULA
PINUS
ULMUS
QUERCUS
TILIA
ALNUS
FRAXINUS
CORYLUS
SALIX
HEDERA
TREES / SHRUBS / HERBS
AS % TOTAL TREE POLLEN
AS % TOTAL POLLEN
GRAMINEAE
CYPERACEAE
CALLUNA
ERICALES
PLANTAGO LANCEOLATA
CRUCIFERAE
POTENTILLA
FILIPENDULA
ROSACEAE
UMBELLIFERAE
RANUNCULACEAE
CARYOPHYLLACEAE
CHENOPODIACEAE
RUBIACEAE
MELAMPYRUM
POLYGONUM
VIOLA
CIRSIUM
VALERIANA
ARTEMISIA
COMPOSITAE TUBULIF.
ANEMONE
SUCCISA
HELIANTHEMUM
NARTHECIUM
DROSERA
EQUISETUM
LYCOPODIUM SELAGO
POLYPODIUM
SELAGINELLA
PTERIDIUM
FILICALES
SPHAGNUM
AS % TOTAL TREE POLLEN

Fig. 19.

Pine values at RSII during Zone VI are consistently lower than at TSI : ± 60% : ± 80%.

X^2 2 x 2 contingency tests on these values taken over the whole of zone VI in both cases (Appendix 3) shows that the difference in these two values is significant i.e. that the probability of the difference between the two samples being due only to sampling error or accident is considerably less than 5%.

Ulmus and Quercus both rise much more rapidly during Zone VI in RSII than TSI and Alnus too, rises rather earlier.

The first rise in Gramineae pollen values before the end of VIIa in TSI is not so marked in RSII. There are, however, two distinct expansions of Grass pollen in Zone VIII which are not shown in TS I.

Red Sike I. This basal sample was taken between TS I and RS II but closer to the sugar limestone outcrop at Red Sike than the other two (Diagram 5). Only the basal 150 cms were counted to establish the early changes in peat development and the pollen record and also to clarify the changes which took place during the Boreal and Atlantic periods.

At the base of the diagram, Betula and Pinus values are high and Ulmus and Quercus are already present. Alnus is present in small amounts (Diagram 19).

The Boreal period, then, is already well established and mixed oak forest trees had reached the area before peat development had spread towards the edge of Red Sike. Tree pollen represents 20% of the total pollen count whilst Corylus reaches very high values at the opening of the diagram but declines quickly to more constant values of 60 - 70%. Pinus remains high during the following 50 cms although declining slightly as Quercus and Alnus rise. There is a brief peak of Calluna at 300 cms which is not accompanied by rises in any other species.

At 280 cms Quercus rises at the expense of Pinus which falls to values of 10 - 20% and Tilia is also present consistently for the first time. There are no other major changes at this stage although there is a rise in Grass pollen and to a lesser extent Calluna before the end of this period. Sphagnum also rises during the period to exceptionally high values.

At 220 cms both Pinus and Ulmus decline to values of less than 5% and the percentage of tree pollen to values of about 30%.

Comparison of Red Sike I with Red Sike II and Tinkler's Sike I.

All the major changes in each diagram have been taken as synchronous with the corresponding changes in the other diagrams and therefore each diagram has been zoned in the same way. Thus the problems involved in the zonation and interpretation of TS I particularly between 70 - 20 cms may be partially clarified by a comparison with RS I and RS II.

The chief differences between the three diagrams are :-

1. The statistically significant differences in each of the three diagrams between Pinus values during Zone VI. (See Appendix IV).
2. The difference in time of the rise of Ulmus, Quercus and Alnus.
3. The time at which peat first began to develop at each of the three points in the area.

Peat began to develop first at TS I, where the pollen record suggests a late Zone III - early Zone IV time for the beginning of the diagram. To the west peat seems to have begun to develop at the beginning of the Boreal period in the lowest parts of the Red Sike basin and to have spread rapidly outwards during the Boreal period.

Pine values in the Red Sike area during Zone VI vary from more than 70% total Tree pollen at T.S.I to between 50 - 60% at RS II with intermediate values at RSI. The difference in pine values at each of these sites may be attributable to:-

(a) a real difference in pine frequency from east to west i.e. that pine was growing closer to site TSI than to the other two sites or

(b) this difference may be a function of the difference in oak and elm curves i.e. the absolute pine frequency may have remained constant whilst that of oak and elm altered.

Quercus and Ulmus both rise steadily during Zone VI at RSI and RSII whilst at TSI there is no corresponding rise until the end of this zone. It is possible that Quercus and Ulmus may have penetrated up the Tees valley to the western side of the Fell rather than over the plateau to the east, thus accounting for the higher percentage of pine at TSI. Edaphic factors must also have played an important part in the expansion of oak and elm on to the fell and it is possible that the better drained soils immediately to the north and west of the Red Sike area may have provided more suitable habitats during the early expansion of these species.

These important differences between three diagrams taken from sites less than 400 metres apart suggest that these differences are derived from the local pollen rain rather than from variations in the regional pollen rain. Tauber (1965,1967) has carried out detailed investigations into local pollen dispersal throughout a full growing season in a small area in Scandinavia. He found that there is evidence for differences in pollen dispersal in the trunk space and above the tree canopy and also strong differences in the distances travelled by pollen. Thus, these factors must be borne in mind when interpreting variations in the local pollen rain.

From the pollen analytical evidence, therefore, it seems probable that during the latter part of zone VI oak and elm were slowly expanding on to the top of the Fell from the valley replacing, to some extent, pine where edaphic factors were most favourable but not until the end of the Boreal when the major climatic change took place together with consequent changes in soil and available habitats did oak and elms really succeed pine and birch as dominant tree species.

In all three diagrams Pinus declines in two stages:-

(a) a partial decline when it is replaced by expanding Quercus and Alnus - the Boreal/Atlantic transition.

(b) a total decline corresponding with the Ulmus decline - zone VIIb.

Zone VIIa is not clearly represented perhaps because peat was being deposited very slowly or not at all during this period. If this is so then the levels attributed to zone VIIa and VIIb may present rather a confused picture. This is supported by the anomolous radio-carbon date for the elm decline at TSI (Discussion page69)and the apparently slow growth of the peat during this period. Zone VIIa is generally accepted as a period of wet Atlantic conditions favourable to peat growth but the evidence from these three diagrams points to the very slow or possibly erratic peat development which could be accounted for by local climatic fluctuations. (Conway 1948).

Changes in non-tree pollen correspond in each of the three diagrams. Later changes during the Sub-Atlantic period are shown more clearly in RS II than in TS I, perhaps because of more rapid and extensive peat development at this site.

The initial rise in Grasses and other herbaceous species just before the Elm decline at the end of zone VIIa is clear on all three diagrams. Two explanations for this may be suggested:-

(a) Disturbance or mixing of pollen at the levels representing VIIa/VIIb.

(b) Mesolithic activity in the area.

Slapestone Sike I and II.

At Slapestone Sike a hollow in the limestone rock covered to a depth varying between 0 and 50+ cms of greyish stony clay began to fill with peat in the centre towards the end of boreal time and the development of blanket peat spread over the whole area at the beginning of the sub-boreal time.

A basal sample (Diagram 20- taken from the centre of the bog to the south of an extensive area of blanket peat erosion shows a Phragmites - sedge peat mixed with bands of clay.

At the base of this diagram there are high values of Pinus and Corylus but Ulmus, Quercus and Tilia are already present as is Alnus, in quite large amounts.

By comparison with the diagram from Red Sike some distance to the south of Slapestone Sike, it is probable that this peat was beginning to form towards the end of Zone VI. Corylus declines from 80% to 60% and at 220 cms Pinus values fall from 50% to 30%. Ulmus declines at a single level only (220 cms) and then recovers. Alnus does not rise appreciably.

There is a peak of Cyperaceae pollen at 220 cms accompanied by

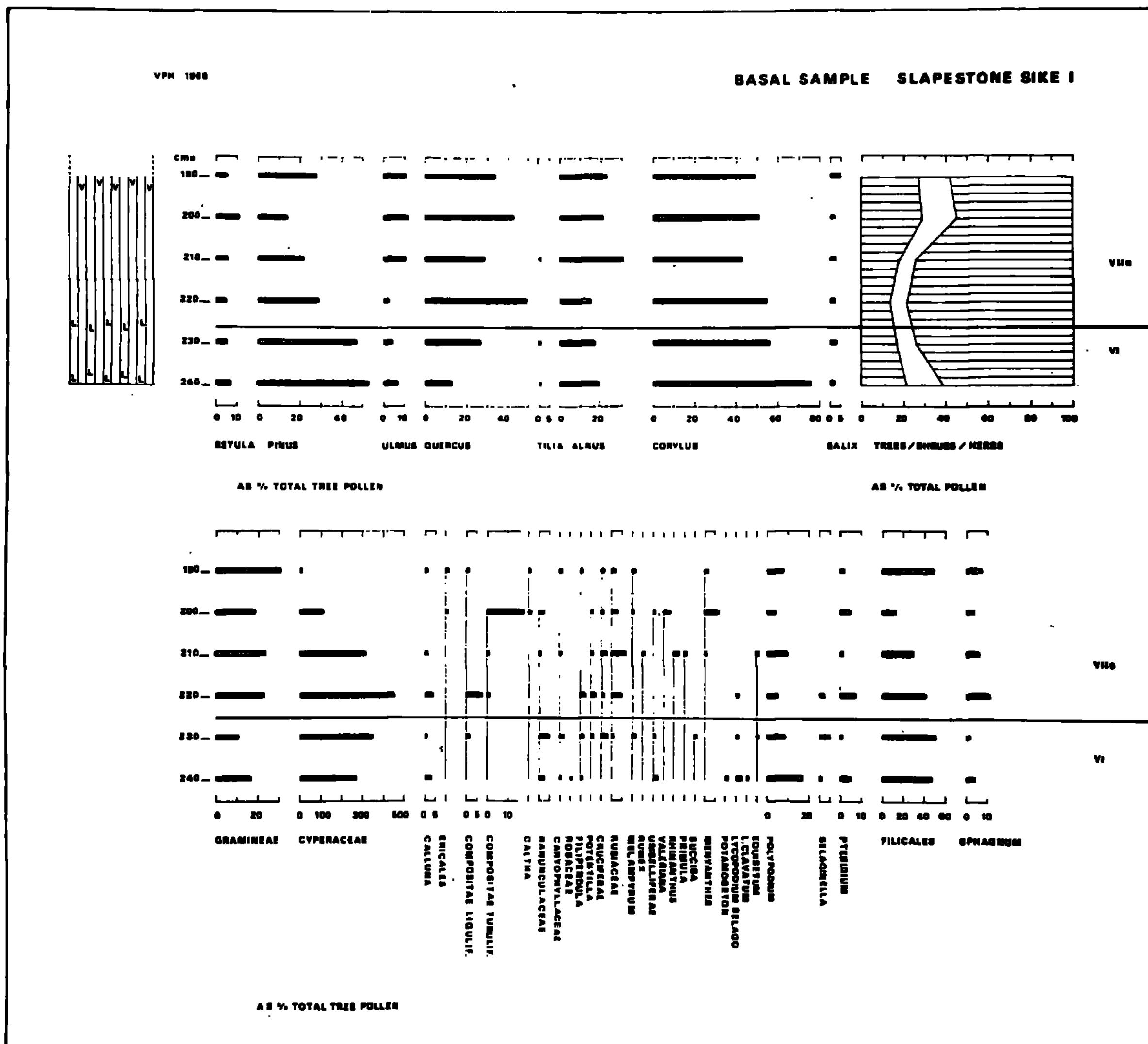

VPH 1968
BASAL SAMPLE SLAPESTONE SIKE I
BETULA PINUS
ULMUS QUERCUS
TILIA ALNUS
CORYLUS
SALIX
TREES / SHRUBS / HERBS
AS % TOTAL TREE POLLEN
AS % TOTAL POLLEN
GRAMINEAE
CYPERACEAE
CALLUNA
ERICALES
COMPOSITAE LIGULIF.
COMPOSITAE TUBULIF.
CALTHA
RANUNCULACEAE
FILICALES
SPHAGNUM
AS % TOTAL TREE POLLEN
VIIa
VI

Fig. 20.

a rise in Gramineae pollen and peaks of Rubiaceae, Cruciferae, Potentilla and Menyanthes. Also represented are Compositae, Caltha and other Ranunculaceae, Caryophyllaceae, Melampyrum, Rumex, Valeriana, Rhyinanthus, Primula and Succisa.

