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# An Investigation of the Pedology of Upper Weardale, Co. Durham

This thesis presents the results of a character study of the soils of Upper Weardale, Co. Durham. Part 1 presents relevant material on the soil environment of the area, emphasising the important characteristics of parent materials, relief, climate and ecology. The results of the field and laboratory investigations are summarised in the form of a soil map of the area on a scale of 2½" to one mile and in the Appendix, which presents the results of detailed field and laboratory analyses of specific profiles. The bulk of Part 2 is concerned with discussions on the origin and properties of the different types of soil. Field and analytical characteristics are used to assess as far as is possible with existing information, the dynamics of past and present pedogenic processes in the soil profiles. Throughout the discussions problems of classification and interpretation are highlighted, and avenues for future research emphasised.

# An investigation of the pedology of Upper Weardale, Co. Durham.

Thesis submitted to the University of Durham
for the degree of Doctor of Philosophy

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Kenneth Atkinson, B.A.(Dunelm), M.Sc.(Aberdeen)

# Declaration

I hereby declare that the work presented in this thesis has been performed by myself and that it has not been accepted in any previous application for a degree.

All quotations have been distinguished by quotation marks and all sources of information specifically acknowledged by reference to the authors.

K. Atkinson

# ACKNOWLEDGEMENTS

Many people have assisted me during the course of the present work and I wish to record my very grateful thanks to them for all that they have done.

In particular, I wish to thank:

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Specific parts of the present thesis could not have been carried out without the specialist help I have received from: Mr. John L. Nowland, on field mapping techniques; Professor K.C. Dunham and Mr. D. McMurdo (Cominco, Ltd.) for their help in the lead survey described in Chapter 13; Mrs. Maureen Kaye for carrying out the clay mineralogical determinations; Miss M. Errington for typing the text, and Mr. D. Hudspeth for the photographic reproduction of the illustrations.

Finally, I wish to record a deep debt of gratitude to my wife, Doreen, for all her encouragement, assistance, and help in preparing this work for final presentation.

".....chemists analysed samples of soil often with no more effect in elucidating its true nature than the analysis of a haggis would have in explaining the behaviour of a sheep....."

W.H.T. Williamson 1959.

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# Introduction

Few detailed analyses of pedogenesis in the North Pennine Uplands have been attempted to date. The majority of the published work on the soils of the region has been concerned with various aspects of agricultural potential (CRAGG 1958; CROMPTON 1958) and specific botanical and ecological problems (BOWER 1959; 1961; PIGOTT 1956), rather than with presenting a holistic picture of soil properties, soil distributions and soil processes in the North Pennine environment. Despite the work of JOHNSON (1963) and of the Nature Conservancy at Moorhouse Research Station, other upland areas of Britain are receiving more intensive attention. In particular, Scotland has been fortunate in receiving the benefits of stimulating research into its highland regions, work largely initiated by the early observations of MUIR and FRASER (1940) and since extended by,(among others) FITZPATRICK (1963 et seq), ROMANS ET AL. (1966) and STEVENS (in preparation). Wales too, still has the legacy of the early interest of ROBINSON (1935) and is notably receiving attention from BALL (1960), CRAMPTON (1963), and SMITH and TAYLOR (1967).

Despite the great increase in soil studies within Britain during the post-war years, the facts and relationships of soil genesis in upland areas are still poorly understood. Upland soils require perhaps different emphases in conceptual approach and scientific analysis than the modal lowland profile. Factors inherent in the geography of uplands - factors of slope, of aspect, of altitude, and of marginality - mean that the concept of the soil body as a multi-dimensional variate in time and space not only becomes important but raises problems of the present-day heterogeneity and complexity of soils that might never be solved. In this context the anxiety expressed by CROCKER (1952) over the lack of a single universal solution to the fundamental equation of soil formation seems forever to be misplaced.

The stimulus for the present work is derived ultimately from ideas of soil dynamism first expressed by DOKUCHAIEV (1898), for whom, "the soil, like any plant or animal organism, lives for ever and changes; developing, being destroyed, progressing, and again regressing....." The soils of Weardale can only be completely understood if they are regarded as part of the wider environment in which they occur. Soils reflect their environment in all their facets - nature, properties, evolution, and profile characteristics; all past and present environmental influences are likely to show manifestations in the soil body. Without trying either to establish too definite a distinction between "active" and "passive" soil forming factors (JOFFE 1936) or to discover too quantitative and numerical an expression for the effects of pedogenetic factors, this thesis attempts to appraise the "environmental and pedological relationships" (CROMPTON 1956) of the soils of some two hundred and fifty square kilometres in Upper Weardale, Co. Durham.

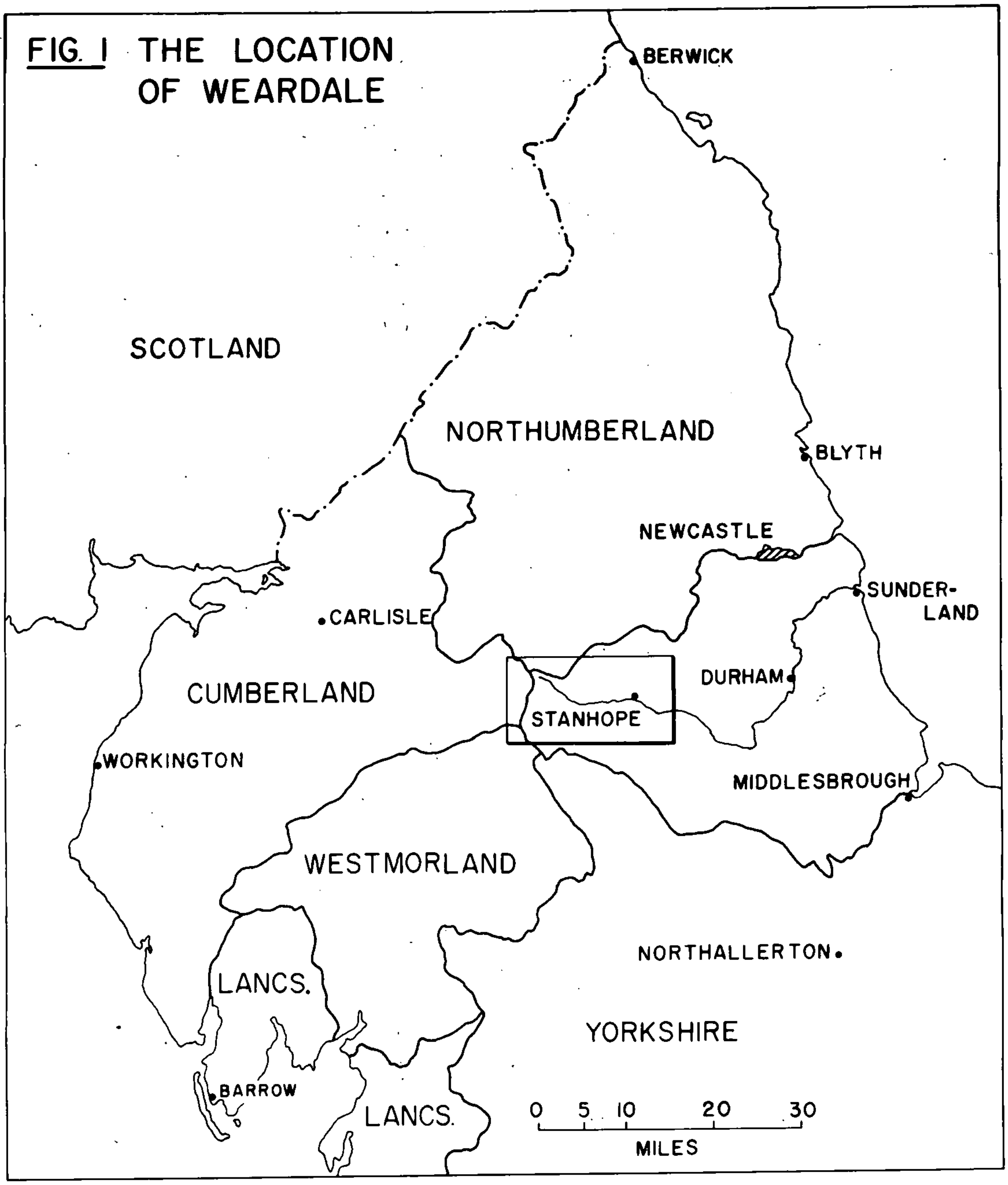
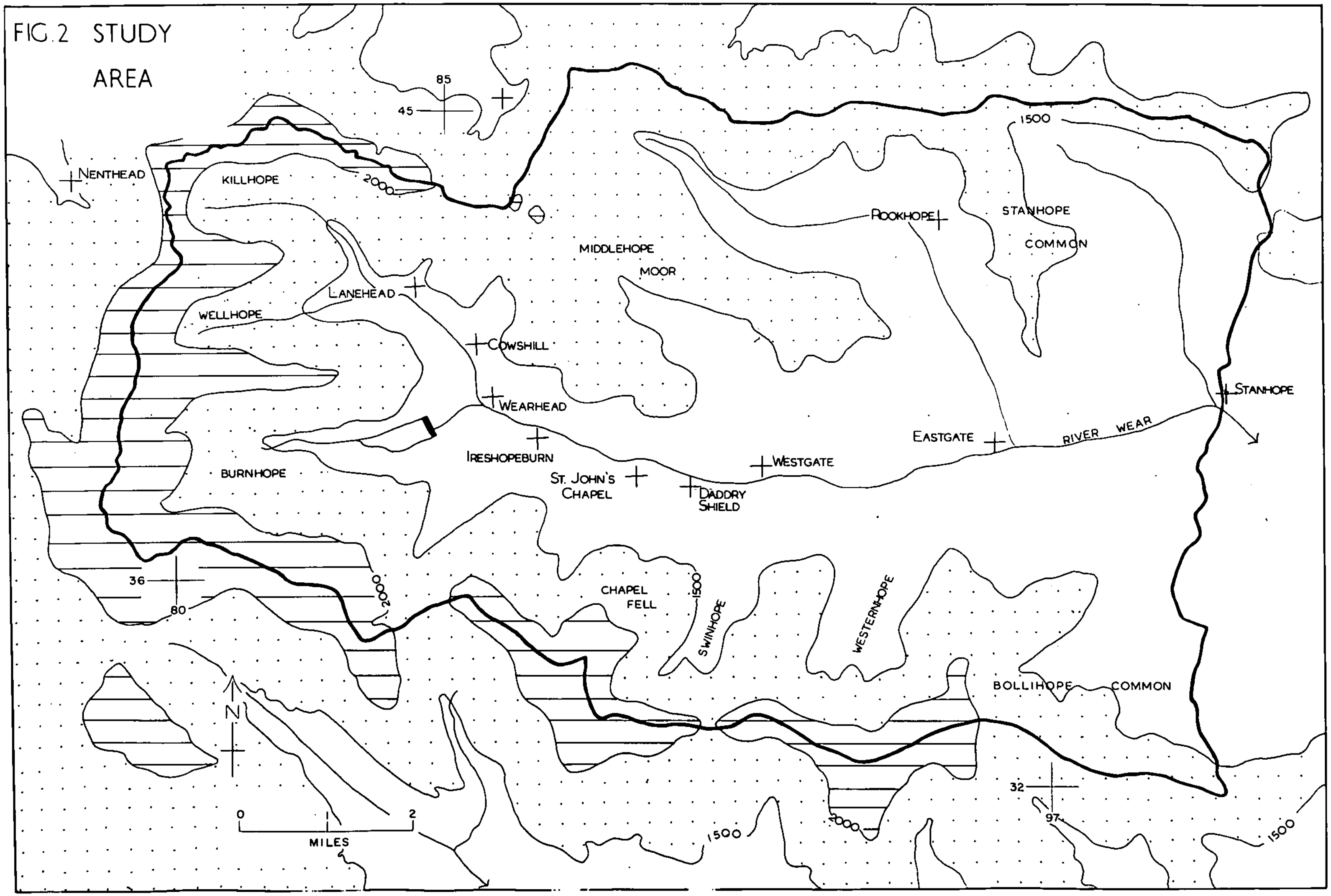


FIG. 1 THE LOCATION OF WEARDALE

Viewed in terms of the surrounding environment, the soil characters of the Pennines are indeed well worthy of specialised scientific study, displaying a remarkable variety of profile characteristics allied to an equal diversity of pedogenic processes. A study of soil formation in Western Durham also appears particularly long overdue on account of the considerable attention which other perhaps more prominent features of the area have received. Research into many aspects of the structure, lithology, vegetation, climate and also human occupancy of the North Pennines has been carried out, but it is not unfair to say that a notable dearth of pedological work exists. Agreeing with KUBIENA (1953) that "identifying soils is not difficult and soil science is not an occult art," it is firmly believed that pedological investigations of the Pennines can stimulate great interest, either direct or indirect, to all those who would wish to know the 'character' or 'personality' of the area (MORGAN and MOSS 1965). Especially would this be true for agriculturalists, foresters, agricultural engineers, plant sociologists, bioclimatologists, geologists, and, not least, geographers.

The aims of objectives of the work outlined in this theis are thus to present as accurate a picture as possible of pedogenesis in a West Durham Dale. Figures 1 and 2 show the location and limits of the area under consideration. Great emphasis has been placed on field study, although laboratory determinations have necessarily played an important role in determining

FIG.2 STUDY AREA



the finer nuances of pedogenesis. The complicated pattern of the soils has been approached by nine major methods of study. These are:

1. Site Investigation.
2. Profile Investigation.
3. Field Mapping.
4. Studies of stone morphometry and alignment.
5. Microscope and fabric studies.
6. Routine physical and chemical determinations.
7. Chemical studies on Iron as indices of pedogenesis.
8. Diagnostic trace element analyses.
9. Diagnostic analysis of heavy and clay minerals.

Part 1. of this thesis outlines briefly the general soil environment of Upper Weardale, both past and present. In Part 2, an account is given of soil characteristics, and an attempt is made at classifying and interpreting the profiles in the light of "existing" information. Specific problems arising from the analysis of individual profiles are discussed and emphasis is given to soil features of upland areas towards which future research might profitably be oriented. All the results and methods of field and laboratory investigation are presented in the form of appendices.

Throughout the course of the investigation it has been felt that a proper understanding of the soil profile can only be gained if the emphasis of study is based on problems of soil evolution and soil history. Whilst it is difficult enough to interpret soil properties in relation to the present factors of soil formation (JENNY 1941), or rather be aware of some probable mutual interrelationships, the problems in pedology can only be resolved by positive thinking in several time scales. The pedologist should concern himself with past, present, and future and, like J.B.S. HALDANE (1956), reconcile the quantitative with the evolutionary approach.

The soils of Western Durham illustrate this remarkably well. The origins and properties of the soil profiles of the area reflect change: change since Carboniferous time when the geological landscape was first fashioned, and change since Tertiary and Quaternary when again remarkable modifications of the entire landscape took place. The polygenesis and polymorphism shown by many of the profiles is ample evidence of this. For this reason a soil map of the area can only be of use if it is interpreted in four dimensions and if specific characters shown in the profiles can be related to the whole scheme of environmental evolution. The approach is thus inspired by KUBIENA (1953 et seq) rather than by the Seventh Approximation (1960), by FITZPATRICK (1967), rather than by a Soil Survey memoir. Throughout the course of the work it has become increasingly evident that a soil is a specifically individual and unique phenomenon, and for each particular site. Studies such as those by PROUDFOOT (1958) and DIMBLEBY (1962) are invaluable for the specificity of soil profile characteristics which they emphasise. Upper Weardale is an area which seems to deserve this kind of approach.

# PART I. THE SOIL ENVIRONMENT

# Chapter 1

## Geological Evolution

The geological structure and lithology of Upper Weardale can only be fully understood in relation to the regional geology of the Alston Block as a whole. Fortunately this structural block of the North Pennines has long been the scene of quite detailed investigations by structural geologists, palaeoantologists, and mineralogists, and an impressive list of geological data has been compiled, the work of RAISTRICK (1936), DUNHAM (1931 et seq) and JOHNSON (1963) being particularly well known.

Upper Weardale is essentially an area of Carboniferous Strata (WESTGARTH FOSTER 1809; WINCH 1817; SOPWITH 1833; WALLACE 1861), where the stratigraphical succession is perhaps best highlighted by palaeoantological indices (GARWOOD 1907; STANLEY SMITH 1910; HOPKINS 1930). Although several subdivisions of the Carboniferous succession have been attempted (JOHNSON 1963), that proposed by DUNHAM (1948) has many advantages in terminology. This succession for the Alston Block is as follows:

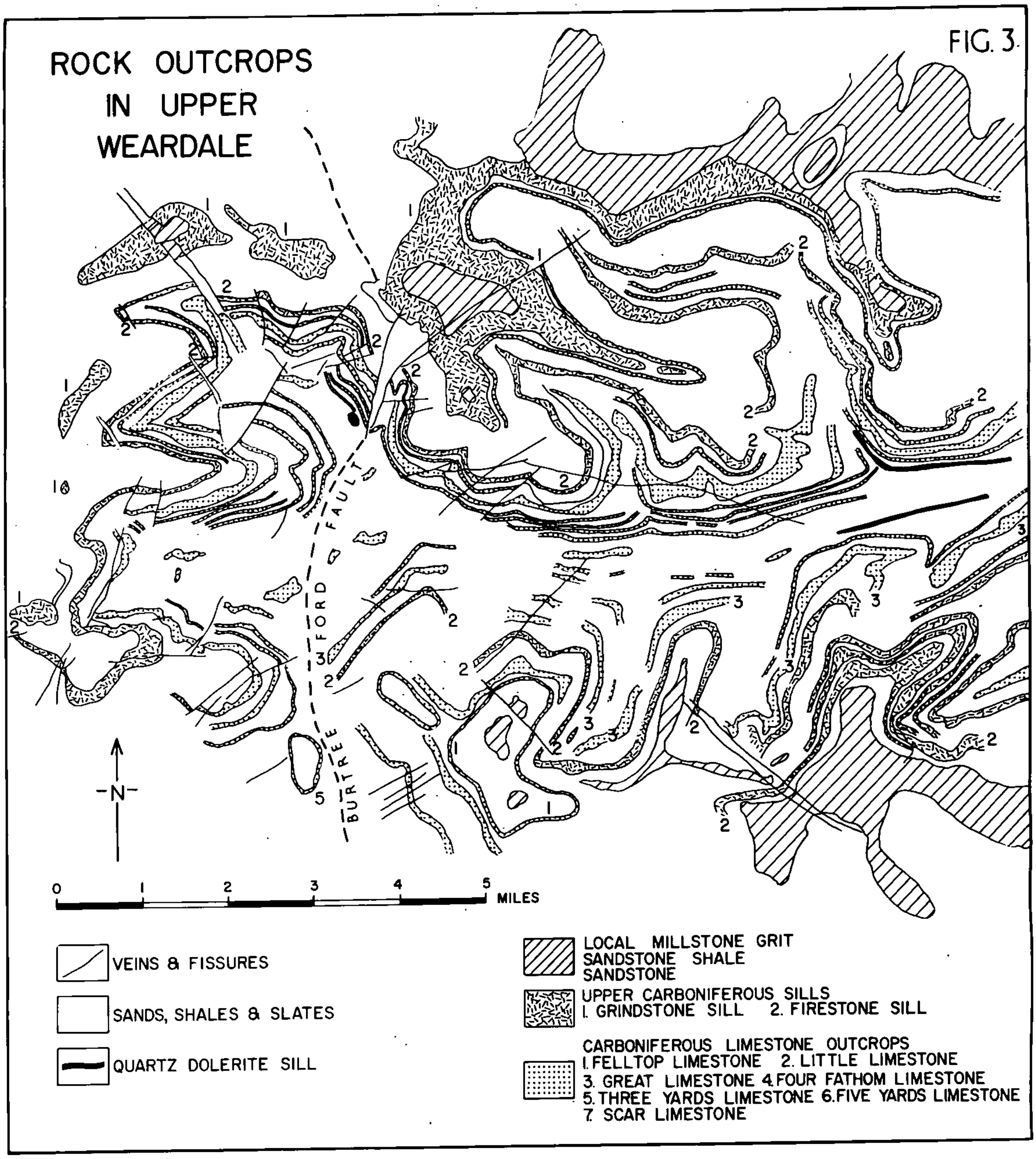
TABLE 1. The Carboniferous Succession of the Alston Block

Dunham (1948)

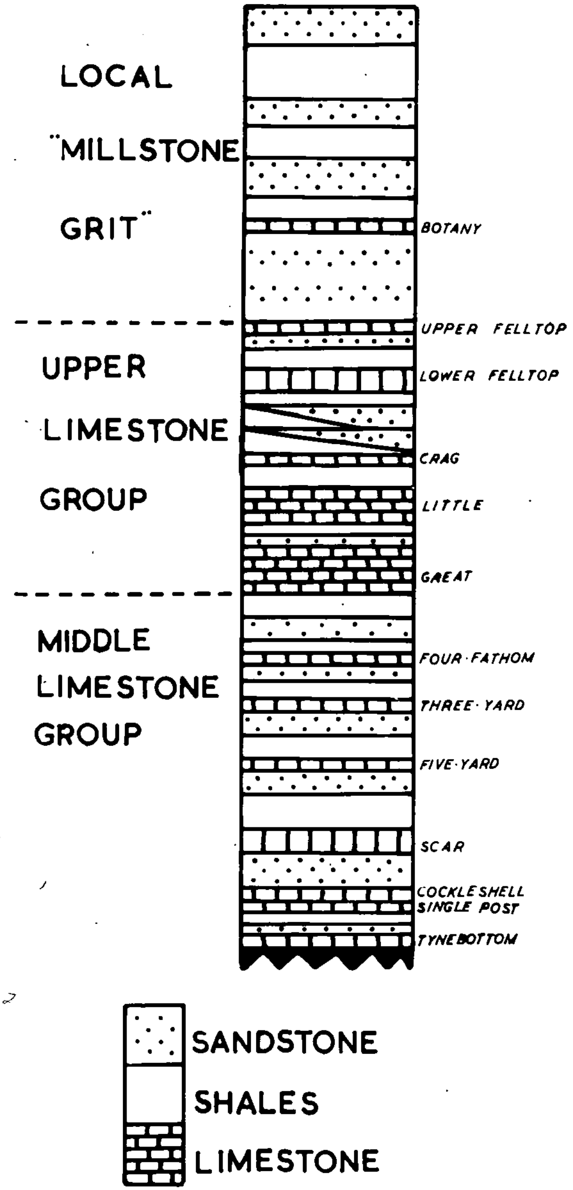
| | |
|---|---|
| "LOCAL" MILLSTONE GRIT | |
| Carboniferous Limestone Series | Upper Limestone Group |
| | Middle Limestone Group |
| | Lower Limestone Group |
| | Basement Group |

FIG. 3.