The total °/o Tree pollen declines around 220 cms at the time when Cyperaceae and other herbaceous pollen temporarily expand. This very temporary decline in tree pollen does not seem to correspond exactly with the first decline in Gramineae in RS I, II and TS I, but rather may be attributable to the commencement of more extensive peat development over the area and a relatively larger % herbaceous pollen. A full profile from Slapestone Sike Bog was taken from the North side of the area of peat erosion (Diagrams 21 and 22). 40 cms of basal clay yielded very low pollen counts and much of this pollen was in a very poor state of preservation. The counts of the number of grains counted are shown as a Table below the diagram.

At 250 cms at the peat/clay boundary the pollen content increased markedly and the preservation became good. At this level Pinus and Betula are very low, values of Quercus, Alnus and Corylus high. Tilia is present in the basal samples and Fraxinus appears at 240 cms. Ulmus values are ± 10% until 190 cms when the values fall to less than 5%. Tree pollen constitutes 20 - 30% of the total. Betula rises at 230 cms and maintains 15 - 20°/o.

Although Ulmus is still represented as 10% total tree pollen at the opening of the diagram, Pinus has already declined so it seems likely that peat formation in this part of the bog did not begin until Zone VIIb sub-boreal time.

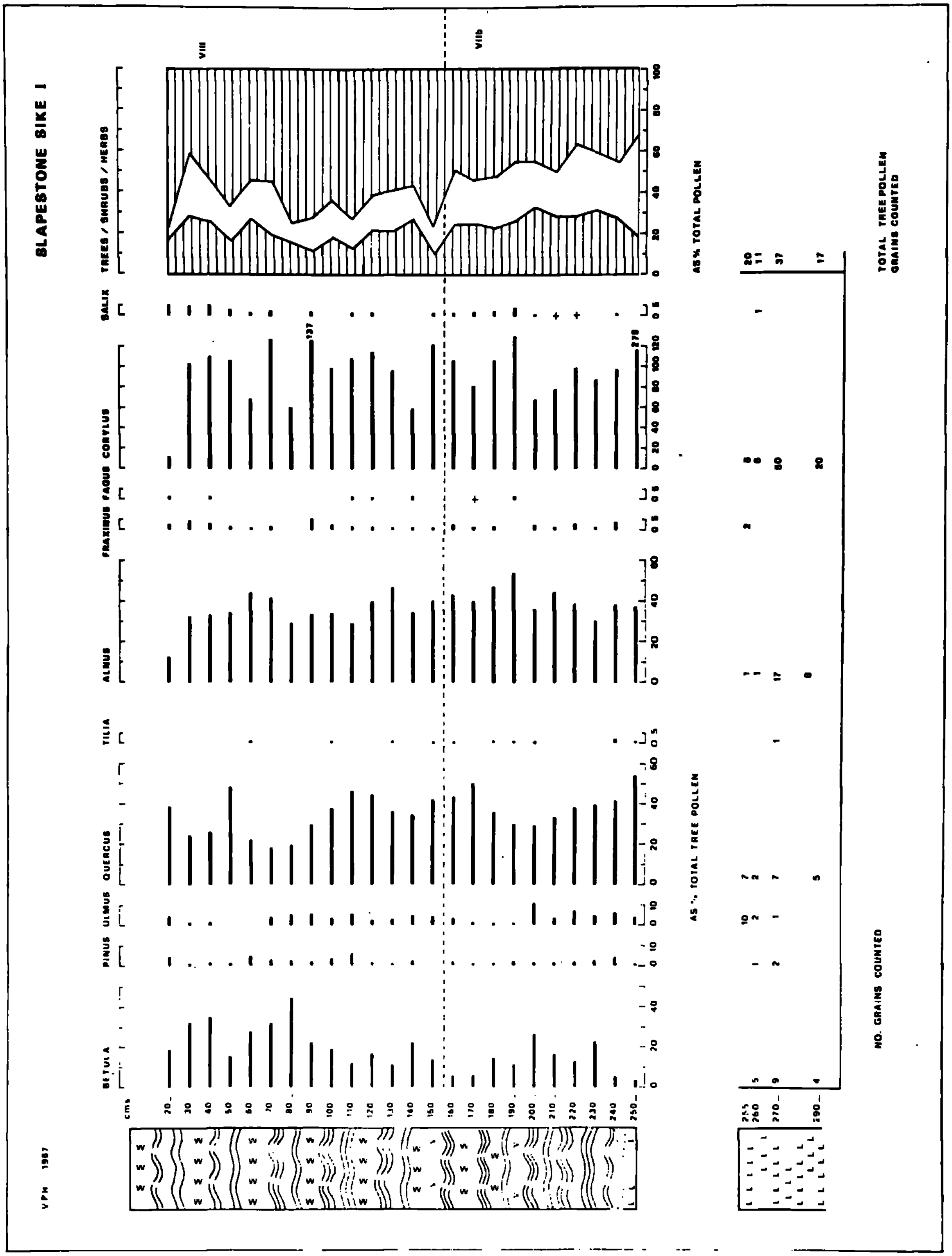

SLAPESTONE SIKE I
VPH 1987
cms
BETULA
PINUS
ULMUS
QUERCUS
TILIA
ALNUS
FRAXINUS
FAGUS
CORYLUS
SALIX
TREES / SHRUBS / HERBS
VIII
VIIb
AS % TOTAL TREE POLLEN
AS % TOTAL POLLEN
NO. GRAINS COUNTED
TOTAL TREE POLLEN GRAINS COUNTED

Fig. 21

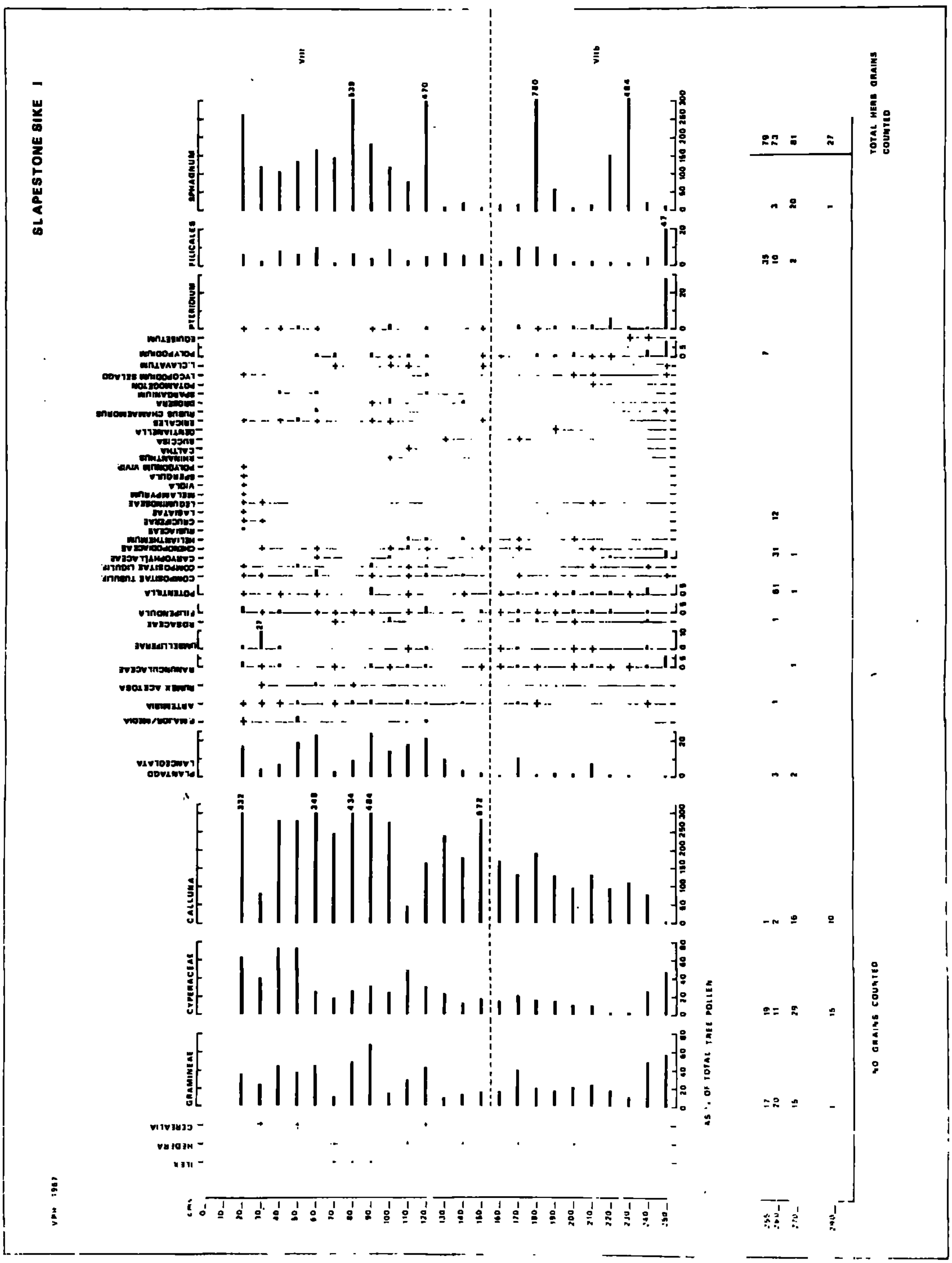

SLAPESTONE SIKE I
SPHAGNUM
FILICALES
PTERIDIUM
CALLUNA
CYPERACEAE
GRAMINEAE
AS % OF TOTAL TREE POLLEN
TOTAL HERB GRAINS COUNTED
NO GRAINS COUNTED

Fig. 22.

At the opening of the diagram, Gramineae and Cyperaceae together with Polypodium, Pteridium and other fern spores show high values but decline rapidly as Calluna expands. This suggests a local change in the herbaceous vegetation where a grass-sedge community was succeeded by one dominated by Calluna and Sphagnum.

Throughout the diagrams herbaceous pollen types are always well represented including Artemisia, Ranunculaceae, Umbelliferae, Filipendula, Potentilla, Succisa. Gentianella, Caryophyllaceae, Chenopodiaceae, Compositae. Plantago lanceolata is present in small quantities 0 - 10% from 230 cms but does not expand until 110 cms.

There are no clear cut changes which signify the boundary between Zone VIIb and VIII, rather there is a gradual change shown in the tree pollen diagram by a slow rise in Betula values and in the non-tree pollen diagram by a rise in Calluna, a slow rise in P. lanceolata and at the same level a rise in grass pollen. At this level too, more herbaceous species are represented including types such as Drosera Sparganium and Equisetum, which are associated with mire communities and Helianthemum, Artemisia and Plantago major type which are associated with open communities.

2 cerealia grains of the type Secale cereale were found at this level (120 cms). The slow rise of Calluna, grasses and P. lanceolata together with a general rise in herbaceous pollen values suggest a clearance in the area brought about by a failure of tree species to regenerate under increased grazing pressure. The presence of Cereal grains at this level indicates that there must have been clearance associated with farming in the region although this may have taken place in the valley rather than on the Fell tops. This rise in herbaceous pollen at Slapestone Sike may

correspond with a similar rise noted at TSI with a radio-carbon date of 620 BC $\pm$ 80 and with a similar rise in RSII and in diagrams from below and on top of Cronkley Fell (Squires, unpublished).

At 60 cms following a slight decline, there is a further expansion in grass, Cyperaceae and P. lanceolata pollen, suggesting a further period of human settlement with which cereal grains of the Avena sativa type are associated.

At the surface there is a rapid decline in total tree pollen and an increase in herbaceous pollen types including Crucifers, Labiates, Leguminoseae, Melampyrum, Viola, Spergula and Polygonum viviparum. The extensive erosion of the peat and drying out of parts of the bog surface which is now covered by Calluna vulgaris, Eriophorum vaginatum, lichens of various types, some Erica Tetralix and patches of Sphagnum spp. suggest that peat formation may have come to a halt at some time in the more recent history of the bog and therefore the profile may not be complete at the top.

Widdybank Moss.

This site is the highest in altitude of all the sites selected on Widdybank Fell and also the most distant from either sugar limestone exposures or species-rich limestone grassland. Its aspect is to the north and east rather than to the west as the other sites, Red Sike, Tinkler's Sike and Slapestone Sike.

The peat profile consists of some 3 - 5 metres overlying a thin layer of greyish clay which rests on a bedrock of Limestone (Diagrams 23 and 24).

At the base of the profile Betula shows values of 20% although

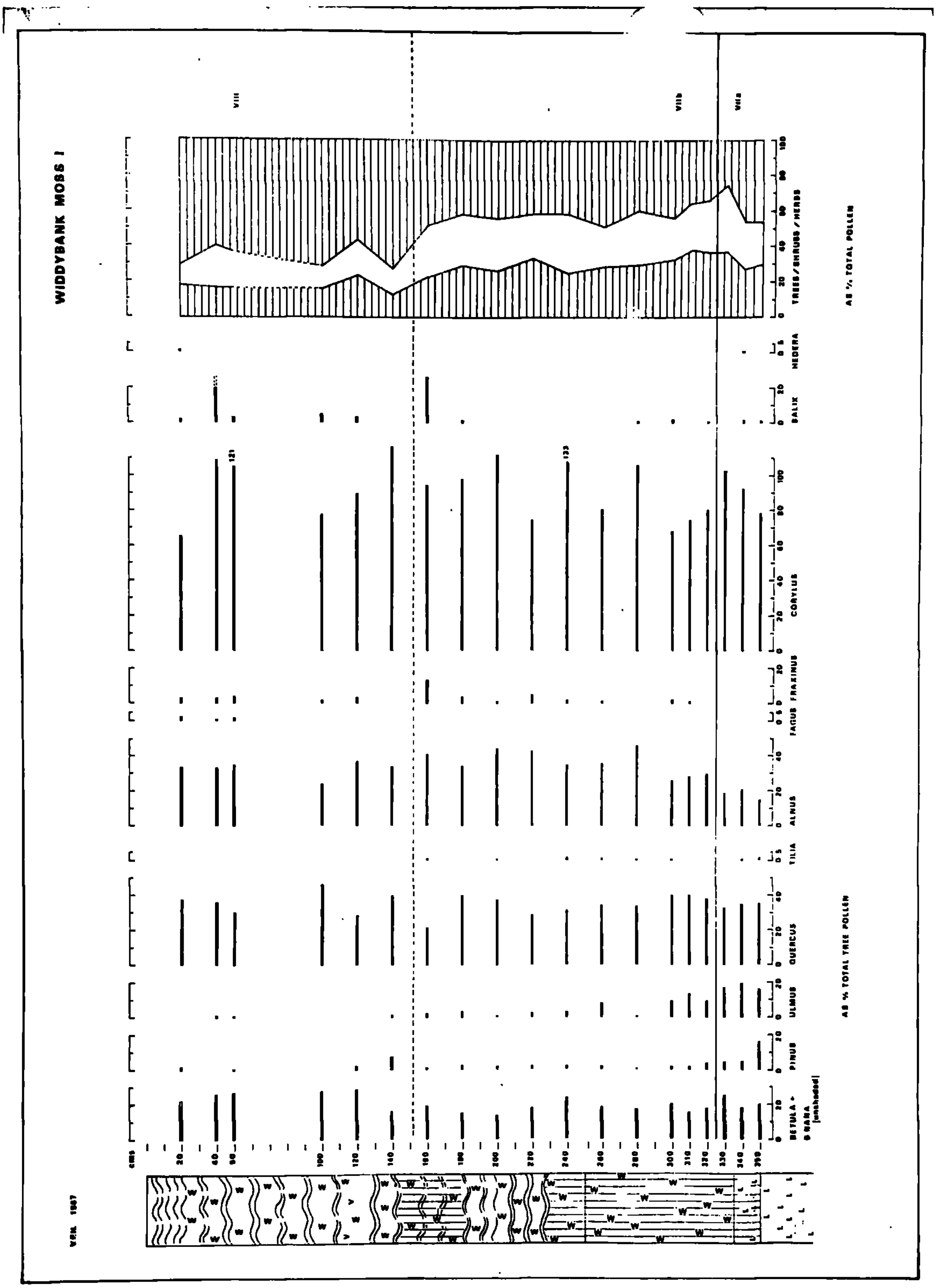
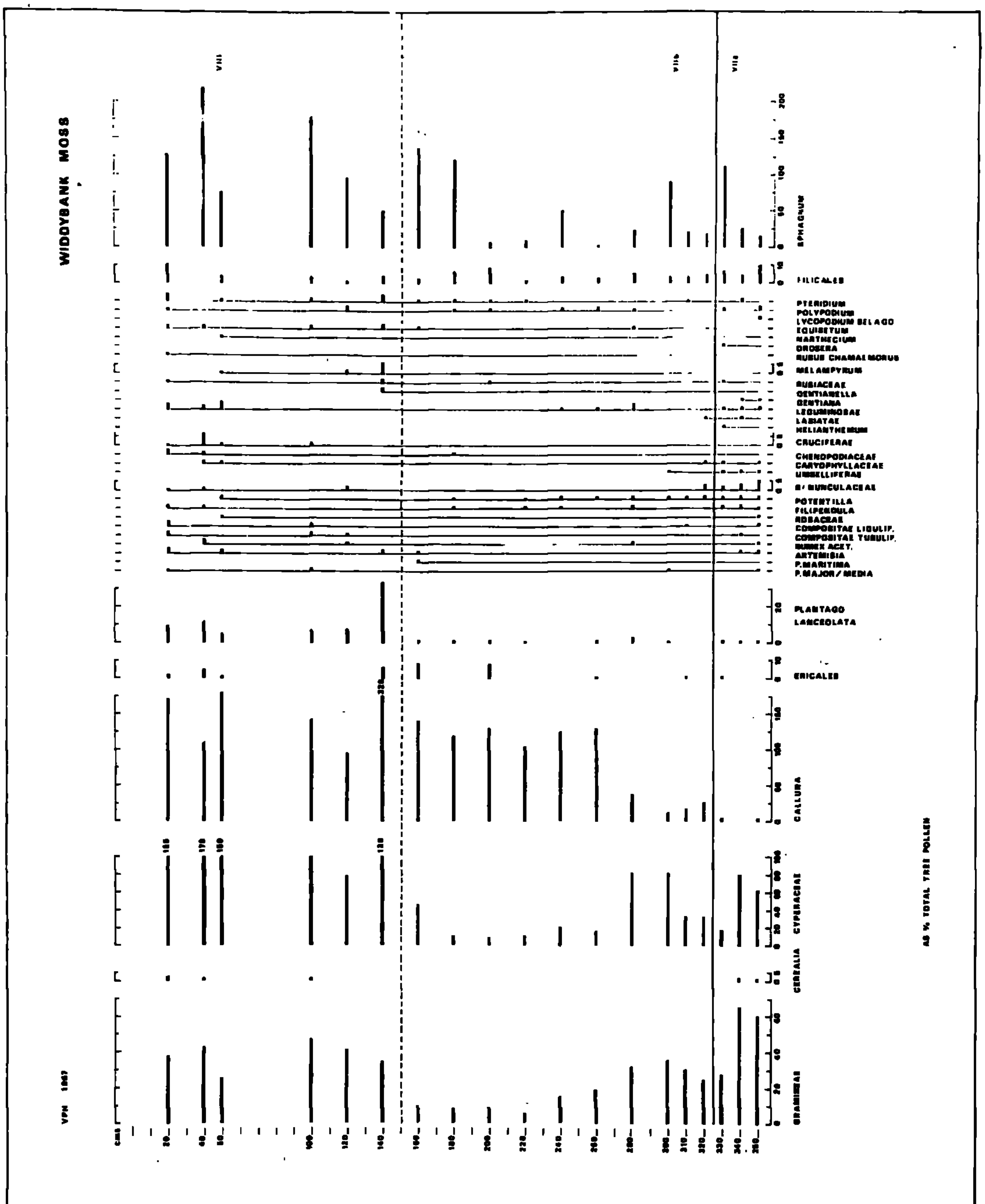

WIDDYBANK MOSS I
VIII
VIIb
VIIa
TREES / SHRUBS / HERBS
AS % TOTAL POLLEN
HEDERA
SALIX
CORYLUS
FAGUS
FRAXINUS
ALNUS
TILIA
QUERCUS
ULMUS
PINUS
BETULA + B.NANA (unshaded)
AS % TOTAL TREE POLLEN
CMS

Fig. 23.



WIDDYBANK MOSS
VPH 1967
VIII
VIIb
VIIa
SPHAGNUM
FILICALES
PTERIDIUM
POLYPODIUM
LYCOPODIUM SELAGO
EQUISETUM
NARTHECIUM
DROSERA
RUBUS CHAMAEMORUS
MELAMPYRUM
RUBIACEAE
GENTIANELLA
GENTIANA
LEGUMINOSAE
LABIATAE
HELIANTHEMUM
CRUCIFERAE
CHENOPODIACEAE
CARYOPHYLLACEAE
UMBELLIFERAE
RANUNCULACEAE
POTENTILLA
FILIPENDULA
ROSACEAE
COMPOSITAE LIGULIF.
COMPOSITAE TUBULIF.
RUMEX ACET.
ARTEMISIA
P.MARITIMA
P.MAJOR/MEDIA
PLANTAGO LANCEOLATA
ERICALES
CALLUNA
CYPERACEAE
CEREALIA
GRAMINEAE
AS % TOTAL TREE POLLEN

Fig. 24.

Pinus values are low - less than 20%. Ulmus and Quercus are both high and Alnus expanding. Tilia is also present. Corylus represents between 80 - 100% total tree pollen.

At the opening of the diagram Grass and Sedge pollen are high and there are very low values of Plantago lanceolata. Cereal type grains are present at both 350 and 340 cms. although they were too badly destroyed to identify further.

The herb flora in this diagram is rather poorer in species in zones VIIb and VIII than in other diagrams although in zone VIIa the number of species represented is comparable with other diagrams. Throughout zones VIIb and VIII the herb pollen still constitutes at least 40% of the total pollen count.

A comparison of the herb species present at Widdybank Moss during zones VIIb and VIII with those found in the same zones at RSII shows that the following were not represented in W.B.M.I during VIIb/VIII but were present at RSII:- Leguminoseae, Labiatae, Succisa, Plantago major/media, Helianthemum, Chrysosplenium, Saxifraga spp., Spergula, Linum, Lysimachia, Selaginella, Botrychium.

Peat formation must have begun during Atlantic times after pine had declined but before the decline of the elm, i.e. during zone VIIa.

Above 330 cms. Ulmus falls from ± 20% to below 10% total tree pollen. At the same level Alnus and Quercus rise although Corylus declines. Both Tilia and Fraxinus are present during this zone which corresponds with Sub-boreal time - Zone VIIb.

At this level grass pollen declines to ± 30% and then steadily falls until at 220 cms only 5% grass pollen is present. Cyperaceae pollen too, declines rapidly above 280 cms and at the same time Calluna pollen rises to very high values.

This early peak of grass and sedge pollen at the end of VIIa and beginning of VIIb correspond with similar peaks in all other diagrams from Widdybank Fell which are followed by a rise in *Calluna* pollen. It is probable that these changes in herbaceous pollen values are attributable to a local succession from a grass-sedge community to a *Sphagnum* - *Calluna* community.

At 140 cms there is a sudden rise in Gramineae, Cyperaceae, *Calluna* and *P. lanceolata* pollen together with small peaks in *Melampyrum*, *Equisetum* and *Pteridium*. Other herbaceous pollen represented during the rise in herb pollen include *Gentianella*, Rubiaceae and *Artemisia*.

Between 100-50 cms, the peat was too filled with *Eriophorum* fibres and modern roots of *Calluna* to sample satisfactorily.

Above 50 cms the herb flora increases being represented in addition to these mentioned above by *P. major/media*, Compositae, Rosaceae including *Filipendula* and *Potentilla*, Caryophyllaceae, *Chenopodium*, Crucifers and Leguminoseae.

Many of these species survive best in conditions of open vegetation. It is interesting to note that during Zone VIIa, species such as *Helianthemum*, *Gentiana*, *Lycopodium selago*, *Rumex*, *Artemisia* and *Plantago* were represented. Thus even on the top of the Fell habitats must have existed during Atlantic times which were suitable for the growth of these plants of open vegetation although the number of species present seems to have declined during the following Sub-boreal period.