ROCK OUTCROPS IN UPPER WEARDALE



STRATIGRAPHIC SECTION OF THE CENTRAL ALSTON BLOCK



DUNHAM (1948)

FIG 4.

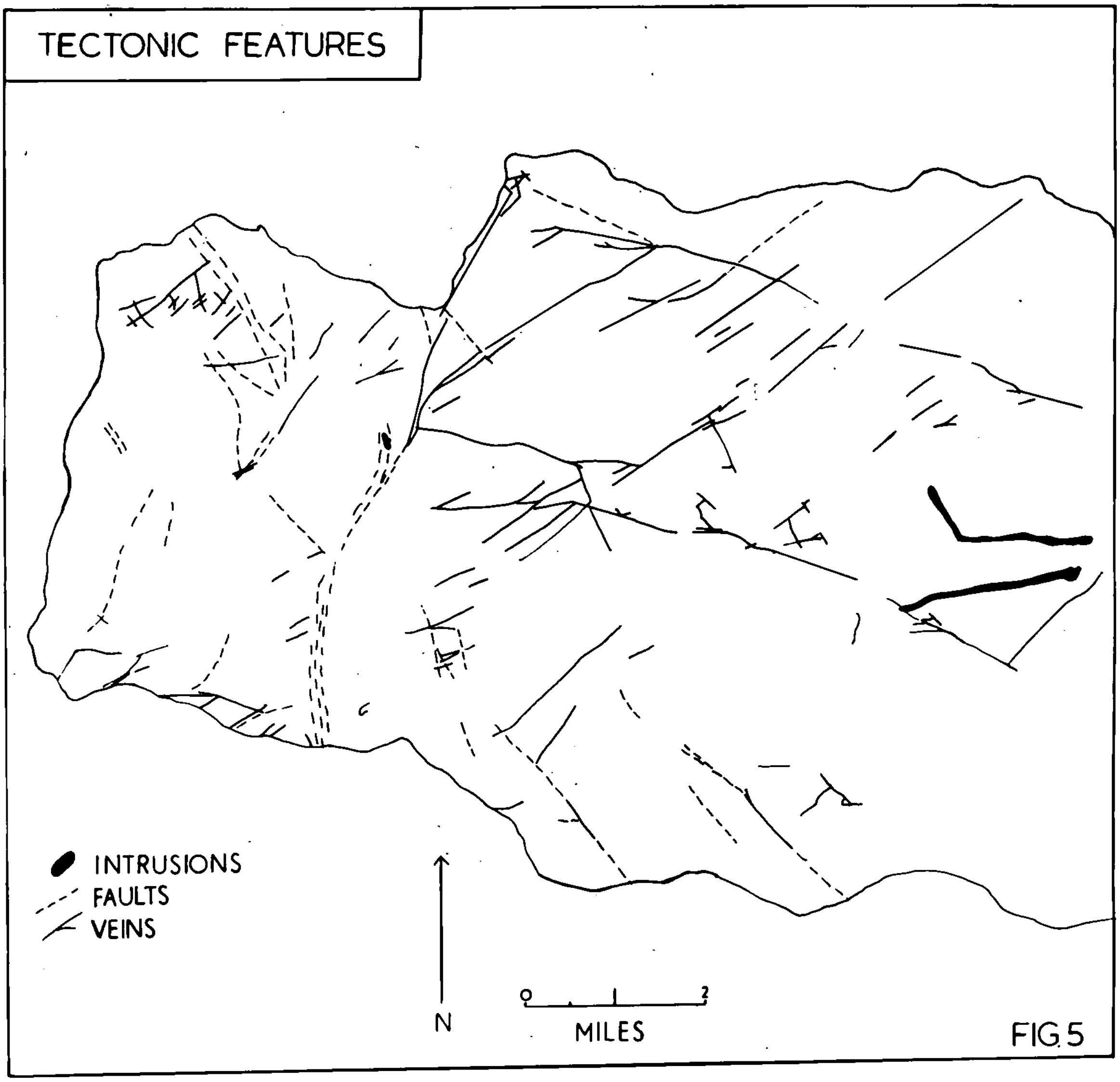
Within this broad chronological scheme, lithological variations are largely governed by the cyclothemic succession of rhythmic sedimentary units (PHILLIPS 1836). The resulting lithological complexity can be summarised as follows:

TABLE 2. Geological Sequence

| GROUP | MAIN STRATA | APPROXIMATE THICKNESS |
|---|---|---|
| 1. "Local" Millstone Grit | Coarse grits, sandstones and shales with ganisters between the groups. | 275-375' |
| 2. Upper Limestone Group | Coarse grits, sandstones ganisters, thin coals limestones and shales. | 580-780' |
| 3. Middle Limestone Group | Rhythmic alternation of limestones, shales sandstones and thin coals. | 725-850' |
| 4. Lower Limestone Group | Massive limestone overlain by alternating limestones, shales sandstones. | 300-550' |

Figure 3. illustrates the solid geology within the Weardale area and figure 4. shows a generalised vertical section of strata for the Alston Block (DUNHAM 1959). Within the confines of the present area of study, strata below the Scar Limestone of the Middle Limestone Group are not exposed.

Within this orderly yet complex pattern, a prime factor of complication derives from the tectonic history of the Alston Block (fig. 5). The great Pennine Fault system has been described by MERRICK (1915), VERSEY (1927),



TECTONIC FEATURES

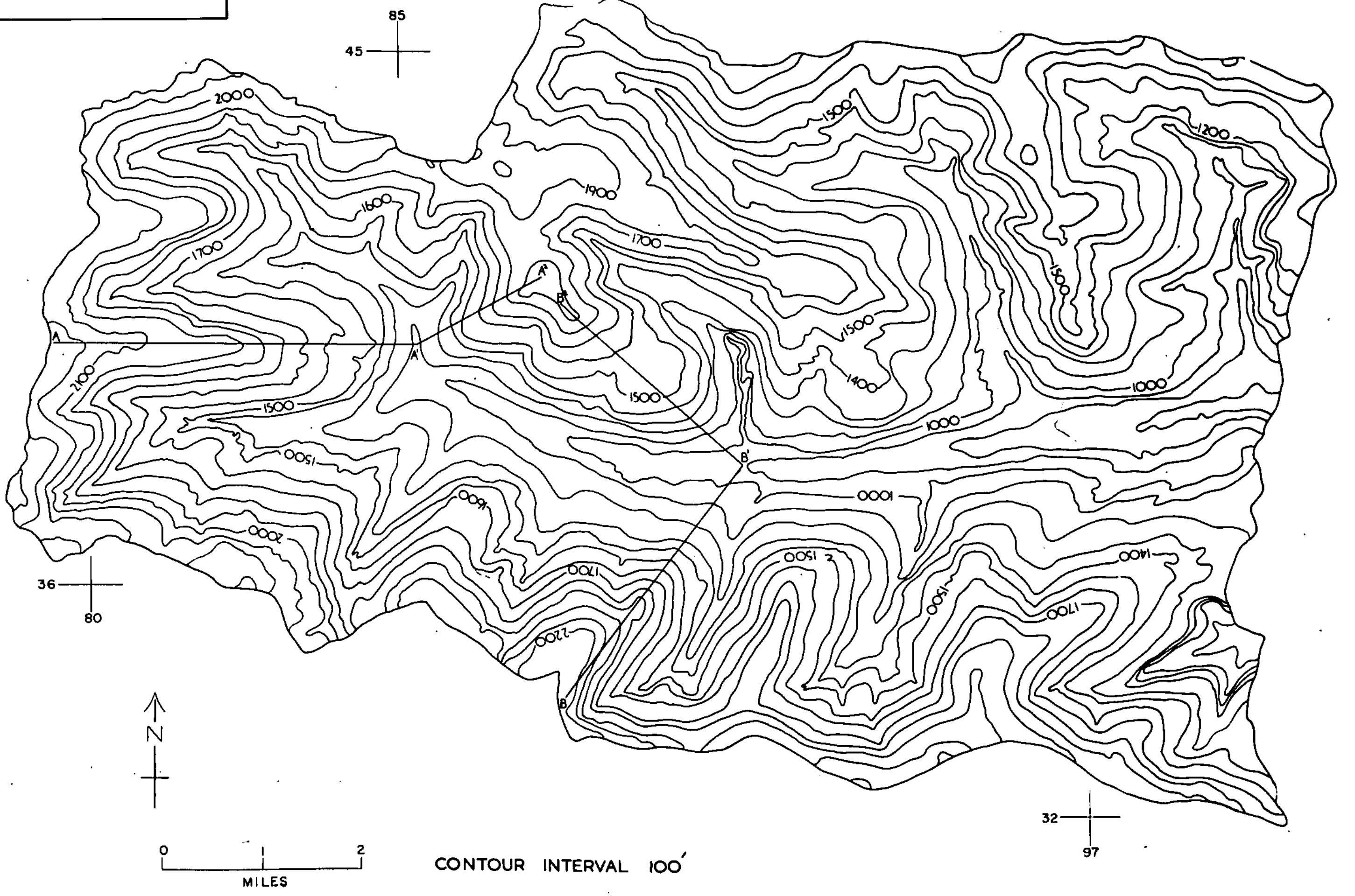
FIG.5

TROTTER (1929) and DUNHAM (1948), and these workers discuss the issues involved in the chronological controversy which surrounds the major structural features. More relevant to the present discussion is not whether the main diagenesis was Tertiary (TROTTER 1953; 1954) or Hercynian (WELLS and KIRKALDY 1948; DUNHAM 1952) in age, but that faulting and folding, mineralisation and igneous intrusion introduce considerable variety into the pedological character of the area. The Burtreeford Disturbance, an eastward facing monocline which crosses the R. Wear at Burtreeford Pasture, introduces a small outcrop of quartz-doleritic Whin Sill into the upper reaches of Weardale whilst, similarly, between Eastgate and Stanhope more linear outcrops occur along the northern and southern sides of the R. Wear. Mineralisation too has been widespread throughout the region and accounts for the proliferation of veins of lead, zinc, fluospar and accessories which have so radically affected the geography of this "Lead Dale" (SMAILES 1960).

Pedogenesis in Upper Weardale has thus taken place, and is at present taking place, in an area of quite varied lithological character. Parent rock variability is great and a principal component of the multivariance of the soil is the basic lithosequence ranging from calcerous rocks, through intermediate igneous, to mudstones and shales, to highly siliceous sandstones, and ultimately to carbonaceous rocks. Occasional intercalated ironstones and non-ferrous metalliferous veins further diversify the background to the geochemical cycles in the soil body. Although soil-parent rock relationships are considerably modified by a complex suite of superficial deposits, these deposits are principally locally-derived. The range of NIKIFOROFF's (1955) "stable acquired soil characters" is hence likely to be wide.

An important aspect of the geological succession is the relative thinness of the Carboniferous strata within each well defined cyclothemic unit. Few beds reach over one hundred feet in thickness without marked lithological change and thus a generally rapid alternation of rocks of differing mineralogies is characteristic. Along any slope section varying lithological outcrop is usual and, in fact, provides a useful source of indicators of soil-topographic processes.

Fig. 6 RELIEF


85
45
36
80
32
97
A
A'
A²
B
B'
B²
2000
1600
1700
2100
1500
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1400
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1200
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1000
1000
1000
1500
1400
1500
1700
N
0
1
2
MILES
CONTOUR INTERVAL 100′

## Chapter 2

## Geomorphic Development

Several of the most powerful studies of regional pedogenesis in recent years have been carried out within a framework of total landscape development (AVERY ET AL 1959; FITZPATRICK 1963). This is primarily an evolutionary extension of what has become a significant prop in British pedology, namely, the placing of prime emphasis for study on factors of slope and parent material (GLENTWORTH and DION 1949), and represents an attempt to meet the mild criticisms of WOOLDRIDGE (1949).

In Upland Britain in general, the lack of an authoritative statement of evolution in landscape terms is often deplored (MACKNEY 1967). The lack of a definitive statement of the type presented by WOOLDRIDGE and LINTON (1955) for South-eastern England is unfortunate, but is perhaps a reflection of the sharp evolutionary variation which one finds over quite short distances. Despite the fact that generalisations can be made for Highland Britain (LINTON 1951), hypothesis of landscape evolution have often only a local significance and cannot be transposed from one drainage unit to another. This is particularly true in the Northern Pennines where the Rivers Tyne, Wear and Tees have been subject to different, although still only partially understood, geomorphic histories since late Tertiary.

### 2.1 Present Relief

The general relief elements of Upper Weardale form a superficially simple pattern. The easterly flowing R. Wear is incised in a relatively steeply-sided valley

FIG. 7 SURFACE DRAINAGE

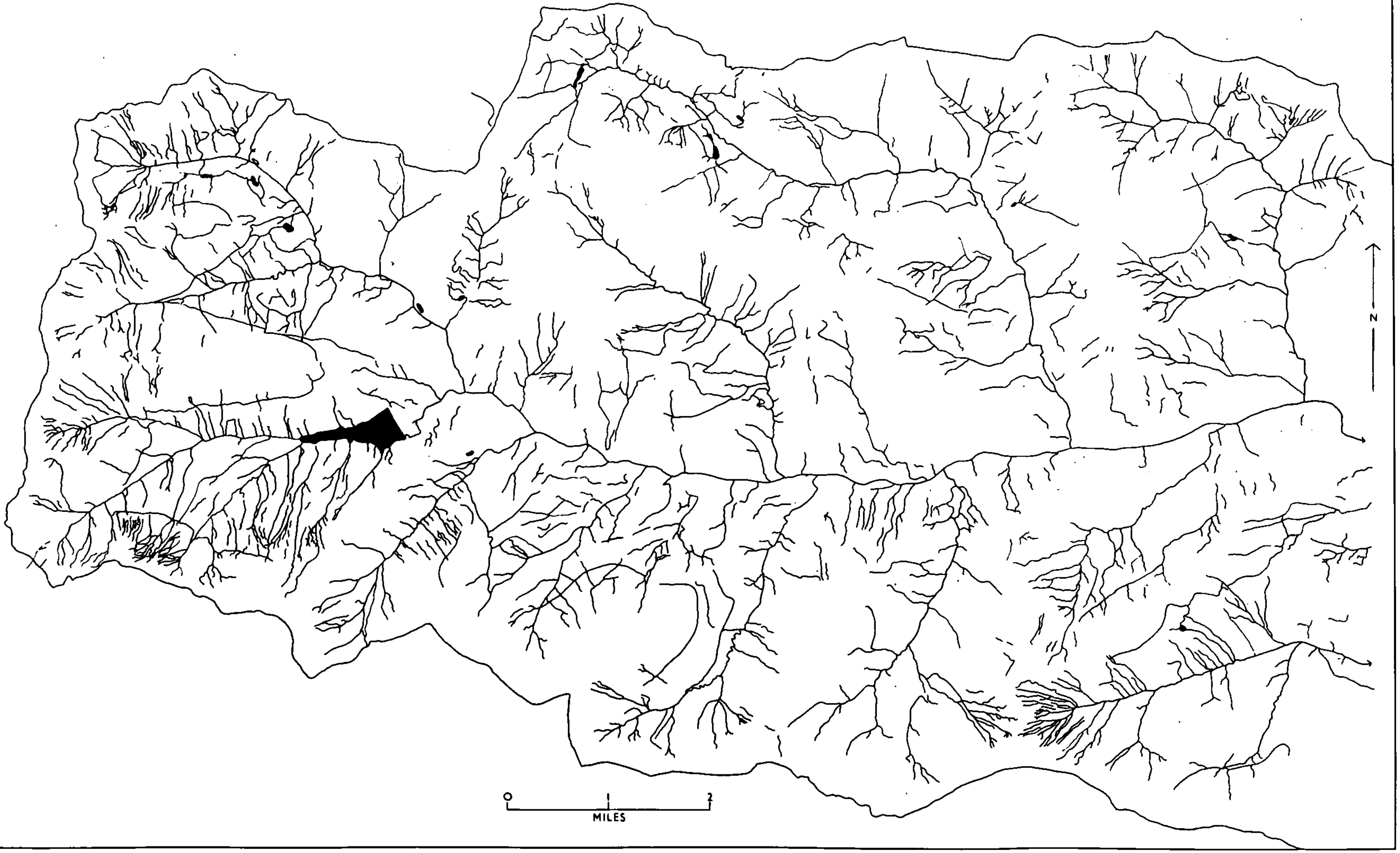
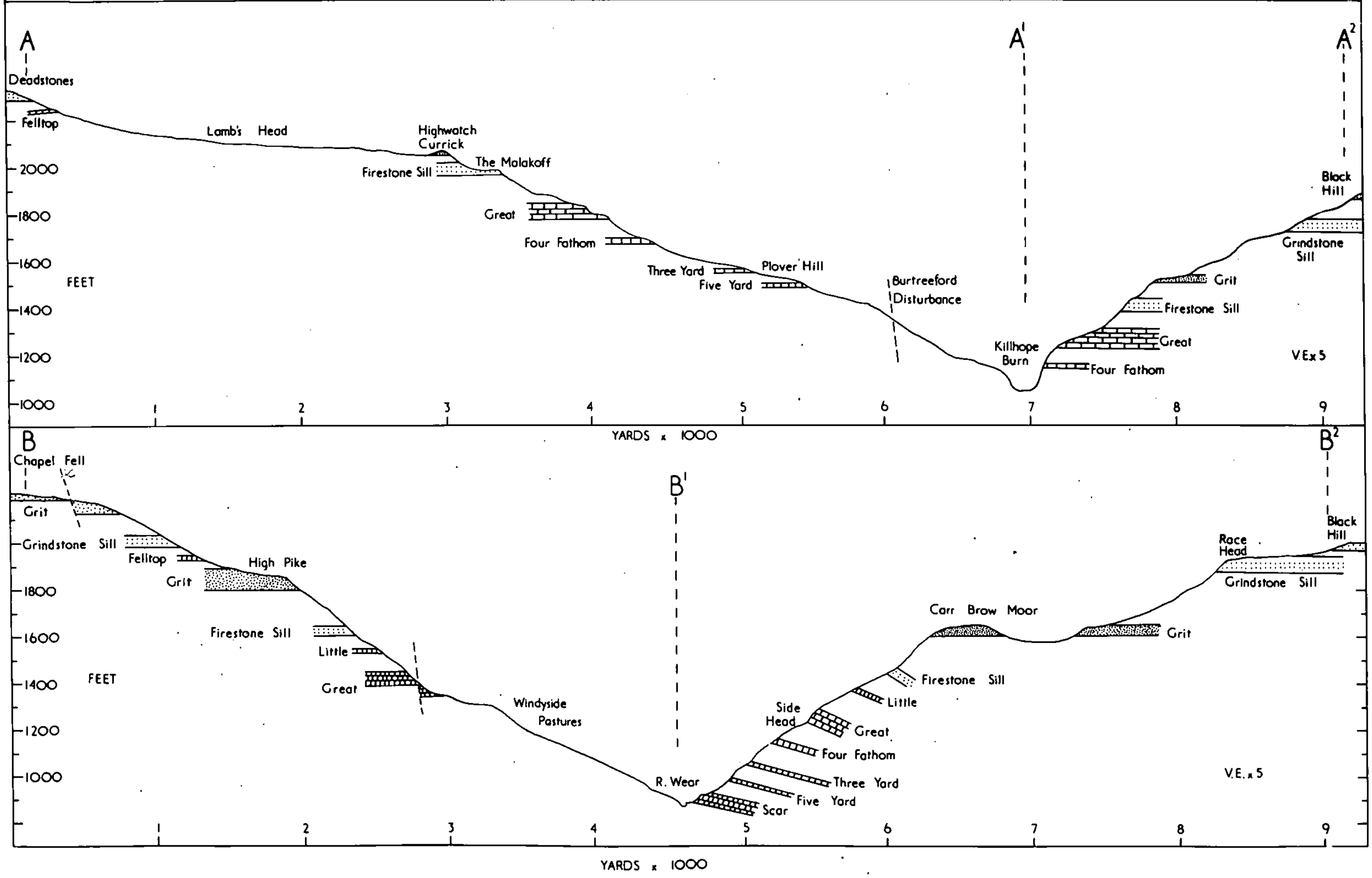


FIG. 8 SLOPE PROFILES

SECTIONS AS SHOWN IN FIG. 6



which is defined by prominent interfluvial ridges along the southern, western and northern boundaries (fig. 6). It represents the upper reaches of a single drainage unit (fig. 7) and is therefore amenable to classical HORTON (1945) analysis. Into the main stream flow a series of tributaries of varying amplitude and incision, which generally form a rectilinear confluence with the River Wear. The Burns of Rookhope and Middlehope form the two major tributaries in this drainage pattern.