It is also worth noting that *Betula nana* whilst not noted either on RSII or SII is present more or less continuously at very low values through this diagram. Thus *B. nana* seems to have survived on the top of the Fell throughout the maximum period of forestation and respread to the Tinkler's sike area during the sub-boreal or Sub-Atlantic periods.

Basal Samples I, II and III

On the west side of the Fell 3 basal samples were taken across the peat/clay boundary and analysed for pollen.

Basal Sample I. (Diagram 25).

At the base of the sample Quercus and Alnus are high, Betula and Pinus low. Fraxinus is already present and Ulmus is declining from 10% to less than 5%. Gramineae, Cyperaceae are high and P.lanceolata is present in small amounts. There is a rich herb flora including Potentilla, Ranunculaceae, Rubiaceae, Umbelliferae, Polypodium, Pteridium and other fern spores.

At 75 cms Gramineae, Cyperaceae, Calluna and Plantago lanceolata rise steeply together with many other herbaceous species including Artemisia, Rumex, Succisa and a cerealoid grain of the Avena sativa type was found.

Peat development here seems to have begum at the end of VIIb and the rise in Calluna pollen at 75 cms probably correlates with a similar rise at Tinkler's Sike, dated to 600 BC. Below the peat/clay boundary some mixing of the pollen has probably taken place but it was probably deposited during zone VIIb.

Basal Sample II (Diagram 26)

The basal two levels taken from the clay were highly polleniferous. Quercus and Alnus show high values and Tilia is present also 20% Betula but values of Ulmus and Pinus are only about 10% total tree pollen. The basal sample contains high Gramineae together with peaks of Ranunculaceae, Potentilla, Filipendula and other herbs such as Cruciferae, Melampyrum,

PLATE 4.

WIDDYBANK MOSS, TRANSECT B, LOOKING TOWARDS THE NORTH-EAST.

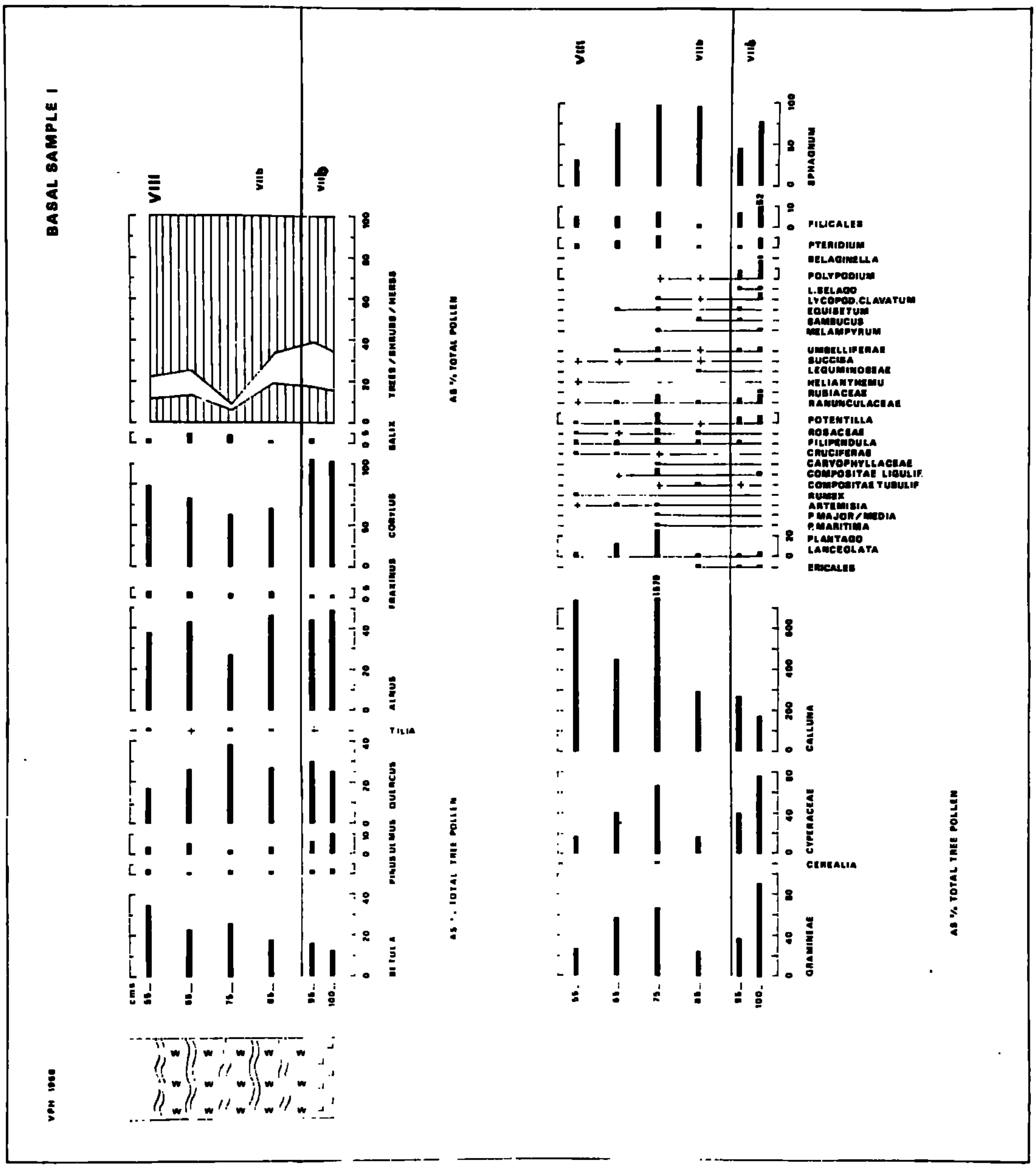
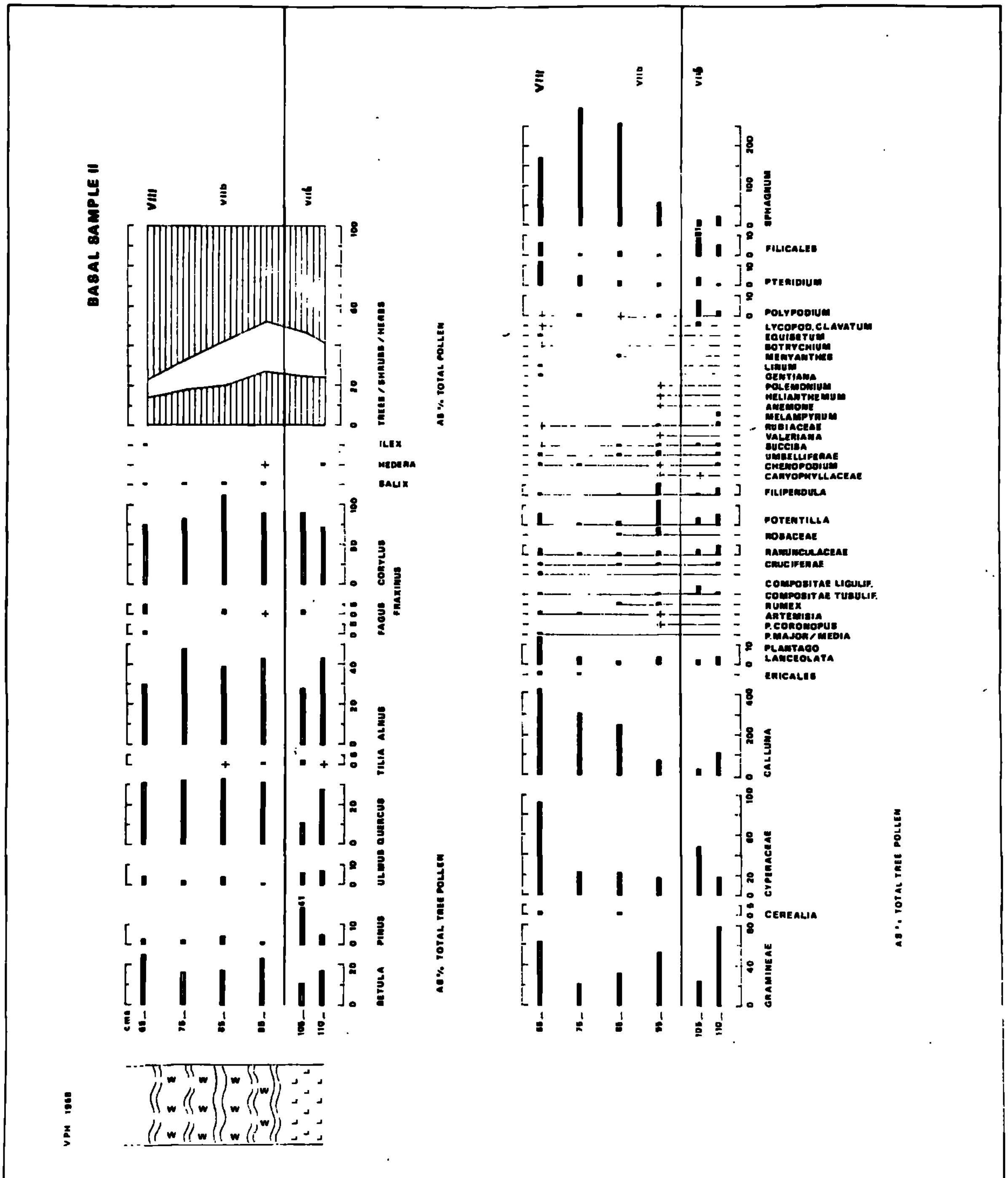

BASAL SAMPLE I
VIII
VIIb
VIIa
TREES / SHRUBS / HERBS
AS % TOTAL POLLEN
SALIX
CORYLUS
FRAXINUS
ALNUS
TILIA
QUERCUS
ULMUS
PINUS
BETULA
AS % TOTAL TREE POLLEN
SPHAGNUM
FILICALES
PTERIDIUM
SELAGINELLA
POLYPODIUM
L.SELAGO
LYCOPOD.CLAVATUM
EQUISETUM
SAMBUCUS
MELAMPYRUM
UMBELLIFERAE
SUCCISA
LEGUMINOSEAE
HELIANTHEMU
RUBIACEAE
RANUNCULACEAE
POTENTILLA
ROSACEAE
FILIPENDULA
CRUCIFERAE
CARYOPHYLLACEAE
COMPOSITAE LIGULIF.
COMPOSITAE TUBULIF.
RUMEX
ARTEMISIA
P.MAJOR/MEDIA
P.MARITIMA
PLANTAGO
LANCEOLATA
ERICALES
CALLUNA
CYPERACEAE
CEREALIA
GRAMINEAE
VPH 1980

Fig. 25.



BASAL SAMPLE II
VPH 1968
TREES / SHRUBS / HERBS
AS % TOTAL POLLEN
ILEX
HEDERA
SALIX
CORYLUS
FRAXINUS
FAGUS
TILIA
ALNUS
ULMUS
QUERCUS
PINUS
BETULA
AS % TOTAL TREE POLLEN
SPHAGNUM
FILICALES
PTERIDIUM
POLYPODIUM
LYCOPOD. CLAVATUM
EQUISETUM
BOTRYCHIUM
MENYANTHES
LINUM
GENTIANA
POLEMONIUM
HELIANTHEMUM
ANEMONE
MELAMPYRUM
RUBIACEAE
VALERIANA
SUCCISA
UMBELLIFERAE
CHENOPODIUM
CARYOPHYLLACEAE
FILIPENDULA
POTENTILLA
ROSACEAE
RANUNCULACEAE
CRUCIFERAE
COMPOSITAE LIGULIF.
COMPOSITAE TUBULIF.
RUMEX
ARTEMISIA
P. CORONOPUS
P. MAJOR / MEDIA
PLANTAGO LANCEOLATA
ERICALES
CALLUNA
CYPERACEAE
CEREALIA
GRAMINEAE
AS % TOTAL TREE POLLEN

Fig. 26.

Succisa, Rubiaceae. At 105 cms Gramineae pollen declines and Cyperaceae rises temporarily together with Polypodium, Pteridium and other fern pollen.

The basal peat level shows a decline in Pinus and Ulmus values together with a rise in Quercus and Alnus and an increase in the number of herbaceous species represented including, besides high values of Potentilla and Filipendula, Artemisia, Rumex, Plantago spp. Caryophyllaceae, Umbelliferae, Succisa, Valeriana, Anemone, Helianthemum and Polemomium. At 65 cms Gramineae, Cyperaceae, Calluna and P. lanceolata rise suddenly and again there is a rise in many herbaceous pollen types including Gentiana and Linum. Cerealoid grains were found at 65 cms of the Triticum monococcum type. A cerealoid grain found at 85 cms after detailed examination could not be classed as any Cereal type.

In this sample it is clear that peat formation did not begin until after the Elm decline during Zone VIIb. The pollen record from the underlying clay may have been of the late Atlantic period or it may have been early Sub-Boreal in time. It is probable that the pollen from these clay samples has been mixed and is therefore not giving a clear picture. The peak of Grasses and other herbs, especially P. lanceolata, at 65 cms correlates with similar peaks in other diagrams from the Fell which has been taken as a possible boundary between VIIb and VIII.

The high grasses at the beginning of the diagrams may correspond with the peaks in all other diagrams around the beginning of VIIb.

Basal Sample III (Diagram 27)

This sample consists of an entire profile of thin blanket peat 55 cms deep and underlying boulder clay.

At the base both Betula and Pinus show high values although Ulmus,

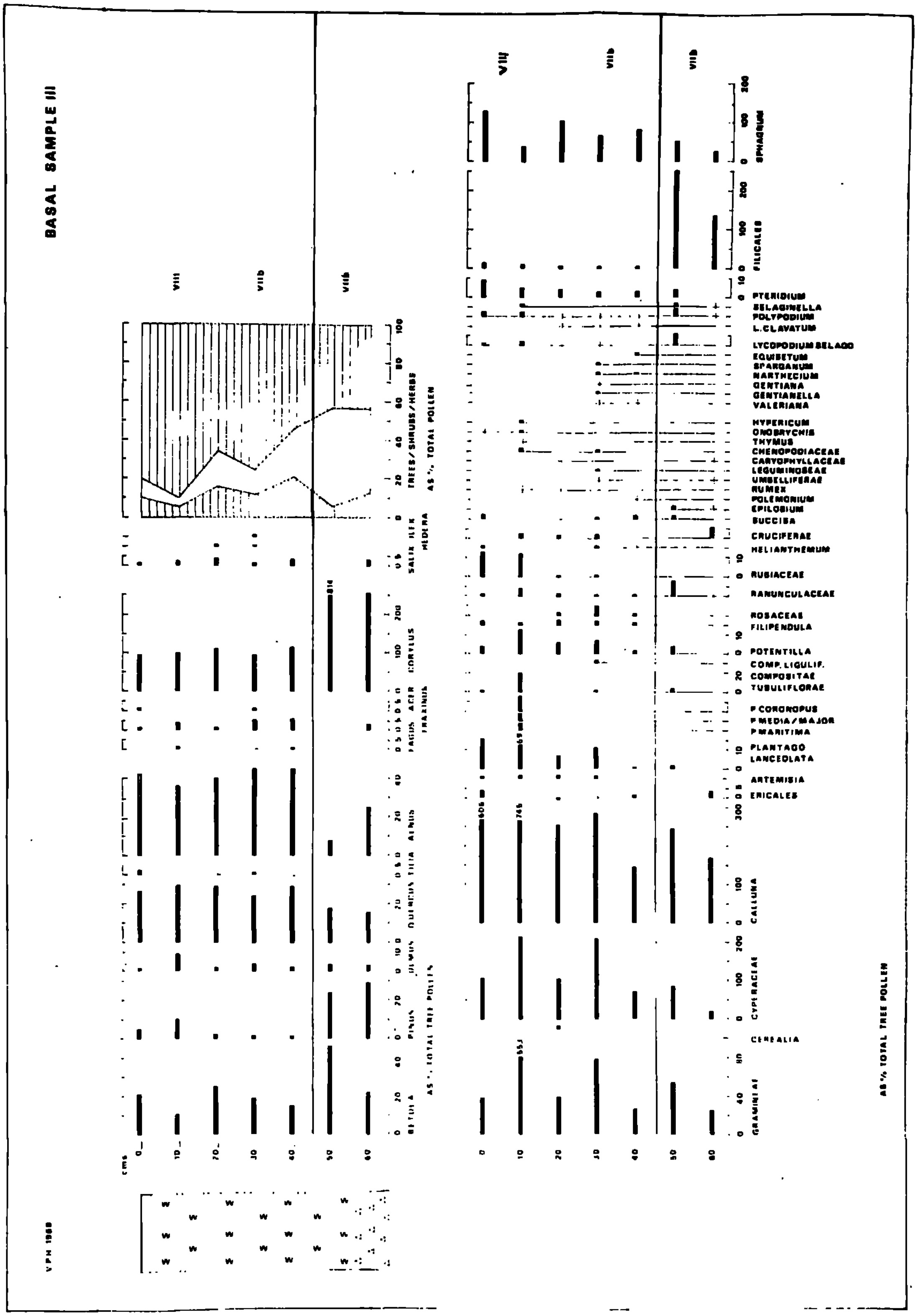

BASAL SAMPLE III
VIII
VIIb
VIIa
TREES / SHRUBS / HERBS
AS % TOTAL POLLEN
SALIX
HEDERA
CORYLUS
FAGUS
ACER
FRAXINUS
QUERCUS
TILIA
ALNUS
ULMUS
PINUS
BETULA
AS % TOTAL TREE POLLEN
SPHAGNUM
FILICALES
PTERIDIUM
SELAGINELLA
POLYPODIUM
L. CLAVATUM
LYCOPODIUM SELAGO
EQUISETUM
SPARGANIUM
NARTHECIUM
GENTIANA
GENTIANELLA
VALERIANA
HYPERICUM
ONOBRYCHIS
THYMUS
CHENOPODIACEAE
CARYOPHYLLACEAE
LEGUMINOSEAE
UMBELLIFERAE
RUMEX
POLEMONIUM
EPILOBIUM
SUCCISA
CRUCIFERAE
HELIANTHEMUM
RUBIACEAE
RANUNCULACEAE
ROSACEAE
FILIPENDULA
POTENTILLA
COMP. LIGULIF.
COMPOSITAE
TUBULIFLORAE
P. CORONOPUS
P. MEDIA / MAJOR
P. MARITIMA
PLANTAGO
LANCEOLATA
ARTEMISIA
ERICALES
CALLUNA
CYPERACEAE
CEREALIA
GRAMINEAE
AS % TOTAL TREE POLLEN
cms
VPH 1969

Fig. 27.

Quercus, and Alnus show rather low values. Calluna pollen and Filicales ferns show extremely high values although Gramineae and Cyperaceae are low.

This sequence does not correlate with any in other diagrams from the Fell. It seems probable that the pollen contained in the peat / clay boundary is disturbed and mixed so that perhaps pollen from more than one period is represented.

Above 50 cms Quercus and Alnus show high values and Fagus, Fraxinus and Acer are also present. Pinus and Ulmus are both very low. At 30 cms Gramineae, Cyperaceae and Calluna together with P.lanceolata and many other herbaceous species rise steeply. This corresponds with the rise in NAP taken as indicating the onset of Zone VIII.

Thus it seems that here as in all other sites blanket peat development began during Zone VIIb - Sub-boreal time. This is rather different from the Southern Pennines and Moorhouse Nature Reserve where blanket peat development began with the onset of Atlantic conditions.

At the same time the spread of blanket peat species seems to correspond with a general increase in herbaceous species, including grassland types e.g. Helianthemum, Succisa, Polemonium, Thymus Onobrychis, and other species of open or disturbed vegetation including Plantago spp, Epilobium, Artemisia, Rumex. There must therefore have been an increase in available habitats for the species during the Sub-Boreal and Sub-Atlantic periods although some habitats of this type must have existed throughout the post-glacial period as herbaceous pollen always equals or exceeds the total pollen count.

CHAPTER 5.

Discussion of the pollen analytical data for Widdybank Fell.

There is no fossil evidence for the vegetational history of the Fell before the very end of the Late-glacial period. During the Late-glacial period, conditions must have been extremely severe. What pollen there is in the clays below the peat deposits is too destroyed for identification. Some of these clays are boulder clays and others solifluxion deposits which contain no pollen.

At the end of the Late-glacial and during the pre-boreal period, the vegetation was essentially herbaceous with a thin cover of juniper, willows, and tree birches. *Pinus* was rapidly becoming established in the area and must have spread quickly into habitats which were less suitable for birch colonization.

At the beginning of the Boreal when the peat was beginning to develop in the waterlogged hollows on and around Widdybank Fell, hazel had already spread into the area and was expanding rapidly. Pine and hazel were also expanding at much the same time and they were followed rather later by *Ulmus* and *Quercus* in that order.

Throughout the Boreal period, the vegetation on the Fell was predominantly open with herbaceous species contributing up to 50% of the total pollen rain. Pine was the chief pollen contributor, although during the early part of the Boreal period, hazel was clearly very important. The vegetation must, therefore, have been one of open woodland rather than one of rapidly closing forest by which the Boreal is characterised in the lowlands. "Open" here does not necessarily imply a parkland type of vegetation where tree species provide a regular but sparse cover, but rather suggests an irregular pattern of tree growth which may have been rather more closed on some habitats than others, and totally absent from some of the habitats existing on the fell at that time. This tree cover cannot ever have been sufficiently dense to preclude the growth of a rich ground flora and must have been either absent or very sparse in other parts to allow the growth of such shade-intolerant species as Helianthemum.

The structure of these Boreal woodlands on Widdybank Fell seems to have depended very largely on edaphic factors. Although from pollen counts, Pinus was clearly the dominant tree species, it is Betula wood which is found abundantly as a layer in the boreal peats in the upper Tees Valley immediately to the west of Widdybank Fell, and also as fragments in the peat at Red Sike and Slapestone Sike on the Fell itself.

The curves for pine and to a lesser extent those for birch vary somewhat over a very small distance. On Widdybank Fell at RSI and TSI the values for tree birches throughout the Boreal period are consistently low constituting only 10-15% total tree pollen. At RSII birch shows values of up to 40% at the opening of zone VI but these decline rapidly to between 10-15% for the remainder of the Boreal period. At Foolmire Sike (Hibbert, unpublished), however, values of 30-50% were recorded during the Boreal period and at Dead Crook less than a mile to the west values of 20% are recorded.

The variation in pine percentages during the Boreal period are even more pronounced. They are represented in Table I.

TABLE I.

Variation in pine % during the Boreal period.

Site	Mean % pine pollen in zone VI	
Dead Crook	69.36% ± 11.28	Turner and Lowry
Weelfoot Moss	77.67% ± 9.93	
Foolmire Sike	41.26% ± 9.8	Hibbert.
Red Sike II	50.28% ± 6.8	
Red Sike I	57.1 % ± 15.7	
Tinkler's Sike I	70.3 % ± 4.6	

The pine values for RSI, RSII and TSI throughout the Boreal period were tested statistically (Appendix IV) and the difference between them found to be significant i.e. the chance of this difference being due to sampling error was less than one in a hundred. The original figures for Dead Crook, Foolmire Sike and Weelfoot Sike, from which the pine percentages were derived were not available for statistical analysis as the statistical tests were based on the original pollen counts rather than percentages. Thus, it was not possible to discover whether or not the differences between these figures was significant. However, as the difference in pine between RSI, RSII and TSI was shown to be statistically significant, it seems possible that the difference in the pine values between Dead Crook and Weelfoot Moss and Foolmire Sike might also be significant and that between Dead Crook and Tinkler's Sike probably not significant i.e. probably due to sampling error.

No clear pattern for the distribution of pine and birch on Widdybank Fell and the adjacent valley during zone VI emerges from this data.

The mean pine values are clearly lowest at Foolmire Sike in the valley basin but the sites which show high pine i.e. Dead Crook, Weelfoot Moss and Tinkler's Sike apparently have few features in common. Dead Crook and Weelfoot Moss are low lying areas of reed-swamp and rough grassland with considerable deposition of peat on the morainic material adjacent to them. Tinkler's Sike, on the other hand, is an area of blanket peat overlying sedge peat some 250-300m from the sugar limestone outcrop at Red Sike and some 100' higher than Dead Crook.

It seems probable, therefore, that birch was the commonest tree on the wetter, lower-lying land around the river and waterlogged hollows on the fell itself, thus giving high values at Foolmire Sike and Dead Crook and pine was the dominant tree on the drier, better-drained areas on the slopes of the Fell.