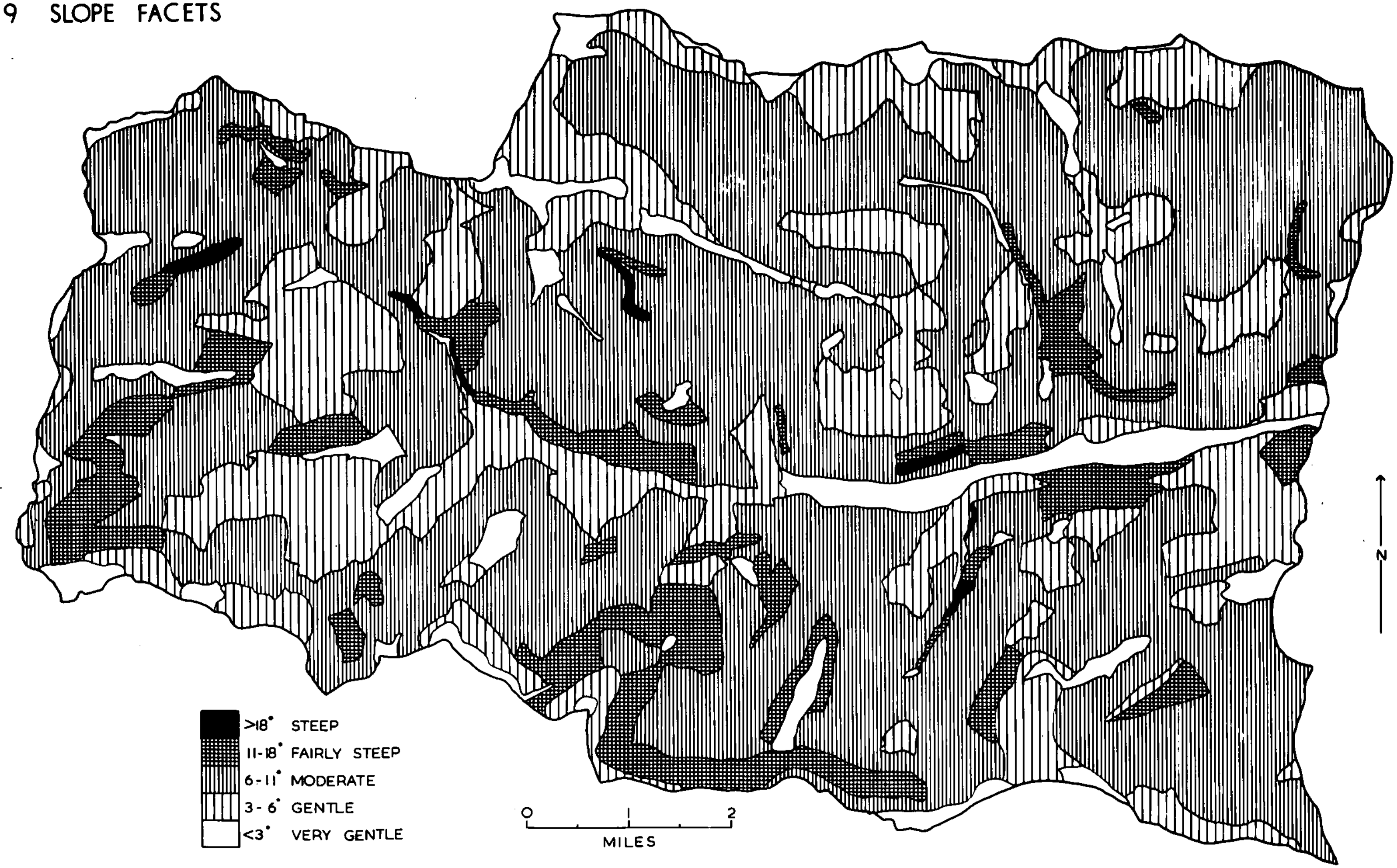
Upper Weardale ranges in altitude from 2452' at Burnhope Seat in the west to 600' at Stanhope in the east. Within this altitudinal range slope form is largely governed by characteristics of lithology, geological dip, and superficial deposit. Long and continuous slope facets are rare, the dominant topographic pattern being one of rock-controlled benches and scarps producing a stepped effect in cross valley profiles (fig. 8). The importance of the Carboniferous cyclothemic alternation in determining surface-structure relations cannot be overemphasised and TABLE 3 gives an indication of the succession and thickness of the main scarp and bench formers.

In addition to valley slopes, the interfluves between Wear and Tees and between Wear and Allen also owe much to solid geology; the breaks of slope and minor platforms within the undulating and gently sloping surface of the interfluve crests may be explained in terms of rock type. Much of the area of the interfluves is underlain by shales, but the highest points i.e. Burnhope Seat, Dead Stones (2326') Nag's Head (2207')

TABLE 3. MAIN SCARP FORMERS

| GROUP | LOCAL NAMES | THICKNESS (feet) |
|---|---|---|
| 1. "Local" Millstone Grit | Sandstone | 30 |
| | Sandstone | |
| 2. Upper Limestone Group | Grindstone Sill | 30-50 |
| | Hipple Sill | 40-50 |
| | High Slate Sill | 20-35 |
| | Low Slate Sill | 20-30 |
| | Firestone Sill | 6-62 |
| | White Sill | 5-30 |
| | Pattinson Sill | 2-28 |
| | Little Limestone | 4-21 |
| | Great Limestone | 60 |
| 3. Middle Limestone Group | Tuft Sill | 3-29 |
| | Quarry Hazle | 11-75 |
| | Four Fathom Limestone | 17-38 |
| | Nattrass Gill Hazle | 12-64 |
| | Three Yard Limestone | 8-15 |
| | Six Fathom Hazle | 15-50 |
| | Five Yard Limestone | 7-28 |
| | Low Brig Hazle | 12-35 |
| | Scar Limestone | 30 |
| | Tyne Bottom Limestone | 21-30 |
| END OF UPPER WEARDALE OUTCROP | | |

FIG. 9 SLOPE FACETS



and Knoutberry (2195') consist of outliers of the Grindstone Sill of the Upper Limestone Group. The flat areas to the east and west of Killhope Law, just over 2100', are similarly developed on this stratum, whilst Killhope Law itself (2208') consists of an outlier of the lowest "Millstone Grit" sandstone. South-eastwards from the western heights the gently sloping spurs and crests of Blackhill and White Edge, just below 1900', are again coincident with a capping of Grindstone Sill, whilst the slightly higher area of Black Hill itself (1977') and the stretch of ground over 1950' to the west of Wolfcleugh Common again represent an outlier of "Millstone Grit" sandstone. The main characteristics of the interfluves are thus the extensive undulating surfaces which stretch from just below the small group of highest hills in the west to below 2000' in the east.

## 2.2 Preglacial Influences

Notwithstanding the importance of the Glacial Maxima in determining surface form and superficial deposits in the Highlands of Britain (BALL 1960), speculation on the still observable effects of Tertiary geomorphology has continued since the early observations of CUNNINGHAM CRAIG (1913) in Scotland. In the North Pennines little quantitative evidence can be adduced to support the thesis that significant portions of the Tertiary mantle still survive, although this does not exclude its influence on present day relief and superficial regolith. If one recognises that the extent and age of relief facets can be of vital importance in pedogenesis, particularly in affecting present topography and parent materials, then all possibilities of Tertiary influences must be explored.

The possible existence of erosion surfaces in Upper Weardale has been the subject of speculation rather than quantitative analysis. WRIGHT (1955) has approached the subject but, basing his remarks on visual observation, appears mainly to have outlined the general problems involved and possible future lines of research. As with many areas of Britain, morphometric analysis suggests the possibility of several distinct surfaces but detailed field mapping over a wide area is unavailable to substantiate these. WRIGHT (1955) in fact proposes four surfaces for the Alston Block as a whole. These are:

1. The Summit Surface.
2. The 1000' Platform
3. The 850/700' Platform
4. The 600' Platform

Much of this must remain tentative, but it is noteworthy that the Summit Surface forms a very striking relief feature and, according to WRIGHT (1955), truncates strata of the Middle and Upper LImestone Groups, in addition to the local "Millstone Grit" series. Less confidence can probably be placed in the other three surfaces in the absence of field evidence, on account of the important lithology-surface form correlations which exist in this part of West Durham. Morphometric curves for the study area are presented in fig. 10.

Because of these difficulties and the further element of complication introduced by PENCK's (1953) concept that base levels of denudation are often functionally independent of, and different to, the lines of eroding streams and their base levels, the origin and genesis of the summit plane continues to arouse controversy. The latest statement by SISSONS (1960) is composite and all

MORPHOMETRIC GRAPHS

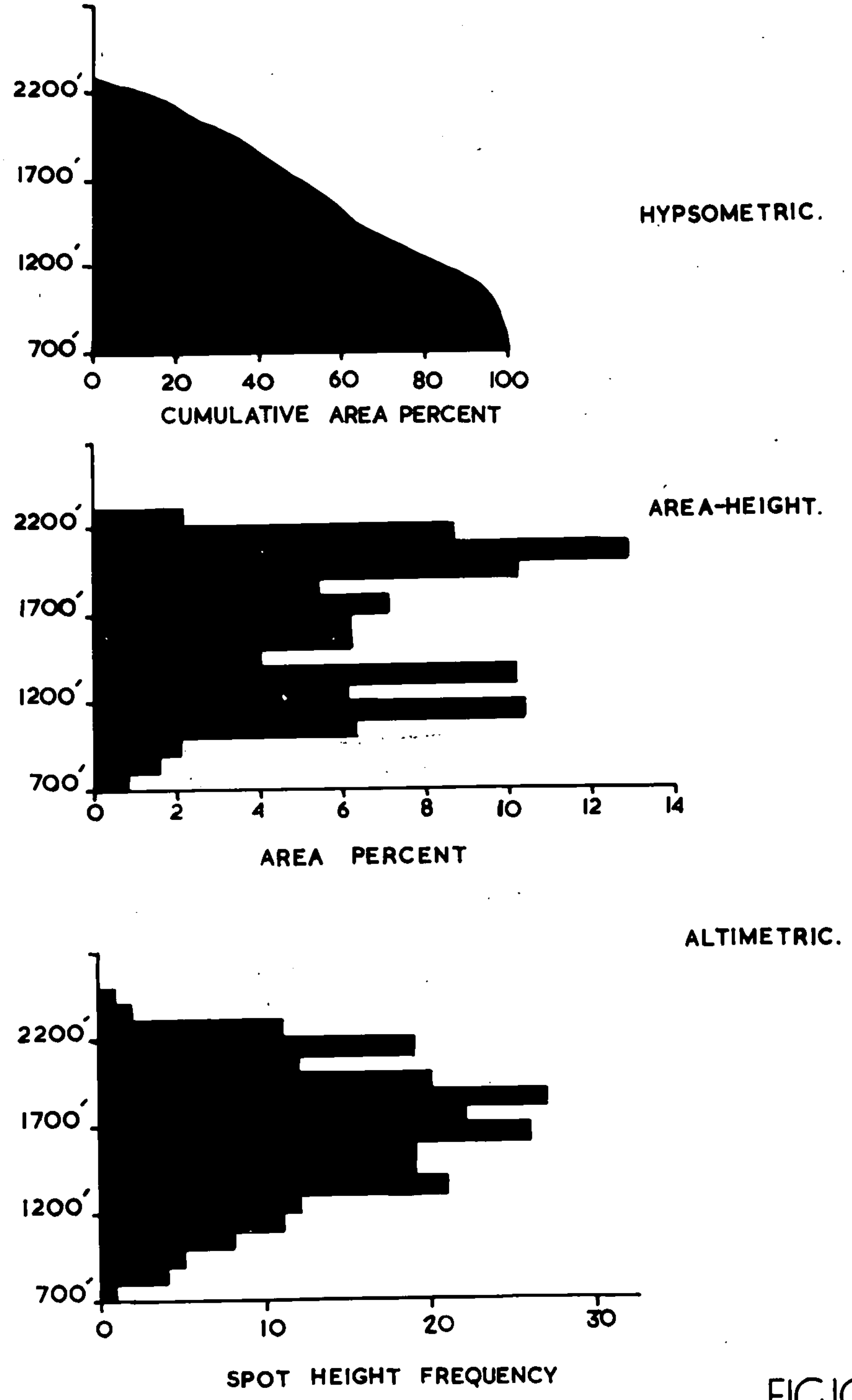


FIG.10

embracing, involving subaerial reduction, submergence, and intermittent emergence with marine planation, the whole chronology being modified by slope retreat. WRIGHT (1955) too stresses the polycyclic nature of the physical landscape; here an extensive surface of marine planation was uplifted and subjected to weathering processes so that it ultimately resembled a sub-aerially produced plain. Neither worker unfortunately invokes an absolute timescale and it is probable that both have underestimated the importance of slope retreat by weathering, mass movement, gullying, and related processes. Colluviation remains the most important denudational and aggradational process at work in the Pennine environment.

A somewhat speculative contribution of the Tertiary period to landscape evolution has burst upon the pedological scene in recent years. This concerns the amount of Tertiary sub-aerial weathering and the importance of its contribution to present soil profiles. Observations on igneous rocks have been most common (FITZPATRICK 1963; ALEXANDRE 1958) whilst sedimentary rocks have been thought to contain relatively small amounts of easily weatherable material. In Weardale the limited outcrops of Whin Sill do not show mantle preservation in protected pockets (LINTON 1955), although it must be admitted that the Whin outcrops occupy erosionally vulnerable positions near the valley floor. The limestone-shale-sandstone sequence similarly shows no in situ deposit similar to that described by AVERY ET AL (1959) and PIGOTT (1962). Presumably post-Tertiary planing, particularly by solifluxion, has been powerful enough to strip off any unconsolidated mantle. Whether such material has been incorporated into the reworked superficial deposits must remain an academic question.

On the northern watershed of Weardale two areas of weathering can be observed. One site is on sandstone to the north of Stanhope (GR.006430) where unconsolidated quartz sands appear to be residual from the underlying local "Millstone Grit". Also at Killhope Law (GR.801435) a heavy clay deposit beneath blanket peat appears to be derived from underlying shales. The mineralogical composition of these two rocks makes it extremely difficult, however, to distinguish between chemical alteration and physical and chemical disintegration. Certainly in both areas chemical and mechanical weathering since late-Tertiary has been sufficient to explain the form of these deposits. The possibility of a Tertiary contribution in this way must remain an interesting speculation.

## 2.3. The Glacial Period

The glacial period has undoubtedly had a marked influence on the character and disposition of superficial deposits in Upper Weardale. However, whilst it is possible to quantify and describe the properties of these soil parent materials (vide Chapter 3.), statements of origin with respect to mechanisms operating during the Pleistocene must remain, at present, highly conjectural. It is to be hoped that work at present in progress (FALCONER, in preparation) will bring forward a more acceptable glacial chronology for the Dale.

A major difficulty in reconstructing the glacial landscapes of Weardale is that whilst several statements - sometimes conflicting, sometimes controversial - have been made for Northern England as a whole, based on stratigraphic studies in such classic areas as Edenside (TROTTER 1929; HOLLINGWORTH 1931) and Eastern Durham (CARRUTHERS 1924 et seq; RAISTRICK 1931), it is difficult to fit Weardale into such broad schemes. This is no doubt due to the fact that the glaciation of Weardale was to some extent individual and peculiar to itself. In particular, the broad tripartite scheme of CHARLESWORTH (1957) who recognises glaciations during Mindel, Riss, and Würm times, with a subsequent Valley Glaciation in Zone 3, needs considerable qualification in the Dales environment (TABLE 4).

The most comprehensive account of the glacial episode in the Alston Block as a whole remains that of DWERRYHOUSE (1902), although he did not realise some of the complications involved. In particular the significance of his work must be assessed in terms of the plurality or otherwise of North British Glaciation i.e. whether the complicated stratigraphies of the drifts is the result of multiple glaciation (WOOLACOTT 1921; RAISTRICK 1931; TROTTER and HOLLINGWORTH 1928,1932) or can be explained by the under-melting of a single ice cover (CARRUTHERS 1947, 1948, 1953; RAISTRICK 1951). Since the discrediting of LEWIS's (1904) interglacial peat on Cross Fell by GODWIN and CLAPHAM (1951) there is no evidence for the multiple glaciation of Upper Weardale; rather than state that only one glaciation occurred, one could confirm that the last glacial episode has left a total impress on the landscape.

TABLE 4. Glacial and Past Glacial Chronology

| Period | Northumberland and Durham (Charlesworth 1957) | Weardale | Zone |
|---|---|---|---|
| | | Peat Erosion | VIII |
| POST-GLACIAL | | Peat Formation | VII |
| | | Birch "Forest" | V-VI |
| | | Cryaturbation | IV |
| LATE-GLACIAL | Valley Glaciation | Nivation Field | III |
| | | Cryaturbation | II<br>I |
| GLACIAL<br>WURM | Northern Boulder Clay (Cheviot & Scottish Ice) | Local Glacier Dynamies, date, duration unknown. | |
| | Last Interglacial | | |
| RISS | Western Boulder Clay (Lake District, Pennines, S. Uplands) | | |
| | Second Interglacial | | |
| MINDEL | Northern Boulder Clay (Scottish) | | |

Plate 1. Mass-moved slope deposits overlying the Great Limestone outcrop near Stanhope. (84/984378)

Plate 2. Valley bottom till on the linear Whin Sill intrusion between Eastgate and Stanhope. (84/968388)

According to DWERRYHOUSE (1902), ice from gathering grounds in the Lake District was, on the evidence of erratic distribution, channelled through the Tyne Gap and over Stainmore in its easterly course. A light covering of ice on the Cross Fell massif fed glacial streams along the valleys of the South Tyne and the River Tees, hence explaining the lack of Lake District erratic material in these valleys. Weardale itself was occupied by a local glacier. The evidence for local streaming in Weardale is provided by several east-west striae at quarry exposures; ice from the larger streams in Tynedale and Teesdale is thought to have crossed into Weardale at Wolsingham, six miles to the east of the present survey area. An important aspect of this work is the emphasis placed on the existence of drift-free areas. The main watersheds of Weardale are thought to have been nunatak ridges, even at the time of maximum ice cover, and hence areas of intense periglaciation.

Whilst much of this hypothesis has received later support, several controversies have arisen. A major one involves the extent and lower altitudinal limit of ice free areas. A Lake District erratic boulder has been discovered at a height of 2200' on the Western Escarpment, whilst some workers suggest that the ice surface was even higher (TROTTER 1929). JOHNSON (private communication) cites glacial plucking and overriding to a height of 2800', although he agrees with CHARLESWORTH (1957) on the difficulty of distinguishing between nunataks and overridden peaks. RAISTRICK (1931) does not support the existence of a high ice cover and gives reasons for supporting the 'nunatak' theory.

## 2.4. The Late-Glacial Period

Within the context of Weardale, a definition of the Late-Glacial Period of GODWIN (1956) may need considerable revision according to the exact dating of the glacial chronology. Proponents of the mono-glacial theory believe that the main glaciation of Northern England was equivalent to the Riss (Saale) glaciation of Europe, thus giving a much longer period of cryoturbation and solifluxion. ZEUNER (1947) estimates that a Saale dating would increase sixfold the length of exposure since the last ice-cover, although it is difficult to believe that Weardale was not at least occupied by a nivation field during Wurm and possibly Zone III.

Whatever the length of time involved, cryoturbation phenomena are extremely well developed in the area, and the periglacial features to be found in the upper mantle have had a marked effect on subsequent pedogenesis. Certainly the soil parent materials of Upper Weardale show many affinities in origin to deposits outlined by FITZPATRICK (1956), GALLOWAY (1958) and TIVY (1962), although there are several important differences in physical make-up and chemical composition. Solifluxion almost certainly proceeded through Zones 1, 2, and 4, with Zone 3 probably representing a névé accumulation. The complete absence of fresh moraines and recession phenomena in Weardale seems to preclude the development of a corrie glacier during the post-Allerod as envisaged by MANLEY (1959).

## 2.5. The Post-Glacial Period

Recent geomorphic history, with one significant exception, has been one of a progressive modification of the Late-Glacial landscape. Stream incision has progressed and mass movement and colluviation have continued to be the dominant slope processes. Signs of wastage in the form of block-fliessen, surface slides and sheet washing are common. In the scheme of RADFORTH (1962) the area remains a zone of "active frost" with microtopography being influenced by seasonal pipkrake and slope movement. The instability of slopes is further influenced by ecological deterioration in unenclosed areas. Peat erosion and the sheet washing of mineral soil are common landscape features.

A major factor in disturbing the character of possible pre-glacial, glacial, and post-glacial deposits in the Dale has been man. The intense economic interest in mining and quarrying is well documented since the twelfth century and reached a peak in the nineteenth century (RAISTRICK 1934), 1936, 1938). Interest in extracting rocks and minerals has varied from era to era, but includes limestone, ganister, sands, non-ferrous metal ores, and fluorspar. Surface disturbance in the form of mine tailings, tip heaps, the removal of overburden, "hushing", and widespread hillside drainage for water collecting have produced widespread scars and impresses on surface configuration. Their effect on soil character too, has been important.