Pine pollen is known to travel much further than that of many other tree species and therefore long distance pine may contribute a large part of the tree pollen total when there are few trees growing locally. Therefore whilst pine was clearly present on the fell, it is probable that it's pollen counts are over-represented.

During the Boreal period, Ulmus and Quercus began to spread up the Tees valley from the lowlands to the east and very low percentages of both oak and elm are consistently present at Widdybank Fell from the beginning of zone VI. There is, however, some variation in the percentages for these species during the Boreal period over the Widdybank area. At Tinkler's Sike both Ulmus and Quercus never contribute more than 10% each to the tree pollen rain during zone VI. At Red Sike II, however, less than 300 metres to the west, both Ulmus and Quercus are contributing 20% each to the total tree pollen count by the mid-boreal period and at Foolmire Sike the Quercus and Ulmus curves rise rather earlier than at Tinkler's Sike, showing values of 10-20% before the major decline of hazel in mid- boreal times. At Dead Crook, however, Quercus and Ulmus contribute only very low percentages - between 5-10% throughout the Boreal.

Here again, it seems likely that, whilst oak and elm spread into the Upper Tees valley early in Boreal time, they did not expand uniformly through the existing woodlands. They must have spread first into the damp, though not water-logged birch woodlands in the valley before spreading into similar habitats on the fell from the west. Dead Crook, which was a low-lying area of reedswamp supporting some birch around the margins, may have been too water-logged for elm and oak to colonize.

The pollen curves suggest that at Red Sike where Quercus and Ulmus expanded during the mid-boreal period, they were replacing Pinus rather than Betula. Oak and elm must, therefore, have begun to spread on to the drier slopes of the fell before the end of the Boreal period. At Tinkler's Sike, however, pine frequencies remain high and those of oak and elm low, suggesting that on higher ground, edaphic factors did not favour the replacement of pine by oak and elm until the onset of the Atlantic period.

It seems, therefore that the difference in the values of pine, birch, oak and elm results from the vastly varying topography of the area and hence the large variation in ecological conditions. Whilst there is little evidence to suggest that ecological conditions at one site were more favourable than those at another for the growth of a particular tree species, it is clear that differences in topography and edaphic conditions must have played an important part during both the Boreal and Atlantic periods. The overall pattern of vegetational during the Boreal period at Widdybank Fell fits in with the general pattern for northern England, associated with the climatic amelioration. Therefore, it seems probable that the differences in the values for these species are of an essentially local nature.

Over the whole country the wetter Atlantic climate which followed the drier Boreal period brought about an important change in forest composition at about 5000 BC (Godwin 1960). During this period, thermophilous tree species such as oak, elm and lime expanded considerably and Alnus glutinosa began to spread into damper habitats.

On Widdybank Fell, Alnus which had been present during the latter part of the Boreal period expanded rapidly to values often exceeding 30% total tree pollen. At the same time oak also expanded to values up to 40% total tree pollen. This rise in oak seems to have been largely at the expense of pine which decreases steadily through this Atlantic period. Percentages for Alnus vary very little from one site to another on the fell and it seems probable that with the onset of wetter conditions, Alnus expanded into the wetter habitats, forming a birch-alder association rather than replacing birch in these habitats.

It is possible that the wetter climate also led to a change in edaphic factors on the better-drained fell slopes which allowed oak to become more widespread and pine to decline. It is important to note that even during this period most favourable to tree growth that herbaceous species represent 30-40% of the total pollen count.

During the Atlantic period, therefore, the structure of the woodlands changed from predominantly pine to oak associated with alder and elm. Lime is extremely low in all diagrams from this area so possibly it did not spread into the upper reaches of the valley although it may have been more common in the more extensive forests of the valley basin.

Despite the generally wetter conditions of the Atlantic period, the stratigraphic and pollen analytical evidence, particularly from TSI, suggest a very slow rate of peat growth. Certainly the major development of blanket peat over the fell did not commence until much later, at the end of the Atlantic or beginning of the Sub-boreal period. Therefore, although there must have been some considerable change in climatic conditions at the Boreal/Atlantic Transition when alder, oak and elm became the dominant tree species not only at Widdybank Fell but throughout the country, there is no corresponding increase in peat growth during this period.

Towards the end of the Atlantic period there is a sudden expansion of some herbaceous species, particularly grasses and heather. About this time too, peat began to develop in other parts of the fell wherever there were hollows in the topography. Total tree pollen percentages are affected to a small extent by these changes which suggests that there must have been at least some opening out of the vegetation. It is interesting to note that a number of Mesolithic microliths have been found on the Tees and Weardale Fells providing evidence that Mesolithic man was active in the area at this time. It is possible that the increases in grass pollen at the end of the Atlantic period may have been associated with a thinning of the trees by man which led to the development of open grassland or heath communities as the climate deteriorated and became less favourable for the growth of such trees as oak and elm although there is another possible explanation (see p69.).

The date of 4,200 BC $\pm$ 160 (GaK 2029) for the Boreal/Atlantic Transition, which was obtained from Tinkler's Sike is a good deal later than those of 5000 BC which are usually obtained (Godwin 1960). This indicates that the spread of oak and alder may have been rather later here than elsewhere, although further dates from the area are needed to clarify this. There is no stratigraphic evidence from TSI to suggest a gap in peat development at this level and therefore no reason why the date should not be accepted at its face value. It is interesting to note that Oldfield (1965) when discussing the pine maximum in Lonsdale suggests that the pine decline and consequently the main alder expansion may not have taken place until 700-1500 years later than in southern and eastern England.

At the end of the Atlantic period, Ulmus pollen declines sharply. This elm decline is consistent throughout the British Isles and marks the beginning of the Neolithic period. At the same time there was a considerable change in conditions which led to the widespread development of blanket peat over Widdybank Fell.

At this time both pine and elm pollen are present in very small quantities although the total tree pollen count does not decline appreciably.

The main evidence for change at this time lies in the marked change in peat stratigraphy. At Red Sike and Tinkler's Sike the peat changes suddenly from a sedge peat to the Sphagnum - Eriophorum - Calluna peat characteristic of blanket bog. At Widdybank Moss the peat which began to develop at the very end of the Atlantic time is of this blanket bog type and at Slapestone Sike peat which had only formed in the waterlogged area around the sike during Boreal and Atlantic times, began to spread over the whole basin after the decline of elm. On the steeper slopes of the Fell too, a thin covering of blanket peat began to develop at some time following the elm decline but before the major rise in herbaceous pollen dated at Tinkler's Sike to 620 BC ± 80 (GaK 2027).

A radio-carbon date obtained from the first sample following the elm decline gives a date of 1440 BC ± 90 (GaK 2028).

This date is extremely late for the elm decline which took place generally about 3000 BC (Godwin 1960). Without further radio-carbon evidence to support this date, the possibility of contamination by modern rootlets cannot be ruled out although this was not apparent in the samples dated. However, if the date should prove to be correct, it requires some explanation: The radio-carbon date is for the first sample with low elm values. This does not necessarily mean that the sample of peat immediately below this i.e. that with high elm values, would have given a similar date. It is possible that there was a gap in peat formation. There is some evidence to suggest that peat development during the Atlantic was either very slow or had halted completely. This is suggested by the very narrow band of peat at RSII which represents the whole of the Atlantic period. It is quite possible, therefore, that peat growth stopped or slowed down sometime during zone VIIa and did not begin again until the middle of zone VIIb i.e. at 1440 BC ± 90.

If during this period some erosion of the peat surface had taken place, the pollen representing the latter part of zone VIIa and the beginning/middle of VIIb may have become mixed or disturbed. The rise in grass pollen just before the apparent elm decline may thus represent Neolithic rather than Mesolithic activity, as was suggested as a possible explanation on p.68.

This period between the decline of the elm and the major change marked by a general rise in herb pollen and decrease in tree pollen on the Fell, must have been one of slow but continual change during which the woodland diminished and gave way to open areas of blanket peat wherever the ground was too waterlogged or the soil too poor to support true grassland. There seems to have been little increase in true grassland species at this time, so it is possible that wherever the trees were thinned either by the activities of man or by less favourable climatic conditions, leaching and podsolization took place encouraging the growth of blanket peat. There is little evidence from Widdybank Fell to suggest how active Neolithic man was in the area during this period. There may have been some tree felling and it is probable that this open woodland with a rich ground flora was already suitable for grazing.

The development and extension of blanket peat over the Fell was well advanced before the last important change in the diagrams for Widdybank Fell took place. In all the diagrams for the Fell, there is a massive increase in all herbaceous pollen species, which was dated at Tinkler's Sike to 620 BC ± 80 years, corresponding with other dates for the Iron age (Godwin 1960). At this stage, total tree pollen counts decline to values of less than 20%. Plantago lanceolata contributes more than 20% total tree pollen and other ruderals such as Rumex and Artemisia are also present in increasing numbers. Over the fell there must have been a widespread decrease in all tree species and the presence of these species of disturbed ground suggests that clearance of the trees by man was occurring.

At the same time there is an increase of species associated with true grassland e.g. Thymus, Gentiana, Gentianella, Helianthemum, Potentilla, Polemonium as well as an expansion of grass species, and species associated with heathland or blanket bog also increased. The onset of the Sub-Atlantic climatic deterioration would encourage the growth of blanket peat species on leached acidic soils and this more severe climate may have been one of the factors which prevented the regeneration of trees.

At Slapestone Sike, numerous burnt fragments of Calluna wood were found within the blanket peat.

Extensive erosion of the blanket peat has taken place and the more exposed areas of the Fell are deeply dissected by erosion channels draining into moorland streams. Exactly when this erosion began was not determined at Widdybank Fell, although Johnson and Dunham (1961) correlated it with the climatic deterioration at the beginning of the Sub-atlantic period at Moorhouse.

There are several sites in the lower and mid Tees valley and also on the northern pennine ridge itself, from which pollen diagrams have been obtained and the evidence from these helps to place the data from Widdybank Fell in context.

In the lowlands of County Durham at Neasham (Blackburn, 1952), Burtree Lane (Bellamy et al, 1966) and Cranberry Moss (Turner and Kershaw, in press) and also in the mid Tees valley at Romaldkirk (Bellamy et al,1966) the Late-glacial and early Post-glacial periods were characterised by a predominantly open, herbaceous vegetation with birch as the dominant tree species. Pine seems to have been present throughout the lowlands in small quantities during the late-glacial and to have spread at the end of this period and during the early boreal, to become the dominant tree species contributing up to 50% total tree pollen, until mid-boreal times when mixed oak forest trees and alder began to spread through the area. At Cranberry Moss in the lower Wear valley, pine never became the dominant species although together with hazel, it spread through the open birch woodland at the end of the Late-glacial period.

Thus in the lowlands, pine was an important species in the early and mid-boreal woodlands although it did not ever become as important as in the highlands.

On the northern pennine ridge at Moorhouse, peat deposition did not begin until the end of zone V. The climate here at altitudes between 1800' and 2500' OD must have been much more severe during the Late and early Post-glacial periods than in the lowlands and there is evidence for cryoturbation and solifluxion at Moorhouse during these periods (Johnson and Dunham, 1963). As in the lowlands birch and pine were already established before the major expansion of hazel at the beginning of zone VI. Pine values at Moorhouse seem to have been rather variable: at Knock Fell pine rises early and maintains values of 70-80% total tree pollen throughout the boreal period, whilst at Hard Hill and Valley Bog pine did not expand until mid-boreal time and never shows the exceedingly high values of Knock Fell. Johnson (1961) suggests that as tree pollen at this site was very sparse and pollen counts low, much of the pine pollen may have been oflong-distance rather than local origin.

If this data then, is compared with that from Widdybank Fell, the most striking variation is the rather higher pine values throughout the Boreal at Widdybank Fell. Similar results have been obtained from Dufton Moss on the valley floor below Cronkley Fell, although on Cronkley Fell itself at 1750' OD, pine does not expand until the mid-boreal period as at Valley Bog at 1800' OD. It seems, therefore, that pine was present in the lowlands well before the major rise in hazel, and spread rapidly up the valley on to the uplands where it became an important tree species, on the lower fells, although above 1700' OD birch rather than pine was the dominant tree species.

Oak and elm spread up the valley during the mid-boreal period, although a slight variation in percentages for these species at both Widdybank Fell and Moorhouse suggest that their spread was limited, particularly in the uplands and must have depended considerably on edaphic factors.

At the beginning of the Atlantic period, oak and alder together with elm began to expand at the expense of pine and birch. These changes were taking place both in the lowlands and in the uplands of the Tees valley, although in the lowlands extensive tracts of closed forest must have existed, whereas on Widdybank Fell and probably also at Moorhouse, the vegetation throughout the climatic optimum remained one of open woodlands with a rich ground flora. At Moorhouse the onset of this wetter climate resulted in the widespread development of blanket peat and similar changes were also taking place at altitudes greater than 1200' OD in the southern Pennines (Conway, 1954). At Widdybank Fell, however, blanket peat did not begin to develop until the end of the Atlantic period when there is some evidence of human activity in the area. On these lower fells, then, the increased rainfall did not apparently increase leaching and podsolization or give rise to waterlogged areas which led to the development of blanket peat on the higher fells.

Diagrams from lowland sites indicate the increasing effect of human settlement after the elm decline at about 3000BC . At Cranberry Moss, there is evidence for two clearance phases and on the fells too, man was becoming increasingly active. Cereal grains of Avena, Triticum and Secale types have been recorded from Widdybank Fell, at a time when the tree species were rapidly declining and both grassland and blanket peat communities increasing. This was dated at Tinkler's Sike to 620 ± 80 BC. This increase in herbaceous species was also recorded at Moorhouse. The rise in grass pollen is not so marked here as at Widdybank and is indicated chiefly by the rise in Plantago lanceolata, Rumex and Artemisia and the very high values of ericaceous pollen. The more exposed position and lack of base-rich sugar limestone and limestone at Moorhouse would have encouraged the development of heathland rather than true grassland.

The pattern of vegetational change through the Post-glacial period at Widdybank Fell, therefore, corresponds with the pattern of change for the Tees valley as a whole, and with that generally accepted for northern England. There are, however, one or two notable differences.

At Tinkler's Sike pine rises early in zone IV and maintains high values throughout the succeeding Boreal period suffering a partial decline at the onset of the Atlantic period and disappearing almost completely at the beginning of zone VIIb. Oldfield (1965) refers to differences in the increase of pine and its decline during the Post-glacial period in Lonsdale from diagrams from southern and eastern England. In this lowland area to the south-east of the Lake District, the increase in pine comes after the expansion of oak, elm and hazel whereas in southern diagrams pine rises early before the expansion of oak and elm and usually at the expense of birch. Pine does not begin to decline until the Boreal/Atlantic transition in Lonsdale which is considerably later than its decline in the south and east. Oldfield, therefore, suggests that the pine maximum in Lonsdale was entirely later than in south-eastern areas. Corresponding with this late pine maximum is the delayed rise in alder which, although present during zone VI, does not expand until pine declines at the beginning of zone VIIa.

Whilst the rise of Pine during the early part of Zone IV seems to fit in with the general pattern for southern and eastern England the later pine maximum and decline correlates more closely with the pattern in Lonsdale. It seems unlikely that pine succeeded such species as oak and elm on Widdybank Fell as Oldfield suggests may have happened in Lonsdale but his idea of a "late 'moist' pine maximum" and the implied edaphic changes seems to correspond with data from Tinkler's Sike.

The other important difference from the general pattern of post-glacial history is the apparently slow development of peat during the Atlantic period and the resumption of peat growth and beginning of Blanket peat development during Zone VIIb.

Much work has been carried out by Conway (1954) and Tallis (1964, 1965) on the development of peat on the Southern Pennines. Tallis concluded that the onset of peat formation in the Southern Pennines did not take place uniformly at one particular date but rather it depended upon local topography and altitude. Thus he states that peat development began first on plateaux at high altitudes around the beginning of Zone VIIa and only later did it begin to form at lower altitudes and the valleys. In exposed areas at lower altitudes peat did not begin to form until sometime during Zone VIIb.

Earlier, Conway had described the development on the high Pennine peaks and shown that at high altitudes this peat growth began at the Boreal/Atlantic transition. However, she pointed out that on the lower slopes peat development was much slower than at high altitudes largely because of the greater rainfall at high altitudes. She also suggests that in this area the climatic change which accompanied the Elm decline at the Atlantic/Sub-Boreal Transition was not a change to drier conditions but rather to a wetter, colder climate which is shown by the increased growth of peat at all altitudes and a rise in alder values. She further suggested that the relatively small amount of peat growth which represents zone VIIa in many of the southern Pennine diagrams may have been caused by variations in the generally accepted Atlantic climate of this period.

Thus the slow rate of peat development during VIIa and the resumption of peat growth during VIIb on Widdybank Fell tie in with the picture which emerges from the southern Pennines i.e. that the onset of peat development began at the beginning of zone VIIa at high altitudes e.g. Moorhouse and the high peaks of the southern Pennines but did not begin until much later at lower altitudes and on exposed fells e.g. Widdybank.

CHAPTER 6.

Discussion of the vegetational history of Widdybank Fell in relation to the present day flora.

From the beginning of this work, it was hoped that the pollen analytical and stratigraphic data from Widdybank Fell might be of value in elucidating the origins of the "Teesdale flora". Pigott (see Chapter 1) envisaged the present day flora as a relict of the Late-glacial period which survived the Post-glacial forest maximum on the upland fells under an open canopy of woodland. Clearly, as Pigott (1956) pointed out, evidence for open conditions and the presence of relict species or species which are ecologically associated with them, during the Post-glacial period on areas such as Widdybank would be of great value.

From the pollen analytical data itself and from the discussion in the previous chapter, it is clear that one of the most important features in all the diagrams from the fell, is the consistently high non-tree pollen values. Non-tree pollen equals or exceeds tree pollen throughout all the diagrams and the values for herbaceous species alone rarely fall below 30% total tree pollen. Therefore, whilst tree species, namely pine and birch and later oak, elm and alder grew on the fell, the vegetation was always one of open woodland with a rich herbaceous ground flora. During the period of maximum tree cover on the fell, many of the relict species must have been rather more restricted than during Late-glacial times i.e. the Habitats available for their survival must have been confined to outcrops of sugar limestone, gravel flushes and the ground flora of open woodland. Herbaceous species intolerant of shade or close competition e.g.

Helianthemum are recorded throughout the forest maximum on the fell, and Betula nana, a plant of the arctic-alpine group of upland moors and wet, montane grasslands and scrub has been recorded from the Late-glacial and early Post-glacial at TSI and from zones VII and VIII at WBMI. Thus the evidence from Widdybank Fell suggests that there were indeed habitats available for the survival of relict species through the Post-glacial forest maximum.

Although the pollen grains of a large number of the species which comprise the present day relict flora are not identifiable to specific level, there are a number which are and several of these have been recorded from Widdybank Fell during the period when there must have been maximum tree cover on the fell. Types such as Gentiana, Gentianella, Thymus, Minuartia Succisa, Knautia, Viola, Linum, Helianthemum, Saxifraga stellaris are all characteristic or common members of species-rich limestone grassland or flush communities at the present day (see Appendix I). Much of the herbaceous pollen belongs to the grass and sedge groups, which have not been identified below family level. Their presence does, however, serve as an indication of the type of communities which may have been present during the forest maximum.

There is evidence from all the diagrams for an increase in grassland habitats at about 620 BC - the transition from zone VIIb to zone VIII. Amongst the species which are recorded are many which are characteristic of the present day species-rich grassland and flush communities. Another, Polemonium caerulium has been recorded in the area in recent times but is now apparently extinct in the area. Bell (1843) records this species growing on limestone rock in a "wild and elevated position" some five miles north west of Cauldron Snout. Other species which are characteristic of this expansion of herbaceous pollen are species of open habitats usually associated with human activity, e.g. <u>Plantago lanceolata</u>, <u>Rumex</u> and <u>Artemisia</u>.

This rise in herbaceous pollen at the beginning of zone VIII and the development of blanket peat communities during zones VIIb and VIII has already been discussed in Chapter 5. These two important events - the spread of balnket peat and the extension of open grasslands was not simply a function of deteriorating climate but was associated with increased human activity, which probably took the form of grazing on the fells and more intensive land use in the valley to the east.

Bellamy et al (1969) in a phytosociological study of the plant communities on Widdybank Fell have shown that plants such as <u>Plantago maritima</u>, <u>Minuartia verna</u>, and <u>Equisetum variegatum</u> are part of an unstable boundary between <u>Sesleria</u> and <u>Tofieldia</u> - dominated grassland communities. They point out that unstable boundary communities such as these are often found where there has been human interference, and suggest that some of these present day phytosociological units in Teesdale may have been produced by recent land use.

Thus the evidence from the pollen diagrams shows that habitats were available for the survival of the relict species through the Post-glacial forest maximum and some of these species have been recorded from the fell, and suggests that the expansion of the grassland communities has only taken place as a consequence of human interference and climatic deterioration since 620 BC.

Summary of Conclusions.

1. Peat formation began locally in wet hollows at the end of zone III when the vegetation was predominantly herbaceous with juiper, willow and pine. Peat development continued throughout zone VI when pine and to a lesser extent birch were the dominant tree species in an open woodland vegetation with a rich ground flora.

2. Oak, alder and elm spread locally on to the fell during zone VI and expanded rapidly during zone VIIa forming an open woodland with a rich herb flora.

3. Active blanket peat development began during zone VIIb, encroaching rapidly down the fell slopes.

4. Towards the end of zone VIIb, extensive tracts of open grassland were created largely as a result of human activity and failure of tree regeneration.

5. There must have existed, throughout the Post-glacial period, habitats favourable for the survival of Late-glacial relict species and these habitats have become more numerous and extensive since human use and deforestation of the fell.

APPENDIX I

Plant lists for Widdybank Fell communities

The following lists were assembled from various parts of Widdybank Fell and indicate species growing in the major types of community found on the fell. These lists are not intended as ecological data but simply as a reference for comparison with species found in the pollen diagrams from the fell. The ecological name describing each community refers to the dominant species in each community.

1.

Dry sugar limestone turf

Sesleria caerulia
Festuca ovina
Kobresia simpliciuscula
Koeleria gracilis
Briza media
Carex capillaris
C. panicea
C. caryophyllea
C. flacca
C. pulicaris
C. lepidocarpa
Campanula rotundifolia
Euphrasia officinalis
Thymus drucei
Linum catharticum
Viola riviniana
Helianthemum chamaecistus

Seslerio-Festucetum

Achillea millefolium
Antennaria dioica
Bellis perennis
Cerastium arvense
Draba incana
Galium boreale
G. vernum
G. sterneri
Gentiana verna
Gentianella amarella
Hieracium pilbsella
Hypochaeris radicata
Lotus corniclatus
Minuartia verna
Polygola amara
Polygonum viviparum
Potentilla erecta

Vaccinium myrtillus

Calluna vulgaris

Agrostis canina

A. tenuis

Anthoxanthemum odoratum

Helictotrichon pratense

Sieglingia decumbens

Luzula campestris

Trichophorum caespitosum

Tortella tortuosa

Cetraria aculeata

Prunella vulgaris

Plantago laneolata

Trifolium repens

Botrychium lunaria

Selaginella selaginoides

Ditrichum flexicaule

Ctenidium molluscum

Rhacomitrium lanuginosum

Hypnum compressiforme

Cetraria islandica

2.

Unaltered limestone grassland.

Agrostis tenuis

A. canina

A. stolonifera

Festuca ovina

Sesleria caerulia

Anthoxanthemum odoratum

Thymus drucei

Prunella vulgaris

Plantago lanceolata

Alchemilla vulgaris agg.

Cerastium vulgaris

Lotus corniculatus

Agrosto-Festucetum

Ranunculus acris

Saxifraga hirculis

Gentiana verna

Minuartia verna

Carex panicea

C. pulicaris

Viola riviniana

Botrychium lunaria

Hyolocomium splendens

Rhytidiadelphus squarrosus

Ctenidium molluscum

Selaginella selaginoides

3.

Species-rich heather moor — Festuceto-Callunetum

Includes these species:-

Calluna vulgaris

Festuca ovina

Seslaria caerulia

Empetrum nigrum

Gentiana verna

Vaccinium myrtillus

Rhacomitrium lanuginosum

Cetraria islandica

4.

Dry Calluna heath. Includes the following species:-

Calluna vulgaris

Deschampsia flexuosa

Vaccinium myrtillus

Hylocomium splendens

Hypnum cupressiforme

Pleurozium schreberi

Cladonia ssp.