Plate 3. Hillside scars produced by the mining operation of "hushing" in Killhope Burn. (84/825422)

Plate 4. Stream incision in Rookhope Burn. Abundant relics of past mining.
(84/904433)

Plate 5. A contour hillside drain for water collection for mining in the Upper Dale. (84/860410)

Plate 6. Tailings and chasms produced by mining. (84/795374)

# Chapter 3

## Soils Parent Materials

Character studies of the horizontal and vertical variations of the soil body have invariably stressed parent material as a major control of soil differentiation (GLINKA 1932). More recent studies have accepted this underlying precept, but have in addition sought to quantify in detail the influences of this soil forming factor and, in so doing, have often achieved a significant re-interpretation of particular soil parent materials (RYAN and WALSH 1966).

In Weardale, soil parent materials are directly derived from the underlying geologic strata. The net result of the rather complex geomorphological history of the area has been to produce a wide spectrum of surface deposits ranging from classic <u>in situ</u> weathered material to completely transported morainic deposits. A convenient framework of parent materials is thus presented by Weathered Base Rock, Solifluxion Deposits and Till, a sequence often reflected in the topographic sequence of interfluves and slope crests, slope flanks, and valley bottoms and toe-slopes. The lack of erratic or other evidence for glacial contributions from outside the confines of the Dale emphasises the local origin of all soil parent materials.

No profile has been examined which fails to show some degree of contaminations, however minor, and the grouping of the parent materials is one of increasing intermingling and mixing as the geomorphic history for

## TABLE 5 A CLASSIFICATION OF SOIL PARENT MATERIALS

| | PARENT MATERIAL | GENETIC PROCESS |
|---|---|---|
| Increasing Degrees of Mixing and Contamination | 1. Weathered Rock (Limestones, Shales, Sandstones, Whin Sill). | Weathering<br>Some hillwash contamination. |
| | 2. Solifluxion Deposits | Mass Movement: Late-glacial and contemporary. |
| | 3. Till | Transport and Deposition by Local Ice. |
| | 4. Alluvia | Fluvial Processes. |
| | 5. Spoil | Man Made Materials |

any particular site becomes more complex. The accompanying table presents a five-fold genetic subdivision of parent materials.

Simple classifications of parent materials are notoriously general, however, even when used for investigations dealing with classification and conventional survey. More detail is particularly required for studies of small scale soil variation and of pedogenetic history. In Weardale correlations between soil and parent material are valid only on a regional scale of study and present several anomalies when viewed on a scale other than this. Several anomalies can be explained in terms of probable developmental differences associated with other pedogenic factors (e.g. vegetation changes in the manner of RYAN /1963/), but the polygenetic character of landscape development itself leads to changes in the character of the parent material within any one genetic group.

The basic differentiae of parent material groupings are physical, mineralogical and chemical (BEAR 1964). By the use of property parameters the degree to which parent material has influenced the direction and degree of soil forming processes both past and present, can be assessed. In Weardale the degree of association between chemical and mineralogical properties of the parent material and its genesis is nebulous. Within any one genetic type (e.g. solifluction deposits) local variations of source material can be very great. This is a reflection both of the thinness of the Carboniferous cyclothem and its heterogeneous lithology. It becomes difficult, for example, to distinguish between geologic and pedogenic influences, and for this reason discussion of chemical and mineralogical indices of pedogenesis often resolves itself to a discussion of particular sites.

## 3.1. The Geologic Source

Petrographic, chemical, and X-ray mineralogical work on the Yoredale series in the Pennines indicates the importance of the depositional environment of the sedimentary rocks in determining the main mineral and clay mineral provinces (BLACK 1959). A general picture of the main clay mineral suites is given in fig. 11. This complicated source provides the mineral material for the derived superficial deposits. Although no particular clay mineral is restricted to a particular environment (WEAVER 1957), and illite can occur in any of the major marine and non-marine environments, kandite is most likely to be dominant in non-marine environments.

### 3.11 Limestones

Limestones of the Middle and Upper Limestone Groups are dark-blue coloured, finely grained, and thinly bedded. They contain variable quantities of organic and terrigenous impurities and have an acid dissolution residue of bitumen, pyrites, clay and fine sand. They are formed of a calcite mudstone in which the organic matter occurs as a dark pigment (JOHNSON 1963). Organic material, ferrous sulphides (as pyrite, marcasite etc.),

THE CARBONIFEROUS CYCLOTHEM

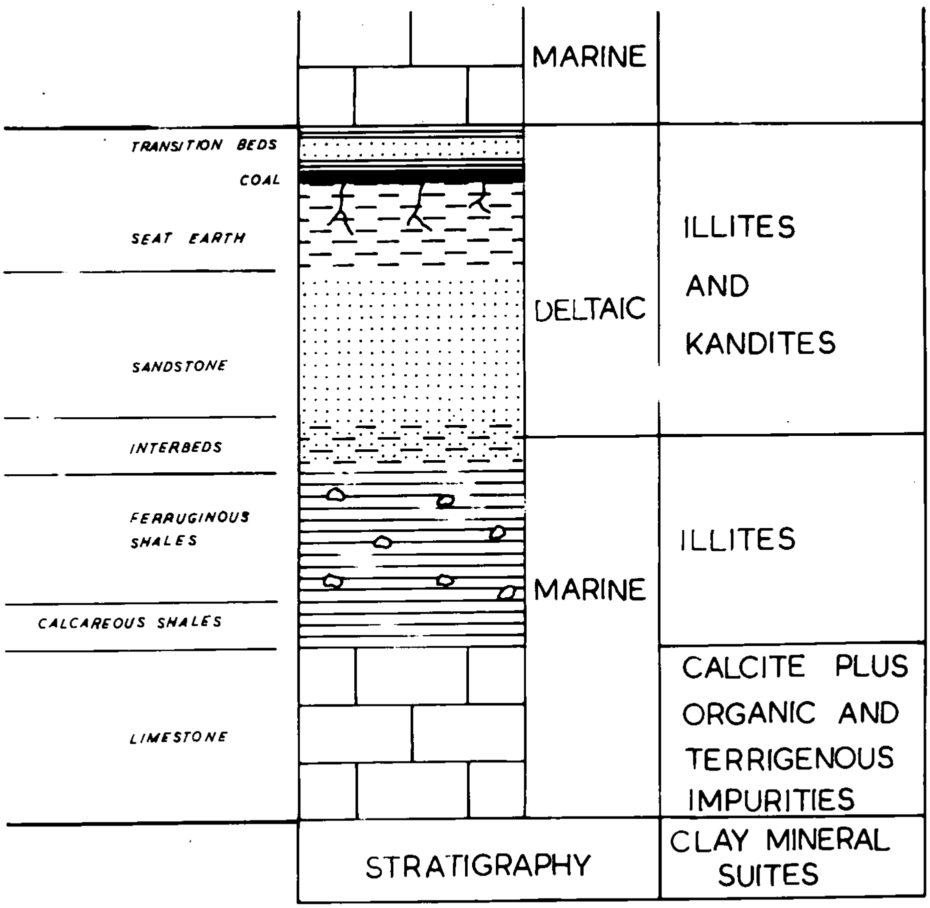


FIG. 11

and smaller quantities of clay minerals and fine sand (quartz) are thus the main weathering derivatives. Analysis of acid residues using the method of CORNWALL (1958) reveals $Fe_2O_3$ contents ranging from 5.0 to 9.3%.

### 3.12 Shales

Three main types of shale occur within the succession. Calcareous shales are found in association with the limestone and are normally dark grey, hard, well bedded, and highly fossiliferous. Above the calcareous shales dark grey coloured mudstones with ironstone nodules are found, and these too grade upwards into micaceous shales and mudstones. Differential thermal analysis shows the illite group of clay micas to be the dominant mineral present whilst X-ray investigation shows chlorite as well which is masked on the D.T.A. by the illite endothermic peak (MARTIN 1955). Bitumen, iron oxides, ferrous sulphide, and quartz are also present, the iron content varying greatly between ironstone and nonironstone varieties.

### 3.13 Sandstones

Several types of sandstone are found in Upper Weardale but they are normally white or brown rocks, moderately micaceous in which the quartz grains are sub-angular, averaging 0.3 - 0.1 m.m. diameter on the Wentworth scale. BUTTERFIELD (1940) has studied the mineralogy of Askrigg Block sandstones in detail and found them to be composed of quartz, feldspar, mica, and occasional calcareous or ferruginous infillings. The heavy mineral suite includes anatase, apatite, rutile, tourmaline, zircon, and garnet, and clay minerals, particularly disordered kaolinite and a mixed-layer illite, are locally abundant.

### 3.14 Whin Sill

Many chemical and petrographic studies of the Whin Sill have been reported (TOMKEIEFF 1929; SMYTHE 1930; DUNHAM 1948). Essentially it is quartz-dolerite composed of 48% pyroxene, 46% feldspar, 8% iron-titanium oxides, and accessory amounts of quartz, orthoclase, horneblende, biotite and chlorite. SMYTHE's (1930) figures for "average Whin" are tabulated below:

TABLE 6

CHEMICAL ANALYSIS OF THE WHIN SILL

| | % s | | |
|---|---|---|---|
| $SiO_2$ | 50.32 | BaO | 0.03 |
| $TiO_2$ | 2.48 | $Na_2O$ | 2.03 |
| $Al_2O_3$ | 15.41 | $K_2O$ | 1.06 |
| $Fe_2O_3$ | 3.09 | $H_2O(+)$ | 1.30 |
| FeO | 8.92 | $H_2O(-)$ | 0.75 |
| MnO | 0.18 | $CO_2$ | 0.46 |
| MgO | 4.89 | $P_2O_5$ | 0.22 |
| $C_aO$ | 8.86 | S | 0.15 |

### 3.15 Seat Earths

Seat earths are common at the top of certain cyclothems and have been interpreted as ancient weathering residues in which coal-forming plants grew (HARRISON and MURRAY 1959; GRIM and ALLEN 1938). Pedologically they are important as a further element of diversification in the source of soil parent materials and a further element in the diverse chemical and clay mineralogical background. In general they show variably crystallised kaolinite, subordinate illite and mixed-layer illite-chlorite, and a strong quartz peak (MACKENZIE 1957).

## 3.2 The Superficial Derivatives

There are three main classes of superficial deposit in Upper Weardale, each occupying a distinctive geomorphic facet and reflecting a particular process history. These are:

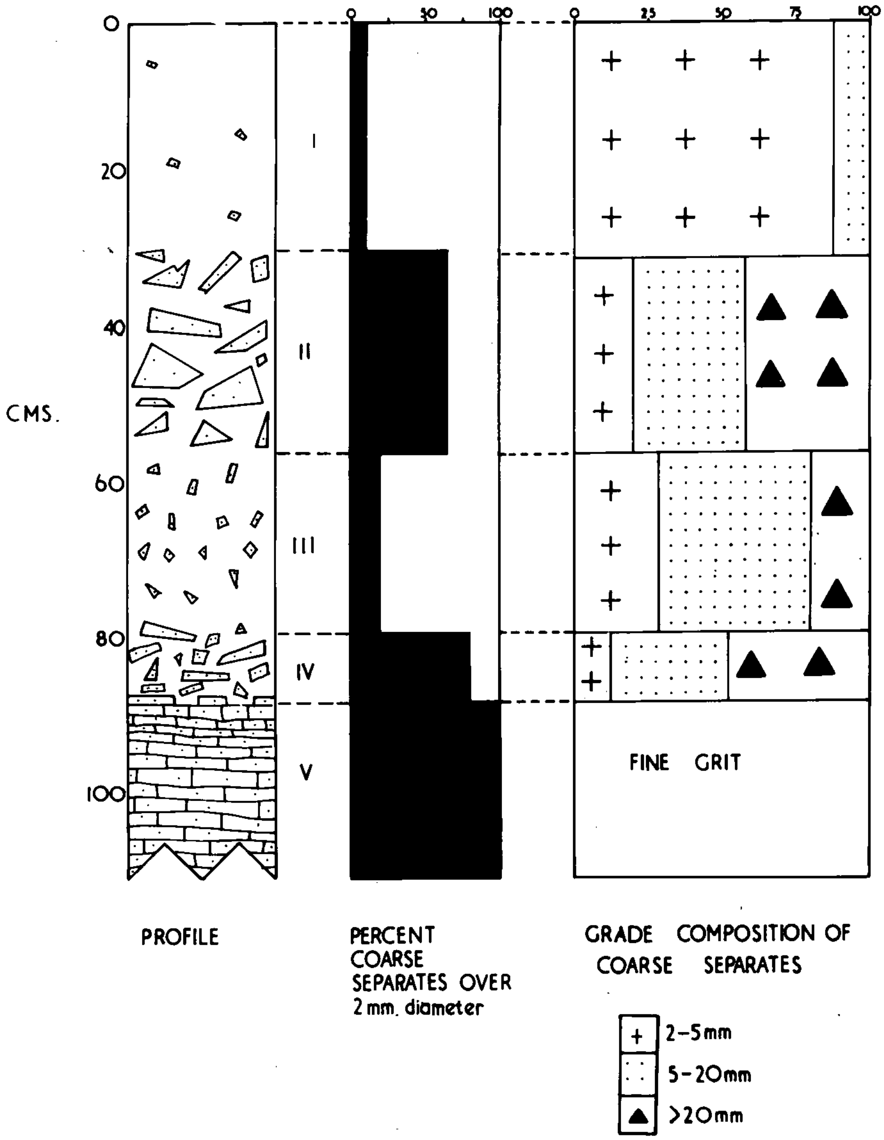
1. the upland regolith on ridges and interfluval crests.
2. solifluction deposits on slope flanks and valley sides.
3. till and riverine alluvia in valley bottoms.

Whilst the possibilities for polymorphism are substantial and all in fact may be the present day expressions of a single genetic feature (e.g. a Saale till sheet), each has received distinctive fashioning in the geomorphic history, at least since Zone 1 and probably for much longer.

### 3.21 The upland regolith

No field and analytical evidence can be found to support RAISTRICK's (1931, 1933) suggestions that certain of the deeply weathered upland clays of the Pennines represent the drifts of an early glaciation which was more extensive than the later one when fresh clays of the valley floors were deposited. Ideas and speculations on the origin of deposits on the upland areas of Britain have recently been intensified by the work of TIVY (1962) and RAGG and BIBBY (1966) in Scotland. In Weardale, too, in areas on the interfluval crests where solid rock occurs

FIG. 12 MORPHOLOGY OF THE UPLAND REGOLITH



near the surface, a superficial regolith often is present and correlates well with what RAGG AND BIBBY (1966) describe as a frost weathering product.

The upland regolith of Weardale shows a pronounced stratified morphology. An upper layer consists of a stony, subangular "rubble layer" (PETTIJOHN 1949), largely composed of angular Carboniferous sandstone fragments, and passes sharply into a layer of fine sandy loam or silt loam containing small angular stone fragments. This second layer gradually becomes more stony in depth as bedrock is approached. This tripartite morphological form is a constant feature of level sites (fig. 12).

An important morphometric feature of the stones in the regolith is the cutanic sheath which marks their upper surface and which differentiates them texturally from the surrounding matrix. The sheathing is similar to that described by FITZPATRICK (1956). Its textural composition is silty clay/silt although in Weardale sites the contribution from pedogenic amorphous sesquioxides has been high. The interstatial fabric between the encased stones is generally only loosely coherent with little true fragipan induration (GLENTWORTH and DION 1949), although the lack of fine material in the Carboniferous sandstone may be a contributory cause of this. Many of the larger sand particles over 1 m.m. diameter show cutanic sheathing on their upper surfaces (fig. 13), but "granules and droplets" (ROMANS ET AL 1966) and "wrinkle marks" (KUBIENA 1938) have not been observed in thin section.

Plate 8. The upland regolith developed on Upper Carboniferous Sandstone on Bollihope Moors. (84/968360)

CUTANIC SHEATHING IN THE UPLAND REGOLITH.

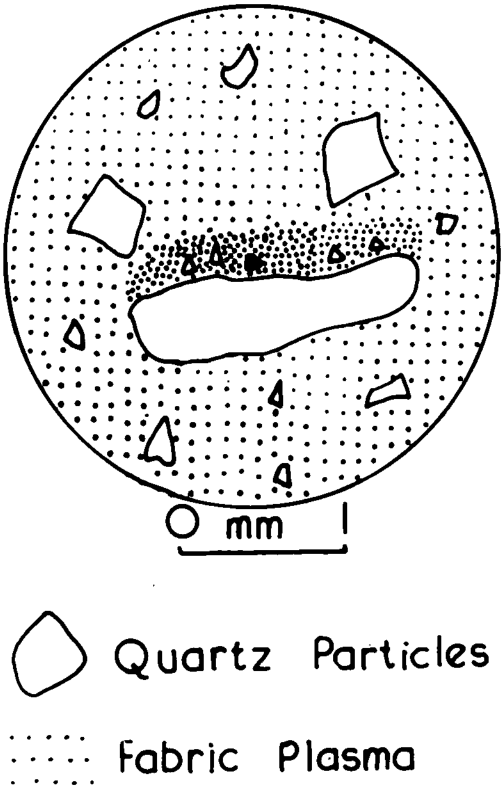


FIG. 13

Plate 9. A truncaled upland regolith on Stanhope Moor.
(84/995424)

An analysis of the orientation of stones for three sites reveals a low order of orientation throughout, although a tendency for vertical alignment can be discerned (fig. 14) when plotted on the 'Schmidt net' (KRUMBEIN 1939).

Mechanical analyses (fig. 15) further illustrate the degree of vertical sorting which has taken place within the regolith. The stone layer shows a unimodal size-grade curve which contrasts markedly with the bimodal curve for the underlying finer horizon. This is in keeping with recent attempts at determining the effects of frost disintegration of rocks which have been made by TRICART (1956), WIMAN (1963) and DUNN and HUDEC (1966). The mechanical analysis for the three Weardale sites correlates well with the range of graded material from silts to angular stones which an annual freeze-thaw cycle can produce (TROLL 1944; HOPKINS AND SIGAFOOS 1951; DOUGLAS AND TEDROW 1960). Frost riving during the winter freeze, with lessivage of fines during the thaw period would initiate stratification (CORTE 1962), and this would gradually form a rubble layer with sheathing on the upper surfaces of stones.

### 3.22 Slope deposits

Whereas on the upland crests cryogenic activity has produced differentiation of material in the classic manner envisaged by TROLL (1944) and CAILLEUX AND TAYLOR (1954) for "strukturboden", evidence for the effects of periglaciation in Weardale is much more visible in the field on slopes. Here traces of the late glacial climatic phase are more visible in morphology and exposure.

PETROFABRIC DIAGRAMS FOR THE UPLAND REGOLITH.