5.

Species-poor limestone grassland, where soils have become acidic.

Agrosto-Festucetum

Agrostis canina

A. tenuis

Nardus stricta

Potentilla erecta

Viola riviniana

Galium hercynicum

various species of Carex

Luzula campestris

Anthoxanthemum odoratum

Festuca ovina

Pleurozium schreberi

Rhytidiadelphus squarrosus

Hylocomium splendens

Thuidium tamarischinum

Cetraria islandica

6.

Flush communities.

Selaginella selaginoides

Equisetum palustis

Agrostis canina

A. tenuis

Briza media

Festuca ovina

Carex capillaris

C. dioica

C. echinata

C. flacca

C. lepidocarpa

C. hostiana

C. nigra

C. panicea

C. pulicaris

Eriophorum angustifolium

Juncus acutifolium

J. bulbosus

Eleocharis palustria

Tofieldia pusilla

Triglochin palustris

Pedicularis palustris

Pinguicula vulgaris

Plantago maritima

Potentilla erecta

Primula farinosa

Prunella vulgaris

Ranunculus acris

Succisa pratensis

Minuartia stricta

Gymnostometo-carecetum:- hummocks in gravel flushes.

Gymnostomium recurvirostrium

Carex lepidocarpa

Juncus articulatus

Kobresia simpiciuscula

Minuartia stricta

M. verna

Saxifraga aizoides

Armeria maritima

7.
Acid peat communities

(a) Blanket peat

Calluna vulgaris

Eriophorum vaginatum

Erica tetralix

Empetrum nigrum

Rubus chamaemorus

E. angustifolium

Sphagnum papillosum

S. cuspidatum

S. rubellum

S. imbricatum

Cladonia spp.

Sphagneto-carecetum dominated by many species of Sphagnun and Carex and including such species as:-

Narthecium ossifragum

Drosera rotundifolia

Trichophorum caesipitosum

Eriophorum vaginatum

E. angustifolium

Erica tetralix

8.

Dolerite cliffe vegetation at Falcon Clints.

Sorbus aucuparia

Juniperus communis — Isolated shrubs on crags and ledges.

Betula pubescens

Rosa canina agg.

Calluna vulgaris

Vaccinium myrtillus

Festuca ovina

Potentilla erecta

Thymus drucei

Epilobium hirsutum

Carex nigra

Pinguicula vulgaris

Lotus corniculatus

Oxlis acetosella

Geranium robertianum

Alchemilla spp.

Crepis sp.

Saxifraga aizoides

Urtica dioica

Galium boreale

APPENDIX II

BETULA NANA

The status of Betula nana as an identifiable pollen type has been discussed briefly in Chapter 4. However, in view of the present day record of the species on Widdybank Fell and it's presence both as macro - fossil remains and pollen grains throughout post - glacial time on the fell, it seems relevant to discuss this in more detail.

Terasmäe"(1951) recognises several distinct differences between the pollen grains of Betula nana and those of tree Betula species. The most important of these are:-

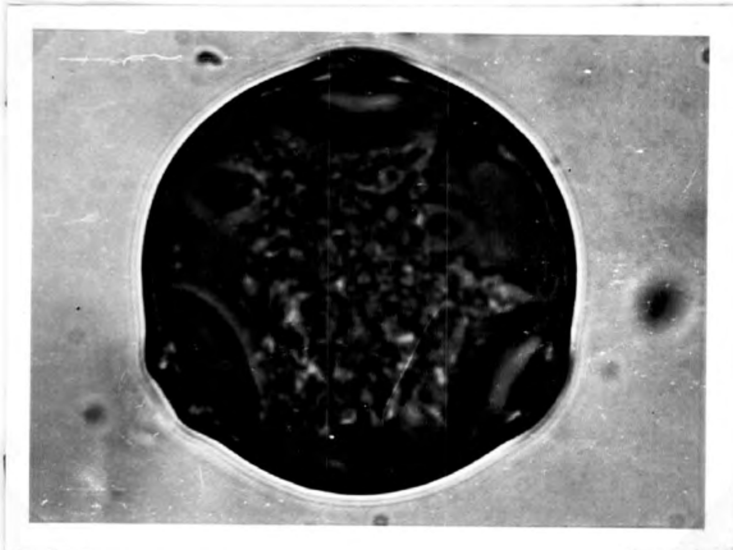
1. Apertures not so distinctly pouting as in other species.
2. Rather thinner exine than other species.
3. Arci less distinct than in other species.

Walker (1955) summarises the occurence of B. nana as a macro-fossil and sets out a method of identifying B. nana pollen.

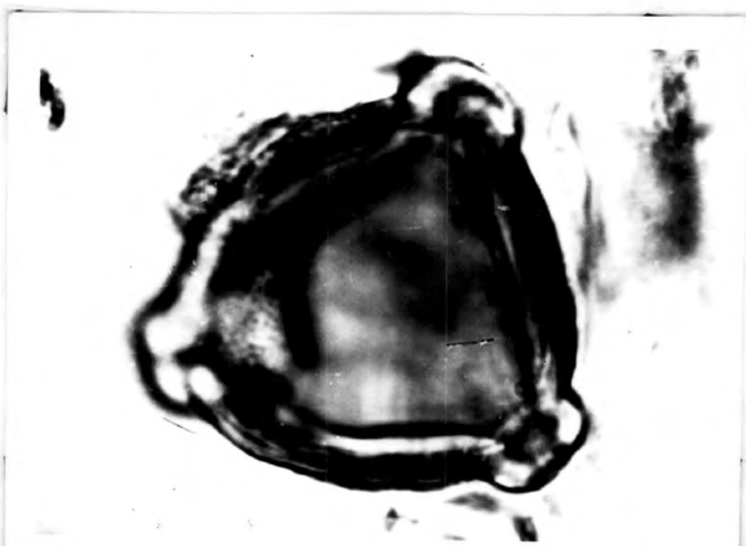
Macroscopic remains of B. nana have been recorded from a large number of sites in the British Isles and Europe from zones I, II, III and early IV. These British sites include:-

Seamer	Zones I, II, III, IV.	(Clarke, 1954)
Kentmere	II	
Neasham	II, III	(Blackburn 1951)
Hockham Mere	Late glacial.	(Godwin and Tallentire, 1951).
Nazeing	III	(Allison, Godwin and Warren, 1952).
Hawk's Tor	II	(Connolly, Godwin and Megaw 1950).
Louth	II, III	(Mitchell, 1951).

PLATE 5.



PHOTOMICROGRAPH OF BETULA NANA FROM ZONEVI, TINKLER'S SIKE.



PHOTOMICROGRAPH OF BETULA cf. PUBESCENS FROM ZONE VI, TINKLER'S SIKE.

At Tinkler's Sike, Widdybank Fell, macroscopic remains have been found in the peat close to the present day record for B. nana (Hutchinson, 1966). They were recorded in the stratigraphy of the peat at TSI up to 112 cms which represents Zone VIa - VIb transition. At this time the AP/NAP ratio began to rise and low values of mixed oak forest trees were recorded on the pollen diagram.

Walker records results of measurements of grain diameter and pore depth of B. nana grains from a number of different sites, both present day type material and sub-fossil grains. He took measurements of a large number of grains from each sample and records them as the mean of the ratio-grain diameter: pore depth, showing that, in general B. nana grains show a higher ratio (9.95 - 11.50) than tree birches (6.7 - 7.84). On the basis of this ratio, tentative identifications of B. nana pollen were made at a number of Late-glacial sites in Britain.

Birks (1968) summarises the three methods for identification of B. nana pollen grains:-

1. Morphological differences i.e. the less protuberent pores and thinner wall of B. nana.

2. Grain diameter : Pore depth ratio. Birks showed that whilst there is little overlap between B. nana and B. pubescens, B. tortuosa shows ratios intermediate between the two, overlapping with both species.

He suggests that in order to make a distinct identification of B. nana from all other species of birch, the last two methods must be used together.

At Widdybank Fell, B. nana pollen was identified by means of the grain diameter: pore depth ratio and pollen morphology i.e. thinner wall, less protuberant pores and generally smaller size. Grains with a ratio of greater than 11.5 were classed as B. nana (Plate 3). Thus, as has already been stated in Chapter 4, the curves for B. nana do not truly represent the amount actually present in the pollen rain, but indicate when it was an important contributor to the pollen rain.

Pollen of the B. nana type has been identified in this way from Widdybank Moss, Red Sike and Tinkler's Sike throughout the post-glacial from the end of zone III onwards. It seems probable therefore, that Betula nana was present on the top of the fell during the late-glacial period and persisted here under the sparse tree cover through the forest maximum. At the present day only one site on the fell has been recorded on dry Calluna blanket peat.

APPENDIX III.

During macro-analysis of peat samples a number of Arthropod fragments were found which were identified by Mr. K. Houston of the Zoology Department, Durham, who supplied the following comments.

250 - 350 cms W B M I

1. Head and Two abdominal Tergites of Ants.

Red ants are not uncommon on Blanket bog at moorhouse and are quite common around old mine spoils.

2. Elytra, head, prothorax, sternum of meso - and meta Thorax and 1st(?) abdominal stermite of Donacia sp (a Chrysomelid beetle). Not common at Moorhouse: Herbivorous.

3. Elytron of a Staphylinid beetle - Olophrum (fuscum?). Common almost everywhere - carnivorous.

4. Cephalothorax of a small spider.

5. Head, thorax and part of abdomen of two Thysanurans.

6. Egg cases of Lepidopteran or Hemipteran.

7. Left fore-wing of a Hemipteran which might be from a Psylid or even a Jassid.

8. Head and meta sternum of a small Dytiscid probably Anacaena globulus - a water beetle.

The presence of these Dytiscids suggest that the sample or part of it may have been deposited in a small pond. If so, it would also account for the good preservation of the Thysanurans and the presence of Donacia sp. If the Donacia died on land, it would have disintegrated fairly rapidly.

Remains from the Blanket peat of TS I

1. Elytron of Lestera (sp. monticola?). A staphylinid beetle common on blanket peat.

2. Elytron of <u>Olophorum</u> (sp. <u>fuscum</u> ?) Another staphylinid beetle common on blanket bog.

3. Remains of head and elytron of a small Curculionid (weevil). These are not uncommon on blanket bog and are thought to feed on heather seeds.

4. Elytra of a small species of Carabid beetle perhaps <u>Harpalinus</u> sp.

It seems unlikely that these insect remains could reveal the exact conditions in which they were living as they all may be found in various types of vegetation. However, those identified could all be found under conditions similar to those existing at Moorhouse today.

APPENDIX IV

Calculation of X^2 for pine values in zone VI of RSI, RSII, and TSI.

The curves for pine in each of the three diagrams RSI, RSII and TSI differ markedly during the boreal period. To establish whether this difference was significant or simply due to sampling error or accident, it was necessary to make statistical tests.

As the count for each level is independent of those for other levels, a count for an individual level may not be directly compared with any individual level from another curve. Therefore, the total pine pollen count for zone VI was taken in each of the three diagrams. The curves for each diagram are based on a count of pollen grains at separate levels and presented as a percentage of total tree pollen. For the purpose of this statistical analysis, however, actual pollen counts were used rather than percentages.

Method.

(a) The total number of pine pollen grains for all levels in zone VI of one diagram were added together (total x).

(b) The total number of tree pollen grains for all levels in zone VI were added together to give the total tree pollen count for that zone. Total x was subtracted from this to give total non-x tree pollen.

(c) Using a 2 x 2 contingency table, x and non-x pollen in one diagram were compared statistically with x and non-x pollen in another diagram. The resulting X^2 was then looked up in tables and the probability of the difference between two samples being due to sampling error or accident read off.

Standard formula for 2 x 2 contingency table :

	I	II	
X	a	b	a + b
non X	c	d	c + d
	a + c	b + d	t

1 degree of freedom

Distribution of X^2 for 1 degree of freedom

P:	0.5	0.3	0.2	0.1	0.05	0.02	0.01	0.001
	0.4	1.07	1.64	2.71	3.84	5.41	6.64	10.83.

Results

Zone VI Pine	X^2
RSI x RSII	7.7
RSII x TSI	133.4
RSI x TSI	61.4

Thus the probability of the differences in pine values during zone VI being due solely to sampling error or accident are less than 0.01 i.e. less than one chance in every hundred.

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