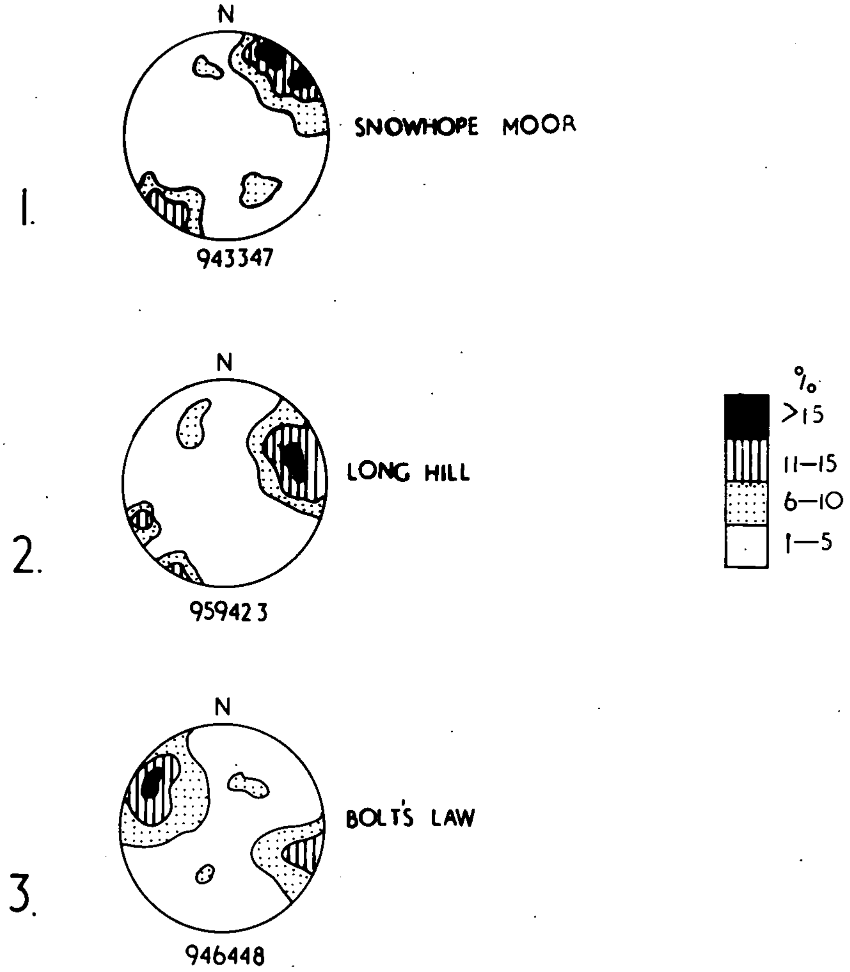
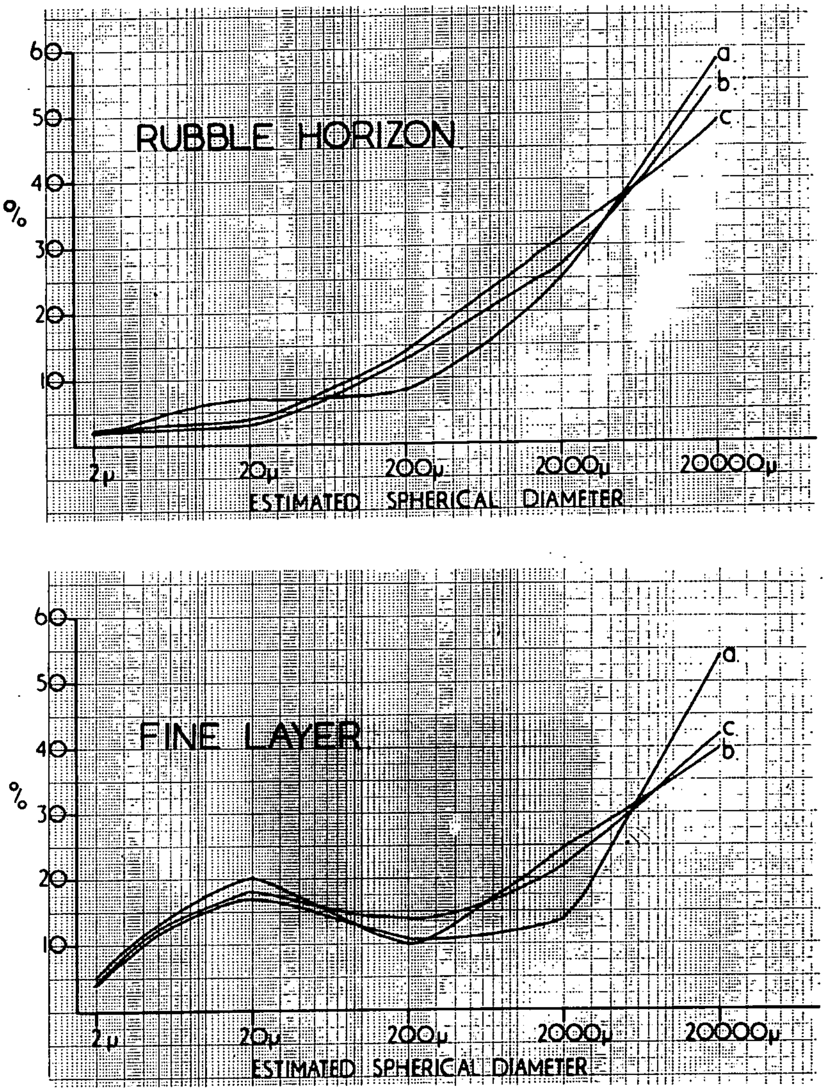


FIG. 14

# MECHANICAL ANALYSIS OF THE UPLAND REGOLITH.



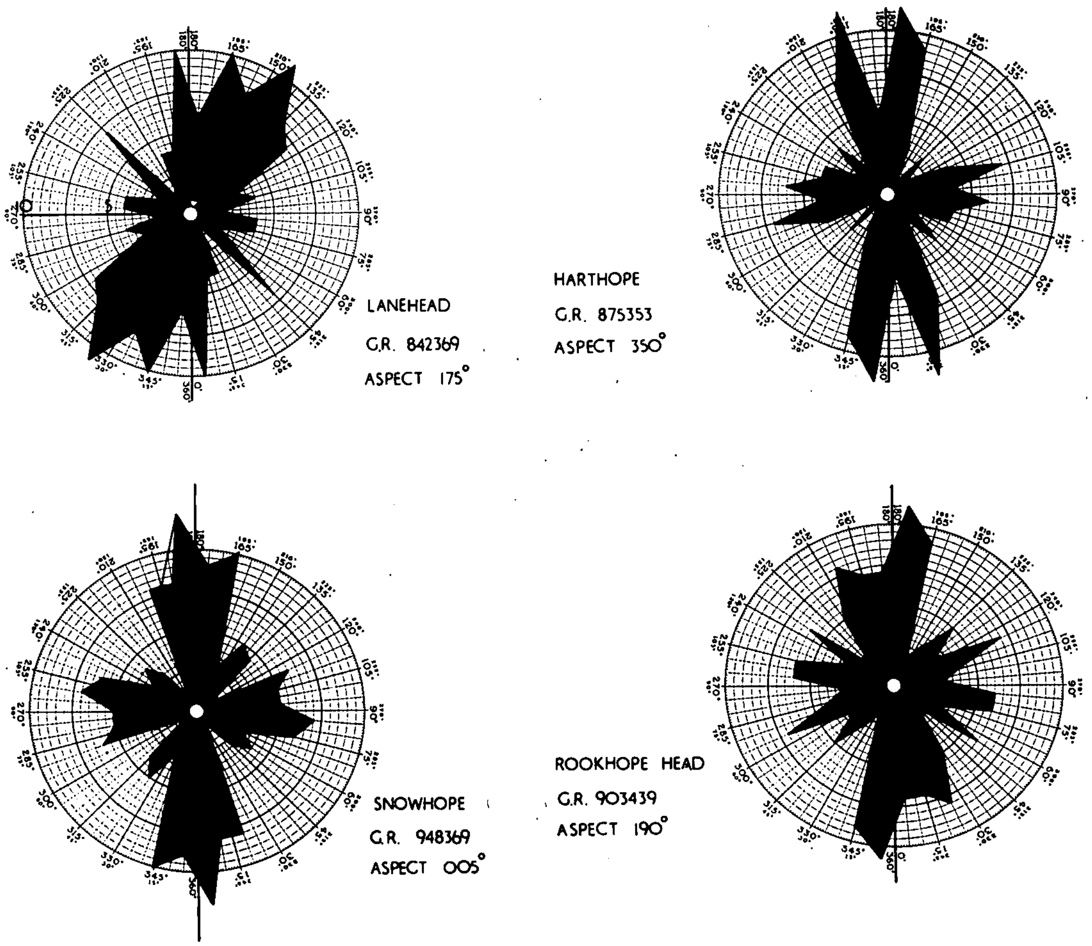
967359

FIG. 15

The most widespread relict of ANDERSSON (1906) - type flowage during depergelation is a dark grey (10YR 4/1) compact, tenacious solifluction deposit which forms one of the most important parent materials in the Dale. It is intensely gleyed, either uniformly or in the form of ochreous mottling, and has a high content of stone-sized fragments derived from local rocks. In fact it has many of the attributes of a glacial till which has undergone considerable congeliturbation since deposition.

Displacement downslope is principally evidenced by the orientation patterns of the included stones. All nets show a significant slope component in response to flowage and sludging (fig. 16). This is an invariable mass movement feature of these deluvial deposits. The analysis of data for stone dip is less clear and dips can vary very markedly within sites and between sites. Many factors of variation are probably involved in this pattern, but it is significant that stone-size is a major control (fig. 17). Larger stones and slabs tend to be aligned at lower angles and therefore more horizontally than the slope on which they occur, indicating a sliding motion independent of the main mass movement. Smaller stones assume a similar alignment to the slope being a much more integrated part of the total fabric of the deposit.

Although it is difficult to distinguish between geomorphic and pedogenic structures in the deposits (BRYAN 1946), the general morphology indicates the importance regionally of turbulent rather than laminar flow. The loam/clay loam fabric is characteristically massive, compact and unsorted. On dehydration it does



LANEHEAD
G.R. 842369
ASPECT 175°

HARTHOPE
G.R. 875353
ASPECT 350°

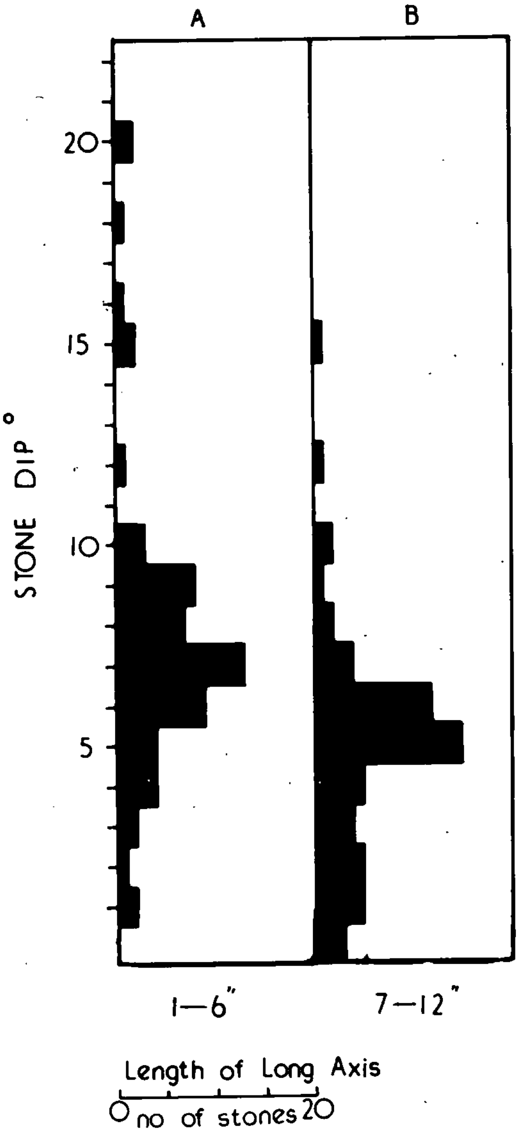
SNOWHOPE
G.R. 948369
ASPECT 005°

ROOKHOPE HEAD
G.R. 903439
ASPECT 190°

STONE ORIENTATIONS IN SLOPE DEPOSITS.

FIG. 16

# RELATIONS BETWEEN STONE DIP AND STONE SIZE.



$\bar{A} = 7.75°$

$\bar{B} = 4.90°$

$t = 4.57$ for 118 d.f.

signif. $< 0.1\%$

PUDDINGTHORN PASTURE
SLOPE 7°

FIG. 17

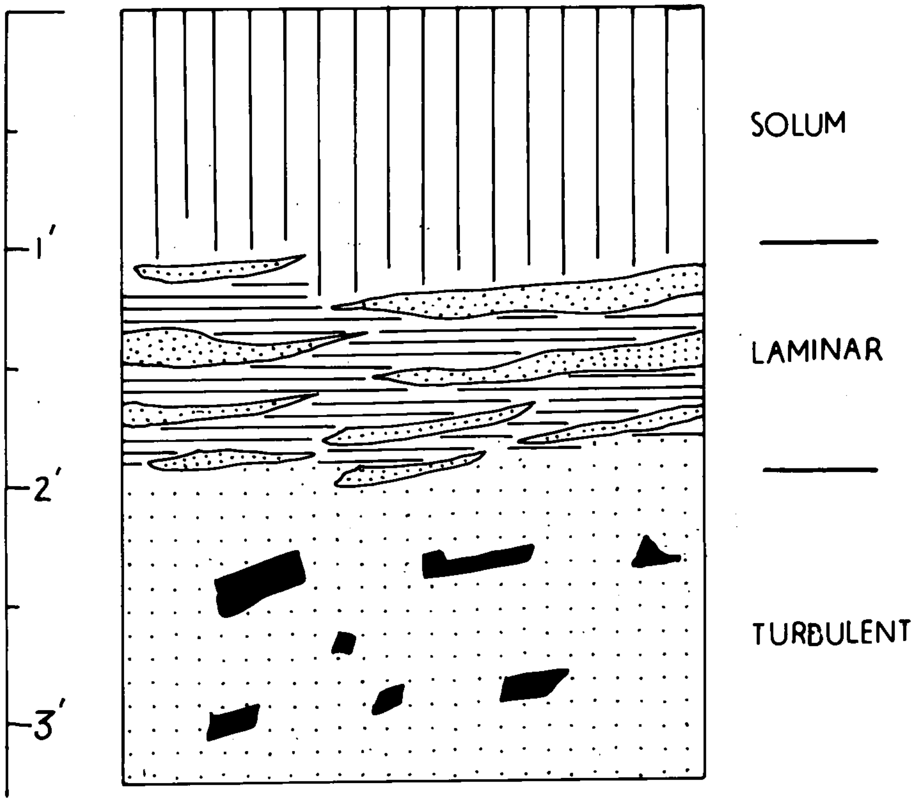
show a compound structure of prismatic and platy units, but generally it has the typical form of an unsorted deposit. This may be the net result of variable hillside slopes, the diverse nature of the autochthonous source material or the intensity of the solifluction phase after the Saale or during the Wurm glacial period.

Areas of slope deposit with laminae and foliated structures are rare and appear to be restricted to intermittent patches on gently inclined slopes near stream courses. (fig. 18.) It is noticeable that even in such locations the laminar material grades downwards into turbulent solifluction deposits, indicating very local displacement and redisposition of clays and silts as fluviatile sediments during the post-glacial phase. As such they resemble the "deltaic deposits" of Knock Shield in East Allendale described by ASHLEY ( 1961 ).

Other relict frost-sorted periglacial forms are common in the zone of solifluction deposits. In particular fossil wedges and fossil stone stripes are important stratigraphical indicators of the periglacial influence. Wedges are usually found beneath the solifluction deposit, indicating the onset of intense cold and permafrost prior to the main phase of mass movement (fig. 19). Stone stripes, in contrast, generally occur within the upper portion of the slope deposit, indicating that their origin is probably contemporaneous with the solifluction period (fig. 20).

Recent work by PIGOTT (1962) on the origin of superficial deposits on Carboniferous Limestone in Derbyshire raises the interesting possibility of periglacial wind action in the development of the present surface cover.

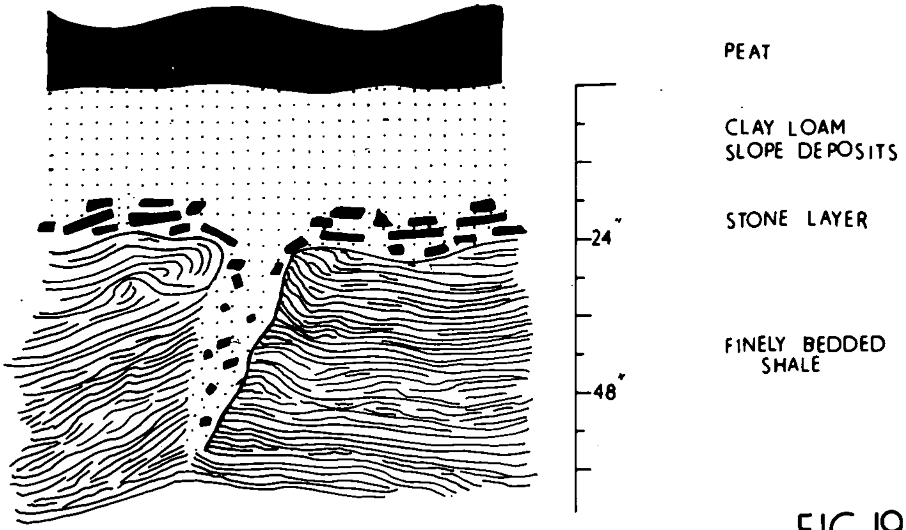
# LAMINAR STRUCTURES IN SLOPE DEPOSIT.



PUDDINGTHORN PASTURE 840425

FIG. 18

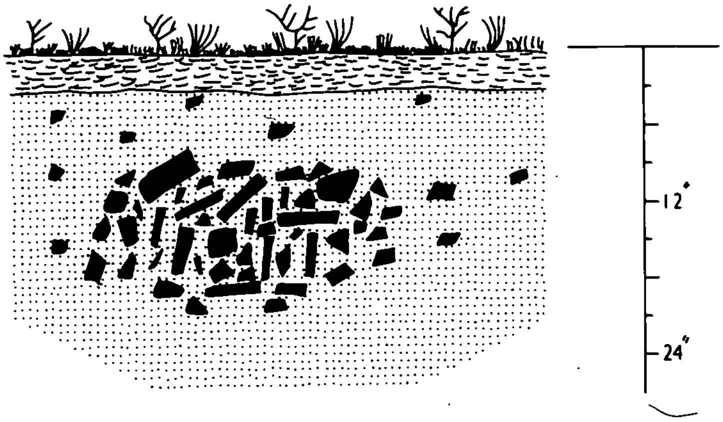
## FROST WEDGE BELOW SLOPE DEPOSIT.



CHAPEL FELL

FIG. 19

## STONE STRIPE IN UPPER SLOPE DEPOSIT.



ROOKHOPE

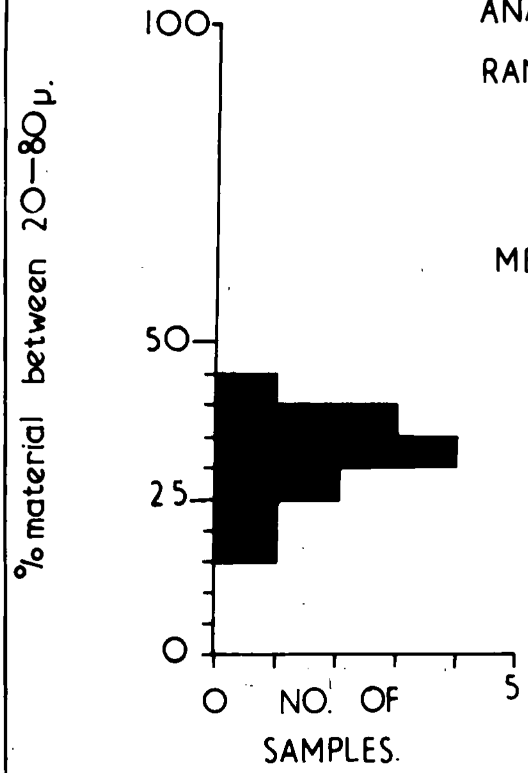
FIG. 20

Such an origin has received sympathetic attention in studies of the deposits of Southern England since the early work of GREENLY (1922), but the contribution of PIGOTT is especially interesting from the point of view of the Pennine environment and the fact that the loessic material is shown to overlie what appears to be a limestone residue of an older intense weathering period. PIGGOTT, in fact, correlates this weathering product with the preglacial disintegration of LINTON (1954, 1955). BULLOCK's (1964) work in W. Yorkshire reinforces the findings of PIGOTT.

Studies of mechanical composition and mineral morphometry of superficial deposits overlying the Great Limestone of Weardale show no evidence for the process outlined above. There is no preferential accumulation of mineral particles in the diameter range between 20 and 80$\mu$ (fig. 21), thus failing to satisfy one of the prime conditions of PERRIN (1956) for regarding the material as wind-transported dust. Another piece of negative evidence is the lack of wind faceting and etching of stones in the field, and the rounded and sub-rounded form of included quartz in thin section (fig. 22) and in the fine sand separates.

A more important feature of the slope deposits is the presence of a distinct stone horizon in their surface portions (fig. 23). A thin rubble layer, consisting of angular sandstone blocks and stones is commonly present in parent material sections. These subsurface formations resemble the "stone lines" of RUHE (1958) and the 'carpedolith' of PARIZEK AND WOODRUFF (1957), rather than the 'stone pavements' of BALL (1967). Surface concentrations

MECHANICAL COMPOSITION OF SUPERFICIAL DEPOSITS OVER LIMESTONE.



ANALYSIS OF TWELVE RANDOM SAMPLES

MEAN 31·7%

FIG. 21

MORPHOLOGY OF QUARTZ IN SUPEPFICIAL DEPOSITS OVER LIMESTONE.

X R

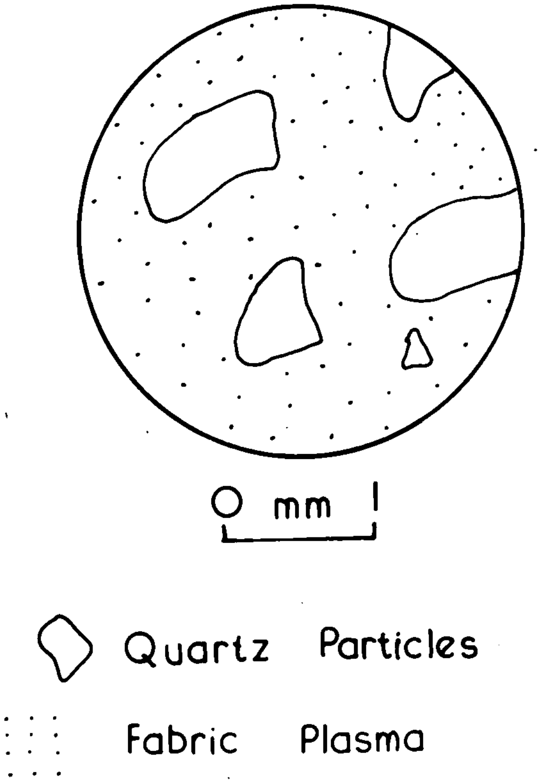
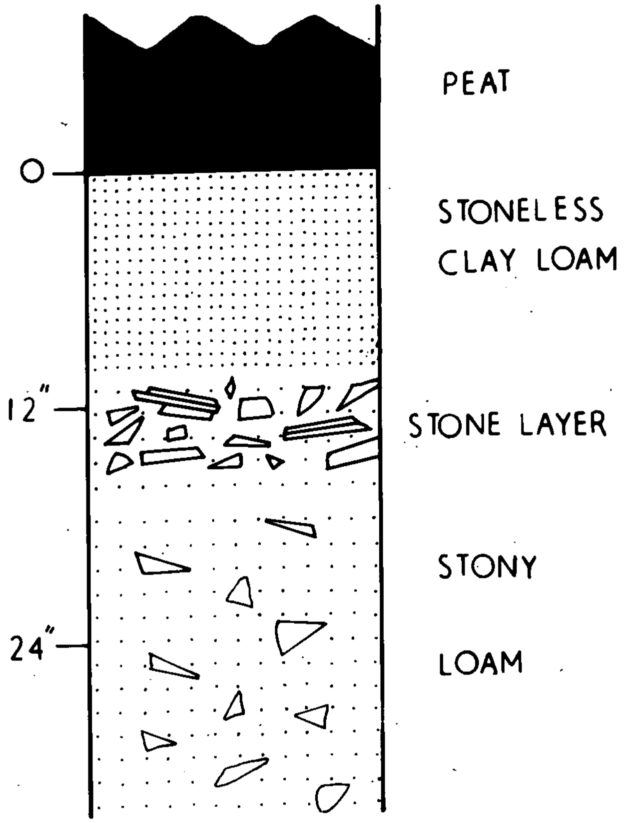


FIG. 22

# STONE HORIZON IN SLOPE DEPOSIT.



KILLHOPE MOOR

FIG. 23

of slabs and stones in the form of both blockmeeren and blockfliessen is a common feature downslope of sandstone rock outcrops in the Dale and indicates the still active periglacial congelifraction in the area. Such material could have become covered locally with colluvial material during late-Glacial times, but it is more probable that the stone lines have developed by sorting processes of congeliturbation in a manner akin to the formation of the stony member of the upland regolith.

Although the major landforms of the slope deposits derive from a previous permafrost period and are hence relict rather than contemporary features, present freeze-thaw cycles are of importance locally. The present 'humid-tundra' type climate of the upland surfaces results in widespread 'pipkrake' needle ice formation during the winter months, particularly in organic surface horizons. This correlates with the zone of 'active frost' of RADFORTH (1962). In addition to important pedologic influences such as peat erosion and increased spring-melt, the formation of ice leads to the heaving of surface organic and mineral horizons and to patterned microrelief features. On gently sloping facets 'thurfurs' are characteristic, whilst on steeper slopes active colluviation produces rather inchoate and heterogeneous 'girlandenböden', with "creeping boulders" and "ploughing boulders" in the manner described by TUFNELL (1966 ) for the Lake District.

A consideration of the effects of geomorphological structures on profile development will be given later. The influence of geomorphological processes on pedological processes is a vital consideration in upland soils, particularly on sloping sites, and there is widespread evidence that soil horizon differentiation results from

Plate 10. Frost and needle ice development in upland peat. April 1966.
(84/845435)

Plate 11. A clayey slope deposit in Rookhope Burn.
Low stone content and intensely gleyed.
Structure massive, breaking down to
prismatic or platey depending on water content.
(84/915429)

Plate 12. A sandy clay/sandy clay loam slope deposit with a high content of angular Carboniferous Sandstone stones. Variable fabric but with preferred orientation of stones downslope. (84/958413)

Plate 13. A fossil stone stripe exposed in a loamy slope deposit.(84/873450)

Plate 14. Thurfur micro-relief on a patch of mineral soil within the blanket peat zone. (84/834439)

Plate 15. A frost wedge exposed at the base of a clayey slope deposit over weathering shale. Distinct stone line of angular sandstone flags. (84/870350)

Plate 16. Heavy slope deposit over weathering shale. Stones aligned downslope at the surface of the deposit. (84/863355)

Plate 17. Contemporary mass movement with creeping boulders.
(84/845431)

primary depositional features as well as from intrinsic pedological processes.

### 3.23 Till

Deposits laid down by a Quaternary glacier in Upper Weardale are restricted to the main valley floor and lower side slopes, particularly along the southern side of the valley. Whilst there is no detailed borehole evidence to show the nature and depth of the sub-drift surface, the lower reaches of the larger southern tributaries of the R. Wear - Middlehope Burn, Westernhopeburn and Swinhope Burn - appear to have a considerable thickness of till (fig. 24). Buried valleys are a common feature of the drainage system of Co. Durham (WOOLACOTT 1905) and it is an interesting speculation whether any of the Weardale tributaries contain buried valleys in view of the fact that DUNHAM (1948) has shown from boring evidence that East Allendale contains drift-filled valleys.

The till of the lower slopes varies in texture and composition, but generally it is a stiff clay/clay loam containing erratics of local rock which are characteristically smooth and striated. It is bluish grey in colour (5B5/1) with reddish blotching around included stones and root channels. It has the evocative description 'Blue Joss' from the local dalesfolk. Its structure is generally massive, becoming prismatic on dehydration.

It is extremely difficult to map the boundaries of regolith, solifluction deposits, and till, and hence statistical trend surfaces may offer a new method of differentiating between these genetically distinct deposits (FALCONER in preparation). In addition to colour and

FIG. 24 SUPERFICIAL DEPOSITS

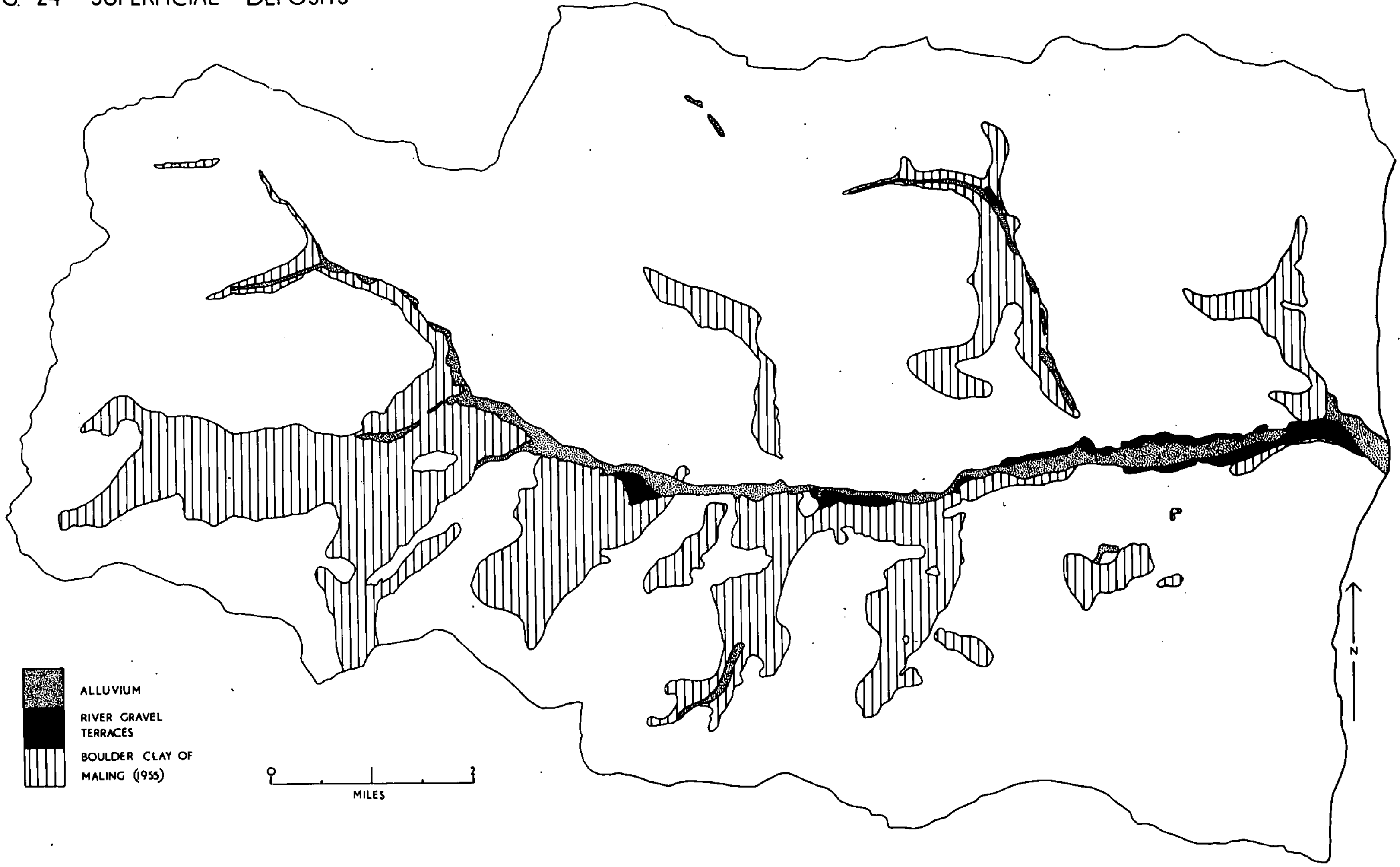


Plate 18. Valley bottom till with small erratic material of Carboniferous Sandstone and occasional Carboniferous Limestone erratics.
(84/904365)

Plate 19. Gleyed clay till with Carboniferous Limestone erratics. (84/979384)

topographic position, however, an important property which distinguishes the till from the solifluction deposits is the nature and orientation of the stone content.

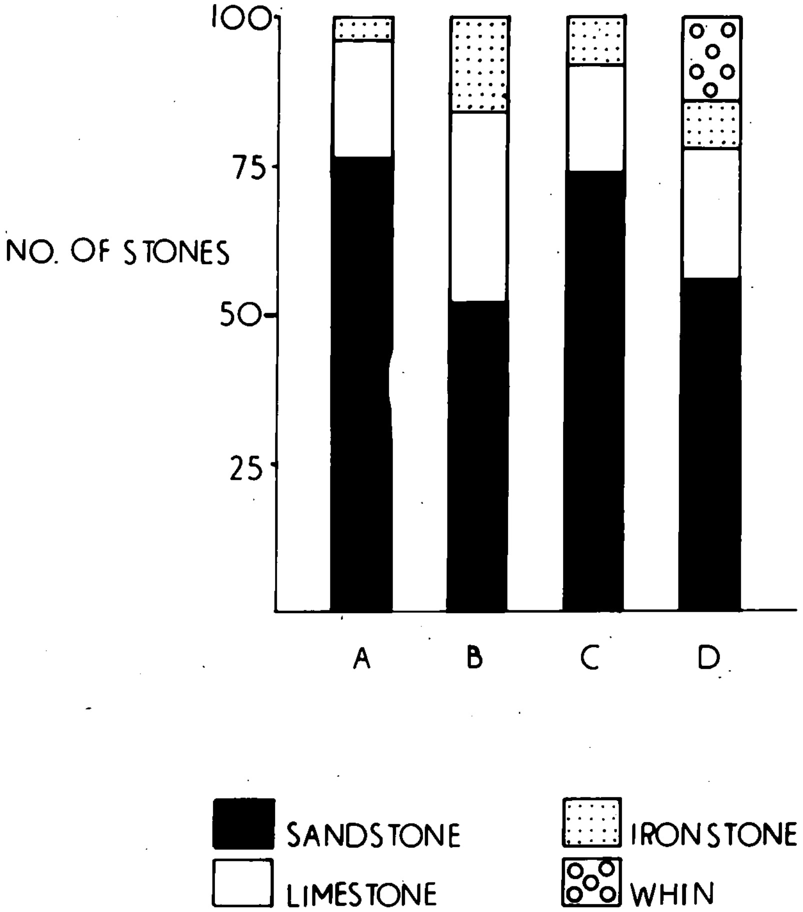
Within the slope deposits the included stones consist predominantly of sandstones which are generally sub-angular and seldom smoothed and striated. Fragments of limestone only occur immediately downslope of a local outcrop. By contrast, till contains large numbers of sandstone and limestone erratics. The content of limestone pebbles and boulders is often high and well rounded, polished, and striated stones are characteristic (fig. 25). The orientation of the stones in the till fabric also contrasts with that of solifluction deposits. At four sites examined a distinct west-east component is observable (fig. 26).

Although hummocky terrain can be seen in portions of the lower valley, there is a remarkable absence in the upper dale of features indicative of ice retreat. No meltwater channels terminal moraines, "dead ice" features, and fluvio-glacial deposits can be recognised despite the claims of MOORE (private communication) for a terminal moraine at Eastgate. CARRUTHERS (1946) argues for a downstream glacial retreat on account of the lack of terminal moraines which might indicate pauses in a headward retreat. This introduces several complications, however, and the thesis of DWERRYHOUSE (1902) for a virtually continuous retreat, without pause or readvance, seems more acceptable.

### 3.24 Alluvial Material

There is a notable absence of fluvio-glacial sands and gravels along the Upper Wear, and all coarse material along the valley floor is fluvial in origin. Although

LITHOLOGY OF STONES IN TILL.



A 860 393

B 908383

C 967382

D 983394

FIG. 25

# ORIENTATION OF STONES IN TILL.

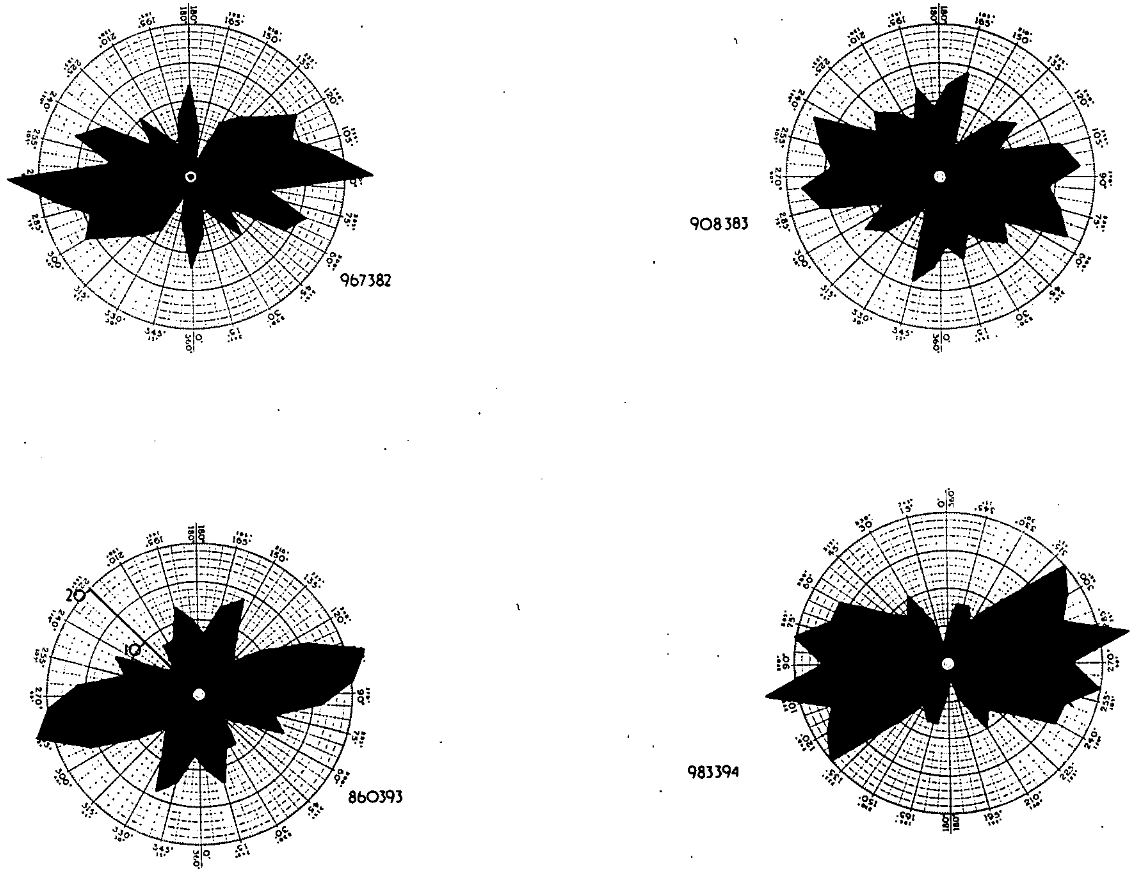


FIG. 26

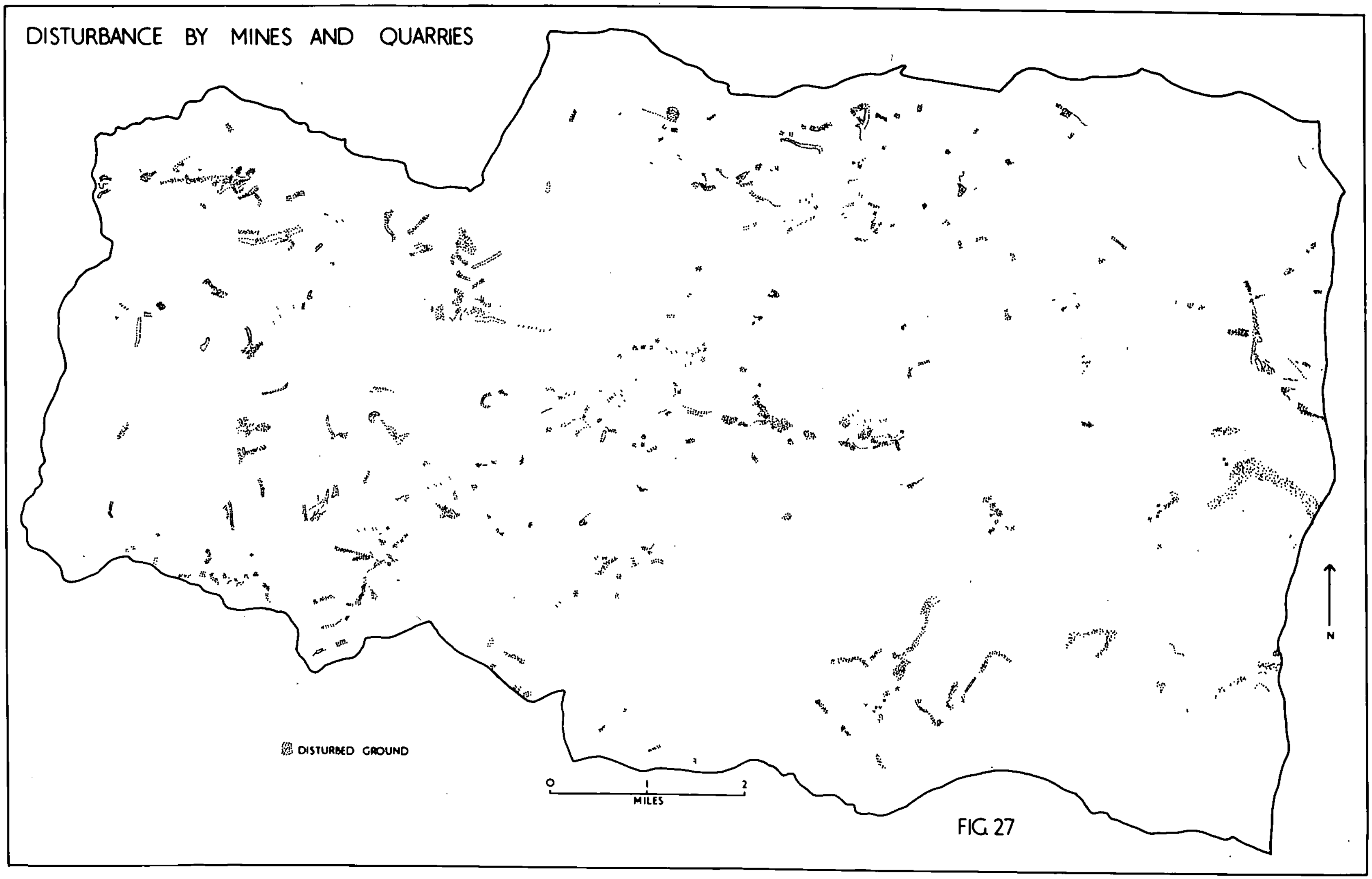
Plate 20. Alluvial gravels deposited over till.
(84/912383)

the post glacial history of the river is incompletely known, a well marked second terrace can be traced from Wearhead to Stanhope. The terrace edge is ten feet above floodplain height at St. John's Chapel, gradually increasing to twenty eight feet at Stanhope. The terrace is composed of coarse gravel and sand and MALING (1955) considers it to be the result of continuous excavation of the valley. A possible minimum age of this terrace is provided by the discovery of several large Mesolithic sites in the vicinity of Eastgate. These have been described by FELL AND HILDYARD (1953) to represent late Tardenoisian culture.

The first terrace or floodplain of the river forms a narrow strip of terrain which only broadens out to the east of Westgate. Many of the gravels are large and form torrent deposits with a fine sand matrix. Locally in patches, however, fines have been deposited from slope erosion to form sandy loam/silt loam parent materials.

### 3.25 Spoil

Human activity in the form of mining and quarrying has a long history in the upper dale (DUNHAM 1948; RAISTRICK 1965). An important pedogenic result is the production of completely man-made topographic forms (tips, fans, embankments etc.) which since the cessation of mining have become the site of renewed pedogenesis. The extent of such relics in the area is truly remarkable (fig. 27) and without a completely documented record for economic activity, the chances of gross geomorphic misinterpretation would be high, and not a little amusing.



DISTURBANCE BY MINES AND QUARRIES

FIG 27

The physical and chemical character of spoil materials will be considered more fully in dealing with soil formation on them. Suffice it here to state that the range of chemical characteristics is very great, ranging from highly metallic tips to the more common spoil of limestone and sandstone quarrying. The areas are extremely interesting, however, as they provide ready made laboratories for studying both the direction and degree of contemporary soil processes.

# Chapter 4

## Ecological History

Whilst pedologists have consistently recognised the importance of the climatic and vegetation influences on soil formation (JENNY 1941), more recent pedogenetic knowledge has considered the evolution of soils within the context of the history of their vegetation cover (MITCHELL 1956; DIMBLEBY 1965). The upsurge of palaeo-ecological, and to a lesser extent archaeological, evidence of post-Glacial environmental change is giving new background material for fresh appraisals of British soils. These appraisals stress the essential polymorphism and dynamism of the British profile, in which the present soil, together with the present climate and associated vegetation, is regarded as a single point on an evolutionary time graph. This time graph may show sequential environmental changes which are wholly dissimilar to those of today; the present environment of the soil is often atypical of what the soil has experienced throughout the bulk of its developmental history.

### 4.1 Post-glacial Vegetation History

The presence of appreciable thicknesses of blanket-peat above 1600' in the Northern Pennines has enabled a comprehensive scheme of environmental change to be established in the manner of BLYTT AND SERNANDER (1908 ) and ERDTMANN (1928). Several of the peat deposits studied by ERDTMANN (op cit.) were in the Pennine region, and detailed work has been continued by RAISTRICK AND BLACKBURN (1931, 1932, 1933). GODWIN AND CLAPHAM ( 1951) reinvestigated a Cross Fell site earlier described by LEWIS (1904), and JOHNSON (1963) has recently produced pollen diagrams for the Moorhouse region.

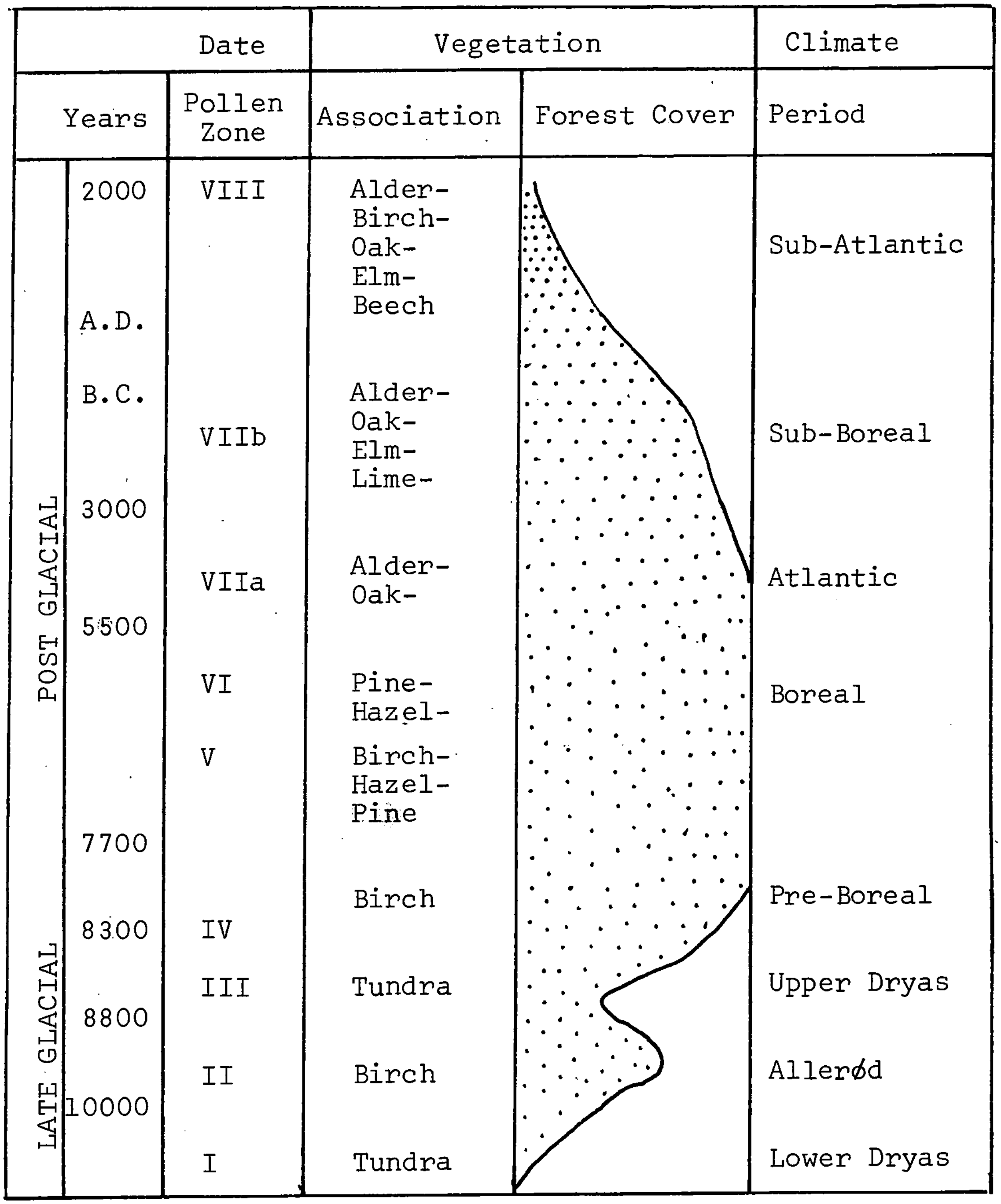
The pollen zonation scheme of GODWIN (1956), now reinforced by radiocarbon dates and archaeological evidence, is reproduced in fig. 28.

Although discussion on the character of the peat is given later in a section on peat soils, a representative blanket peat profile from Harthope Fell (fig. 29) allows the main features to be shown. The substrate horizon is of a solifluction clay with included coarse sandstone fragments. Ample evidence of late-Glacial periglacial activity can be found in this layer. Immediately overlying the mineral substrate is a thin zone of amorphous peat. This passes into the main forestrian layer with many remains of birch stems and roots, a very common feature of the upland peats. On top of this soligenous layer the peat of ombrogenous bog proper is represented by a great thickness of fibrous Eriophorum-Sphagnum-Calluna peat. On top of the sequence the living vegetation of the present day mixed Eriophorum-Calluna heath is found.

During the late-Glacial period intense cryoturbation and plant colonisation appear to have been active simultaneously, arctic plants and tundra shrubs advancing particularly during the Allerod oscillation. These processes continued during Zones 4, 5, and 6 and account for the interstatification of narrow organic peaty bands within the cryoturbation deposits at several sites. They are in evidence exposed by recent Forestry Commission tracks at Broad Meres and correspond to similar bands investigated by GODWIN AND CHAPMAN (1951) on the flanks of Cross Fell. Here they are thought to be of Boreal (Zone 5) age. During Zones 5 and 6 further colonisation of favourable sites by plant species

Plate 21. The basal forest layer developed on a clay loam slope deposit beneath blanket peat at 2000' (84/864341)

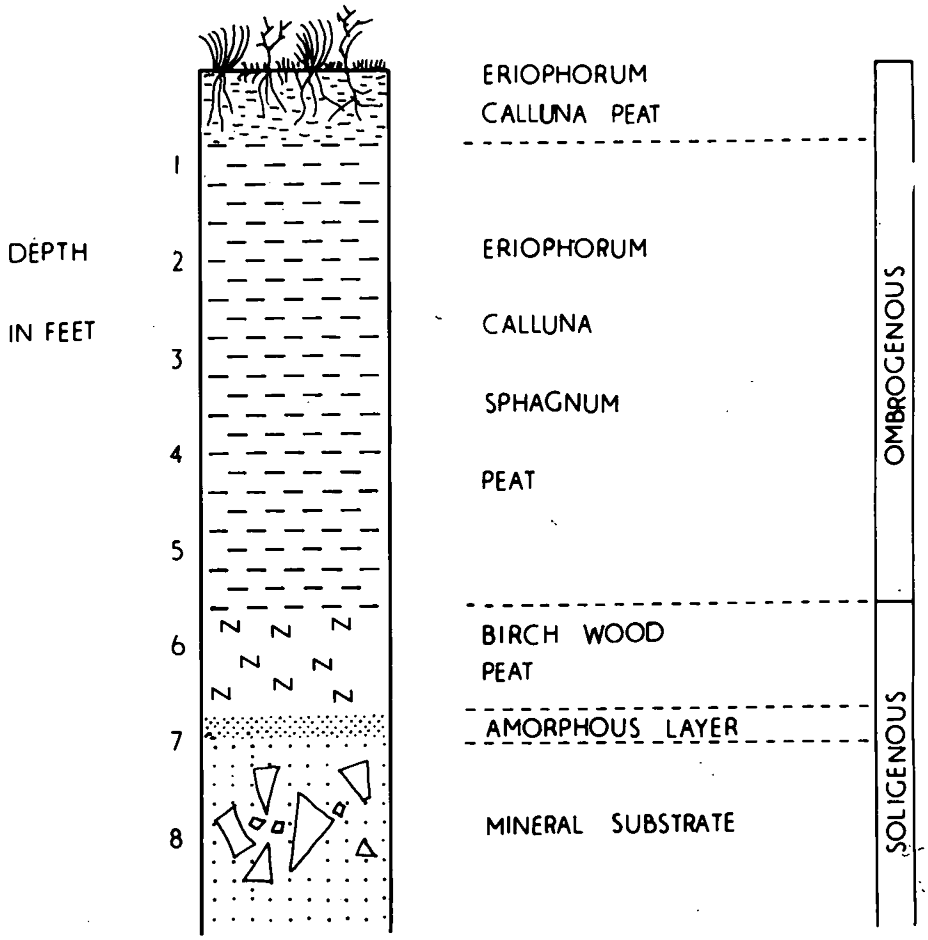
LATE-GLACIAL AND POST-GLACIAL CHRONOLOGY OF GODWIN (1956)



| Date | | | Vegetation | | Climate |
|---|---|---|---|---|---|
| Years | | Pollen Zone | Association | Forest Cover | Period |
| POST GLACIAL | 2000 | VIII | Alder-Birch-Oak-Elm-Beech | | Sub-Atlantic |
| | A.D. | | | | |
| | B.C. | VIIb | Alder-Oak-Elm-Lime- | | Sub-Boreal |
| | 3000 | | | | |
| | | VIIa | Alder-Oak- | | Atlantic |
| | 5500 | | | | |
| | | VI | Pine-Hazel- | | Boreal |
| | | V | Birch-Hazel-Pine | | |
| | 7700 | | | | |
| | | | Birch | | Pre-Boreal |
| LATE GLACIAL | 8300 | IV | | | |
| | | III | Tundra | | Upper Dryas |
| | 8800 | | | | |
| | | II | Birch | | Allerød |
| | 10000 | | | | |
| | | I | Tundra | | Lower Dryas |

Figure 28

## SECTION THROUGH BLANKET PEAT.



HARTHOPE FELL TOP

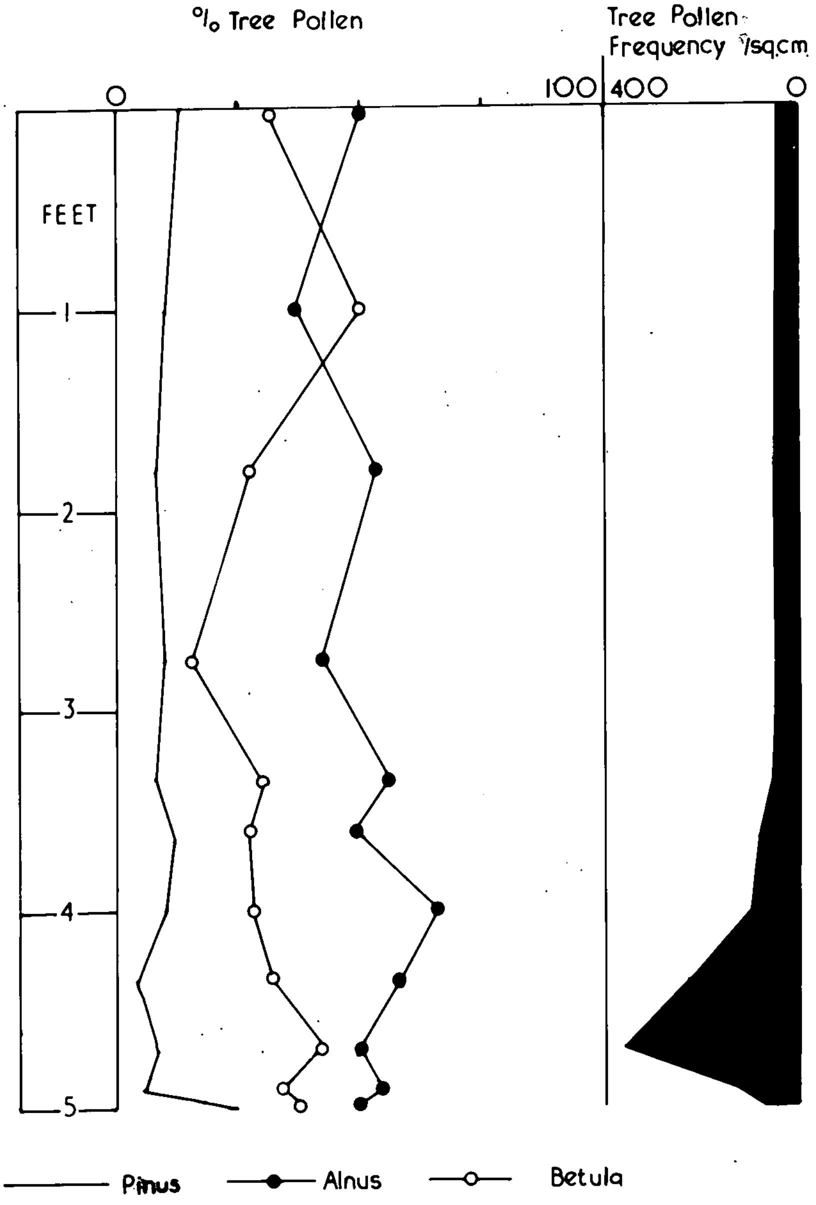
FIG. 29

was taking place under the impact of a general and rapid climatic amelioration over the British Isles. By the last stage of the Boreal period (Zone 6a) light forest covered the whole area, dominantly composed of Betula with some Salix and Juniperus, and thick layers of forestian peat were laid down. The small diameter of the wood remains may indicate the scrub-like nature of the 'forest' cover.

At the end of the Boreal period, at about 5500 B.C., according to the absolute dating of GODWIN ET AL. (1957), widespread blanket-peat growth started as more humid conditions returned to the British Isles. Eriophorum vaginatum was the dominant peat forming plant with sub-dominant Sphagnum and Calluna. Ombrogenous bog deposition is thought to have started on the higher watershed ridges at the Boreal-Atlantic transition and rather later on the lower slopes.

The period of bog formation continued for a long period of time and has only been interupted by the dramatic signs of peat erosion which are so conspicuous today (BOWER 1959, 1960a, 1960b, 1961). The date of the onset of erosion conditions is a matter of conjecture, as is the nature of its trigger mechanism, but one suggestion is that it may be correlated with climatic deterioration at the beginning of Zone 8 (Sub-Atlantic) about 500 B.C. The present nature and extent of peat erosion will be considered in a later chapter. Valuable information on the ecological history of Western Durham is given by the pollen diagrams of RAISTRICK AND BLACKBURN (1931), 1932) and JOHNSON (1963). All profiles documented emphasise the importance of a Boreal woodland habitat, the development of thin soligenous peat at the Boreal-Atlantic transition, and the subsequent deposition of an Atlantic ombrogenous cover (fig. 30).

POLLEN SPECTRUM.



KILLHOPE MOOR 2050′

after Raistrick and Blackurn (1932)

FIG. 30

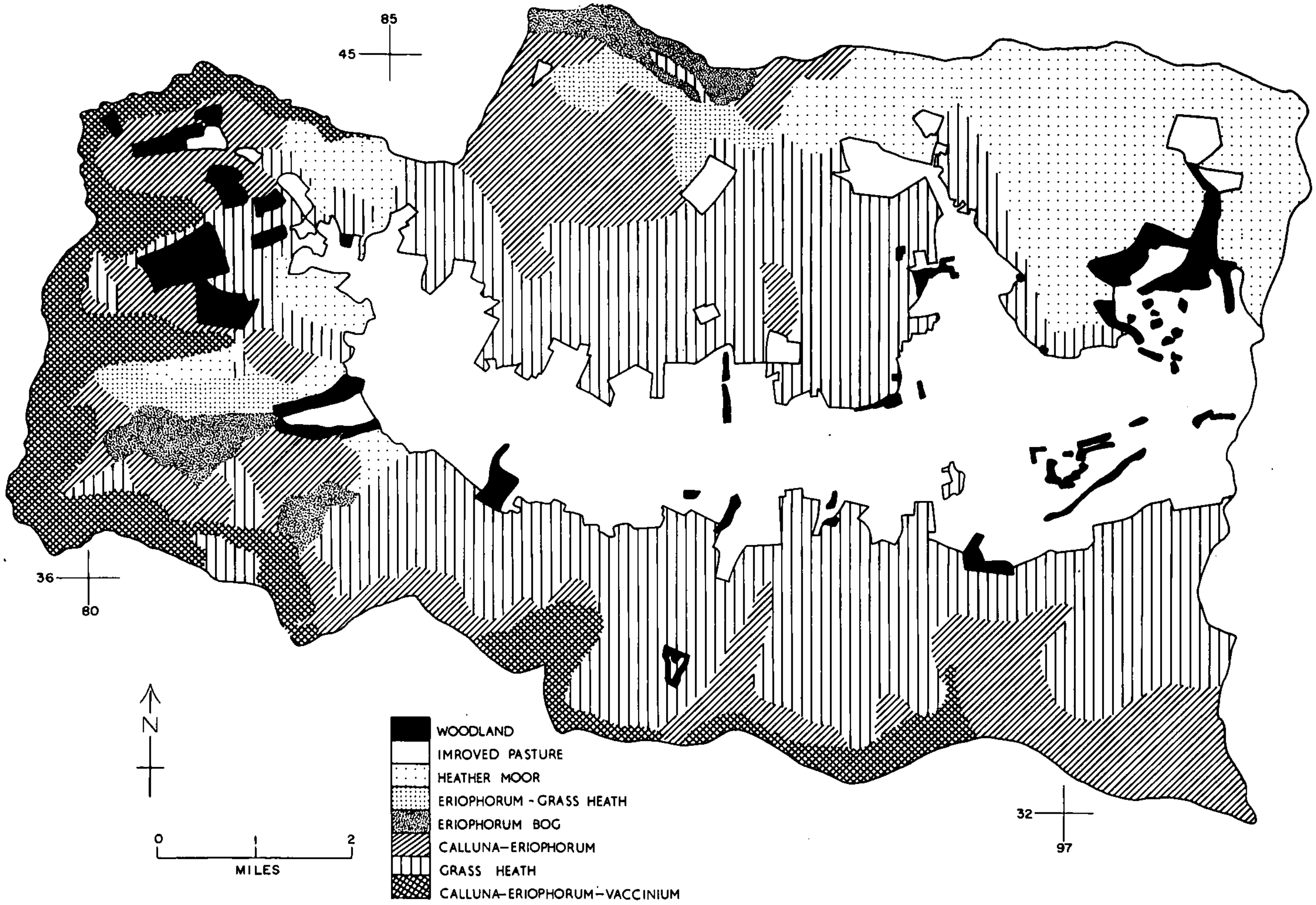
Information on the ecological characteristics below the lower limit of peat growth is more scanty but can be inferred from wind-transported pollen recorded in certain valley-bog sites. The Waskerley Peat of RAISTRICK AND BLACKBURN (1932) is situated only three miles to the north-east of the study area. In the Boreal subdivision *Pinus* is dominant with secondary *Betula* and *Alnus*, with *Pinus* decreasing rapidly and *Alnus*-*Betula* taking preeminence after the Boreal-Atlantic transition. The increase in *Alnus* also heralds the first signs of an invading mixed oak woodland with *Quercus*, *Tilia* and *Ulmus* being represented.

## 4.2 The Present Vegetation Pattern

The vegetation of Upper Weardale belongs to an Oak-Scots Pine-Birch-Heath and/or Moor association and occupies a regional site which, under natural conditions, would show a sequence from oak woodland on the more sheltered lower ground to montane peat and wind-eroded heath on the higher interfluves. LEWIS (1904b) presented a generalised vegetation association map of the Alston Block, although the present vegetation pattern shows significant change since his original mapping. The present revised map of the dominant associations(fig. 31) incorporates remapping during the present fieldwork and modifications suggested by WARDHAUGH (personal communication).

The present complicated mosaic of vegetation is the result of several interacting factors. On account of the amplitude of relief, a major ecological trend consists of altitudinal zones with indefinite boundaries; for MANLEY (1936) this constitutes one of the major environmental facets of the geography of the Pennines. Further elements of diversification in association form

## Fig.31 DISTRIBUTION OF VEGETATION TYPES



occur along a given ecological contour in response to microclimatically controlled differences in exposure and aspect. A final series of irregularities on the local scale is produced by small scale features of microtopography, particularly those associated with water movement, and by changes in the nature of the parent material. Notwithstanding the vegetation map, rapid and complete changes in floristic composition are characteristic over quite short distances.

The status of the plant communities, however, owes much to human interference. The present ecological pattern must be viewed merely as a single point on an evolutionary sequence - a sequence much influenced by changes wrought by prehistoric, historic and contemporary human activity. Direct and indirect influences in the past have already been referred to. Present day management practices in the form of improvement, afforestation, sheep grazing and moor-burning continue to affect the dynamic nature of the vegetation distributions. Even the simplest observation of the Weardale landscape reveals the effect of enclosure on vegetation boundaries.

Although regional vegetation studies often make use of a simple Grassland - Heathland - Moorland - Woodland scheme of classification (LEWIS 1904; MUIR AND FRASER 1940; PEARSALL 1950; and RATCLIFFE 1959) and this has been accepted in broad outline in Upper Weardale, the limitations of this scheme in the study area are significant. Many of the vegetation associations are "mixed" rather than homogenous and thus show an intergrade composition between two or more of the main climax types. This heterogeneity of floristic composition, in fact, reflects the dynamism of the vegetation patterns and can be interpreted as the ever operating response of vegetation to management practices. Comparison of the present situation with that shown on LEWIS's (1904b) map suggests that many of the "mixed" associations are changing from one vegetation type to another as a result of human pressure.

A classification of vegetation in terms of floristic composition is given below. The communities represent mappable units and no attempt has been made to give Lowland/Subalpine/Alpine designations based on arbitrary contours.

1. GRASSLANDS
    1. Meadow Pastures
    2. Agrostis - Festuca
    3. Nardus
2. WOODLANDS
    1. Mixed Deciduous
    2. Betula
    3. Pinus
    4. Spruce
3. HEATHS
    1. Calluna-Eriophorum-Vaccinium
    2. Calluna - Eriophorum
    3. Calluna - grass heath
    4. Calluna - Juncus squarrosus
    5. Calluna - Nardus
    6. Pteridium
4. MOORLAND
    1. Sphagnum Bog
    2. Juncus squarrosus Bog
    3. Juncus effusus Bog
    4. Cotton grass Bog
    5. Molinia Bog
    6. Mixed Wet Bog
    7. Molinia - Cotton Grass
    8. Cotton Grass - Vaccinium
    9. Erosion Complex

## 4.3 Pedological Implications

The vegetation history of Upper Weardale can be reconstructed in a generalised form from the palaeo-ecological evidence of particular sites. Intense studies of peat structure and pollen content allow one to recognise the major sequential changes in ecology which the Northern Pennines have experienced. Such regional chronological trends are becoming more widely understood.

The reconstruction of palaeo-ecological sequences points to the changes in the nature of the biotic factor in soil genesis. Although vegetation has long been assigned a major role in pedogenetic study, several detailed features of that role are only now being fully understood. Two aspects of especial importance for pedology are, firstly, the importance of the time factor in the biotic sphere, and, secondly, the power and importance of profile mechanisms dependant on the surface vegetation. The first results from concepts of environmental change and polygenesis as emphasised by DUCHAUFOUR (1956) and DIMBLEBY (1965) among others. Here the evolutionary effects of plants, animals and man is expressed in relation to "prehistoric soils" and "historic soils". Only lack of data prevents these workers from assigning a particular soil type to each recognisable sub-zone of the post-Glacial.

The second aspect of vegetation influence, namely as the determinant of chemical reactions in the profile, increases the importance of the first. Perhaps the major significance to pedology of the work of BLOOMFIELD (1952 et seq.) and others on the relative efficiency of leaf and litter extracts to mobilise certain organic constituents by a chelation mechanism is that it can be interpreted to emphasise previous processes associated with earlier vegetation covers no longer prevailing. This is a particularly important conclusion and one which assumes massive pedological proportions when allied to a later conclusion that the action of certain polyphenolic groups in such leachates is independant of pH conditions prevailing in the soil (BLOOMFIELD 1953). The vegetation effect can thus transcend a range of parent material characteristics.

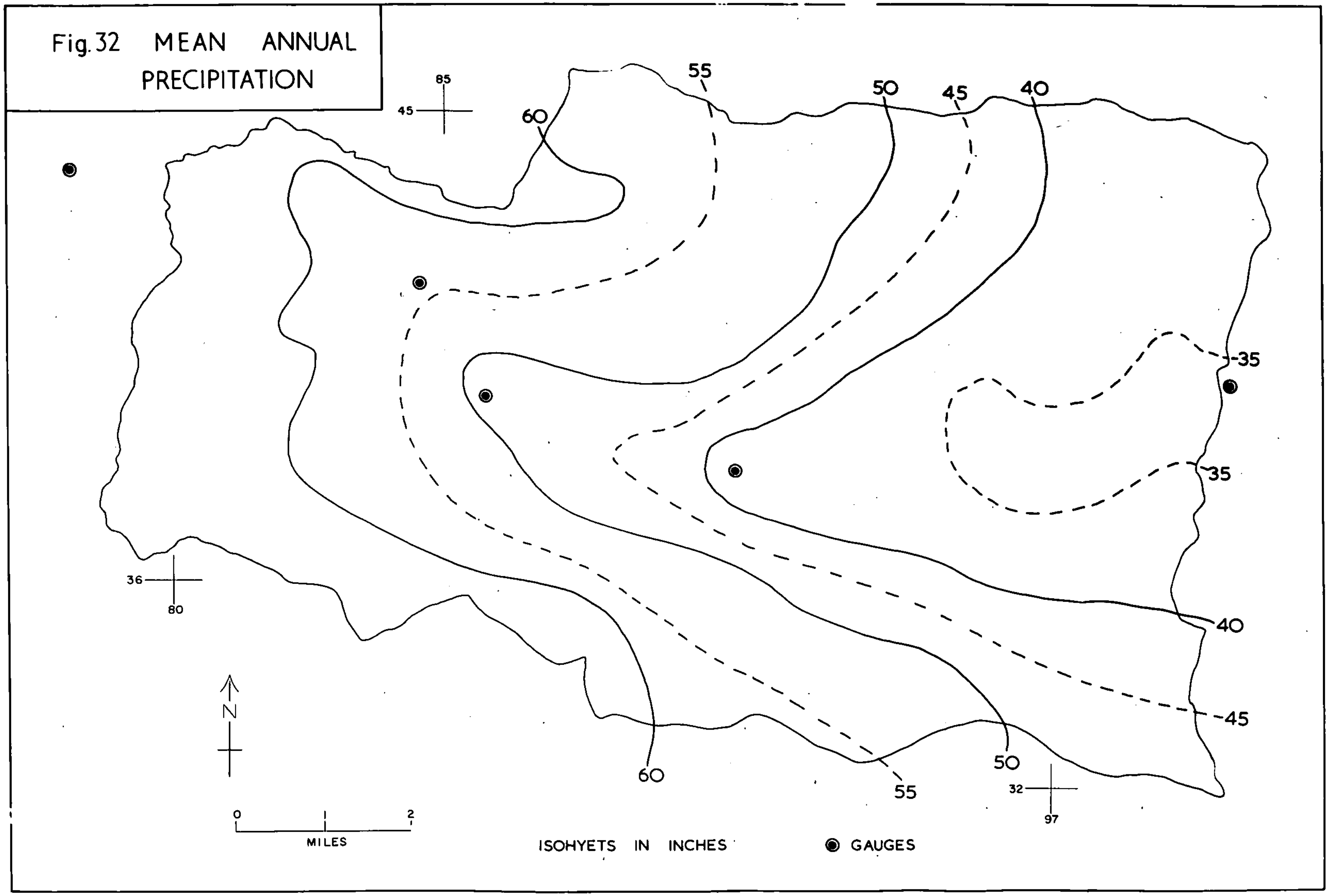
## 4.4 Present Climate

The climate, or climates, of the Pennine Uplands have been a subject of especial interest to climatologists and meteorologists on account of the great contrasts to be found over relatively short distances. Striking variations in altitude, aspect, exposure, and land configuration lead to marked climatic contrasts within the study area although these contrasts have not received the study and experimental analysis they deserve. Nevertheless climatic data collected by MANLEY (1935 et seq.) on the Cross Fell massif, by WARDHAUGH (private communication) and by CATCHPOLE (private communication) at Laneheads Field Centre during the 1960/1961 season do allow the regional Meteorological Office data to be supplemented to some degree.

The prime climatic contrasts within the drainage basin of the Upper Wear are conditioned by altitude and exposure. The higher fells to the west and the bounding west-east interfluval ridges have climatic affinities with Southern Iceland (MANLEY 1936) and have been designated as 'sub-arctic'. The extremes and severity of the climate over 2000' is are moderated on valley slopes, and further moderation is in evidence in the relatively sheltered tract of the valley floor proper. The topographic character of the area is thus neatly mirrored in the climatic character in the classic manner expounded by MANLEY (1944).

The effect of the altitudinal and exposure components on climatic elements can perhaps be most strikingly illustrated in the distribution of precipitation (fig. 32). Figures for precipitation on the higher fells are scanty, due principally to difficulties of experimentation, but totals are most probably far in excess of the 60" indicated (WARDHAUGH, private communication). Nevertheless the wetness and humidity of the upland environment is emphasised, as is the steady diminution eastwards. The effect of altitude on precipitation is twofold within the Northern Pennines as a whole. The direct effect is for mean elevation to be lower as one moves eastwards, thereby reducing the orographic component and the indirect effect is for exposure to the predominant westerly air-streams to be correspondingly reduced. The net effect is to give a very close correlation between altitude and precipitation (fig. 33). Whilst precipitation tends to be evenly distributed throughout the year and rain can be expected on more than seventeen days in August and on more than fourteen days in both July and September (MANLEY, quoted in SMAILES 1960), the general Northern England situation of an autumn and winter maximum is characteristic (fig. 34). Snowfall records presented by MANLEY (1939, 1943) and records from Alston and Nenthead, just to the west of the study area, indicate that the snow-cover gradient follows the dominant altitudinal gradient, averaging 80 days over 1800' in the west and decreasing steadily to 30 days at Stanhope (600') in the east. Variations in absolute lengths of snow cover

Fig. 32 MEAN ANNUAL PRECIPITATION



ALTITUDE-PRECIPITATION RELATIONSHIPS

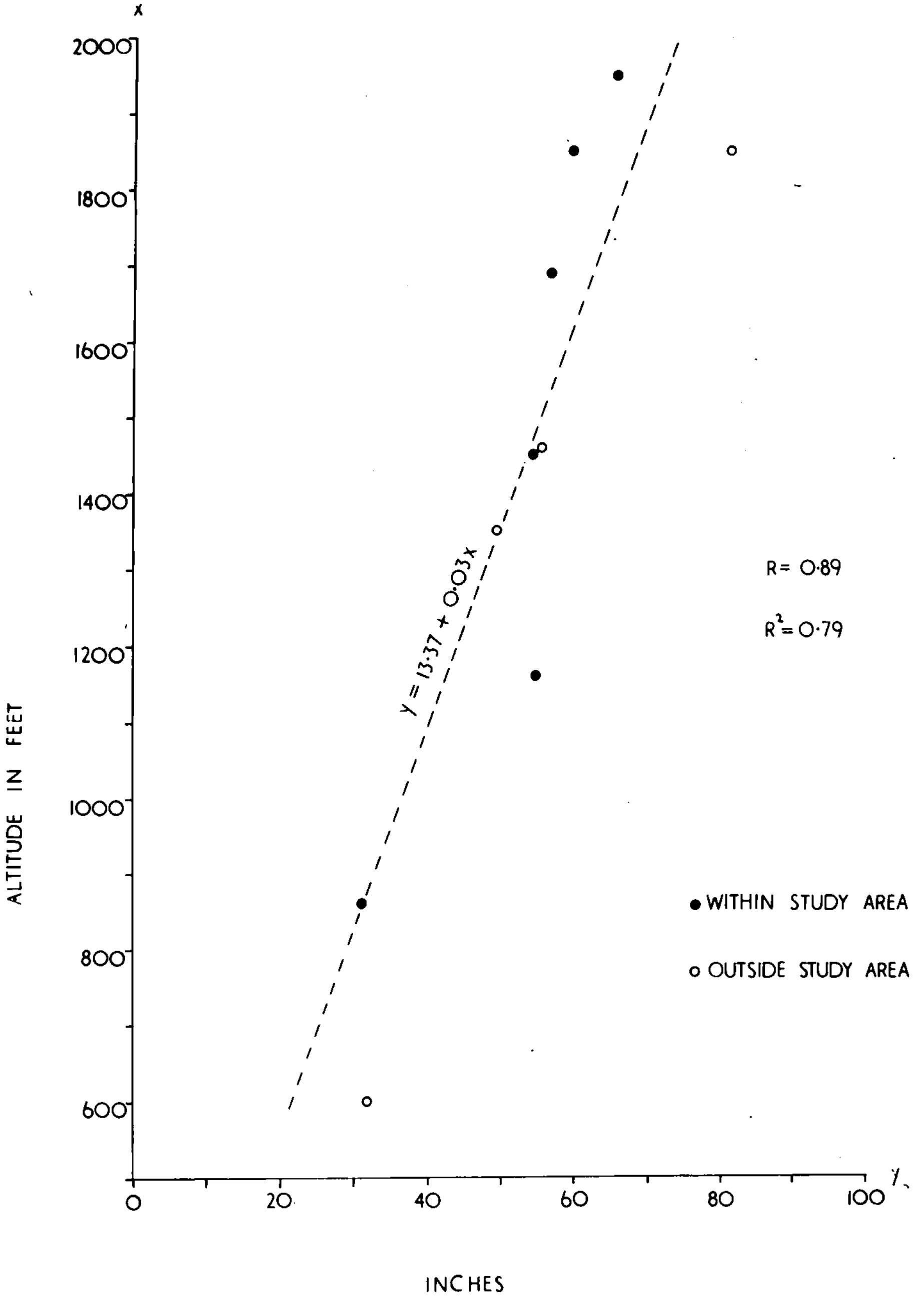


FIG. 33

PRECIPITATION REGIME

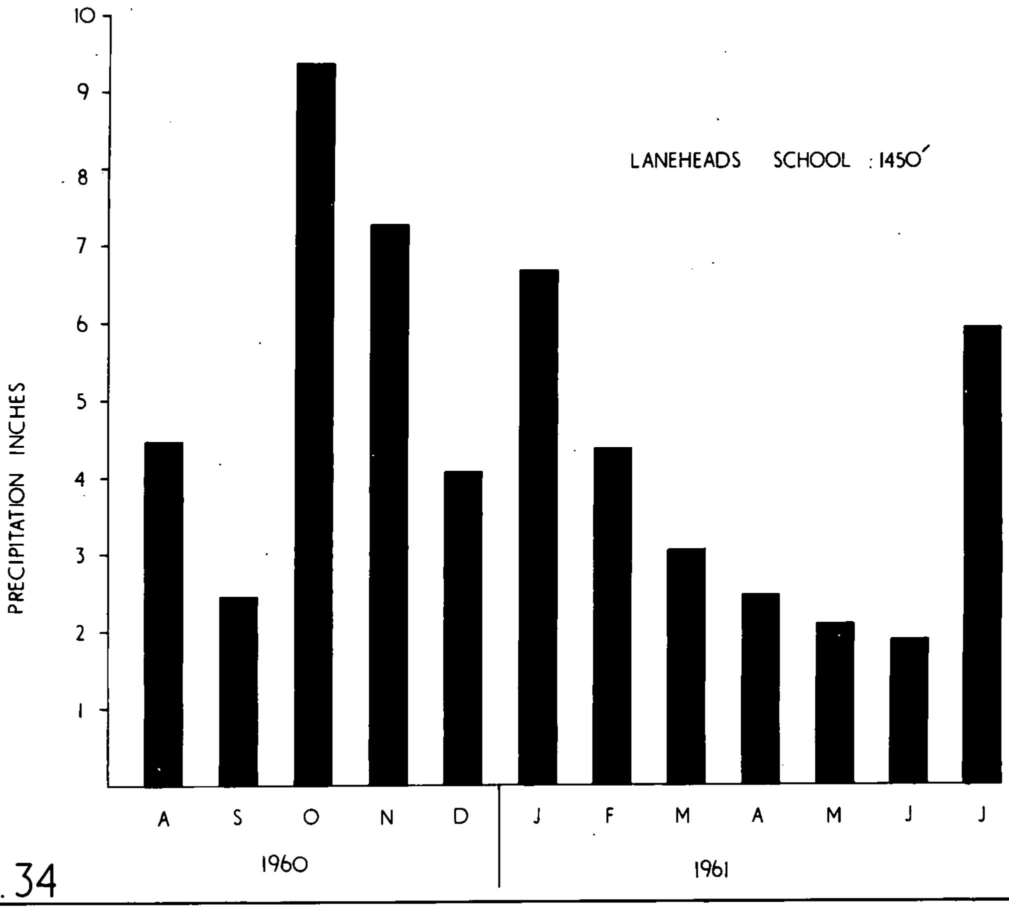


FIG. 34

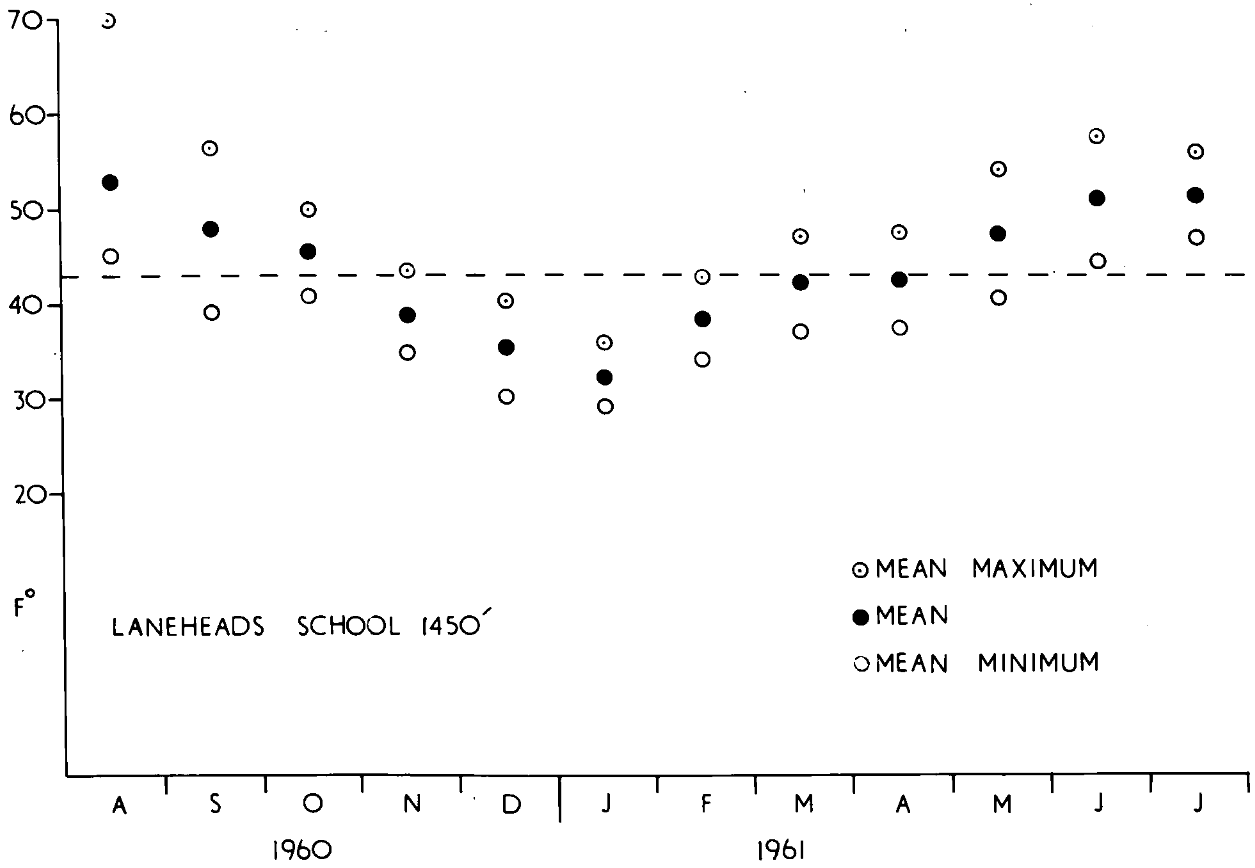
are great from year to year (e.g. the extended period of snow-lie from October 1965 to May 1966 at Laneheads School 1450'), but snowfall records exist for all months except July and August, with maximum falls occurring in January, February and March. It is interesting to note that the persistence of snow on upland crests is of the order of twenty percent lower than computational predictions derived from temperature and precipitation data alone, a fact which MANLEY (1943) attributes to the effect of drifting. Certainly exposure to wind rather than aspect seems to govern the persistence or otherwise of large drifts.

Within the area of study, data on temperature are even more meagre than those for rainfall, a situation previously bemoaned by MANLEY (1936). Records collected by CATCHPOLE for Laneheads School (1450', aspect south) are useful additions, however, and are presented in fig. 35 and fig. 36. Although of short duration, this record provides a convenient link between the higher level Moorhouse Nature Reserve records and the better documented lowlands to the east.

Both graphs of temperature characteristics illustrate the low amplitude of temperature variations throughout the year. The Laneheads record shows a difference of 20°F between the lowest monthly mean of 33°F (January) and the highest monthly mean of 53°F (August). This compares with the longer standing records at Nenthead (1500') with mean January and July temperatures of 33°F and 54°F respectively. Statistics for both stations indicate the prevailing pattern of cool summers and cold winters and might both be designated as mid-points on

# MEAN AIR TEMPERATURES

FIG. 35



## TEMPERATURE VARIATIONS

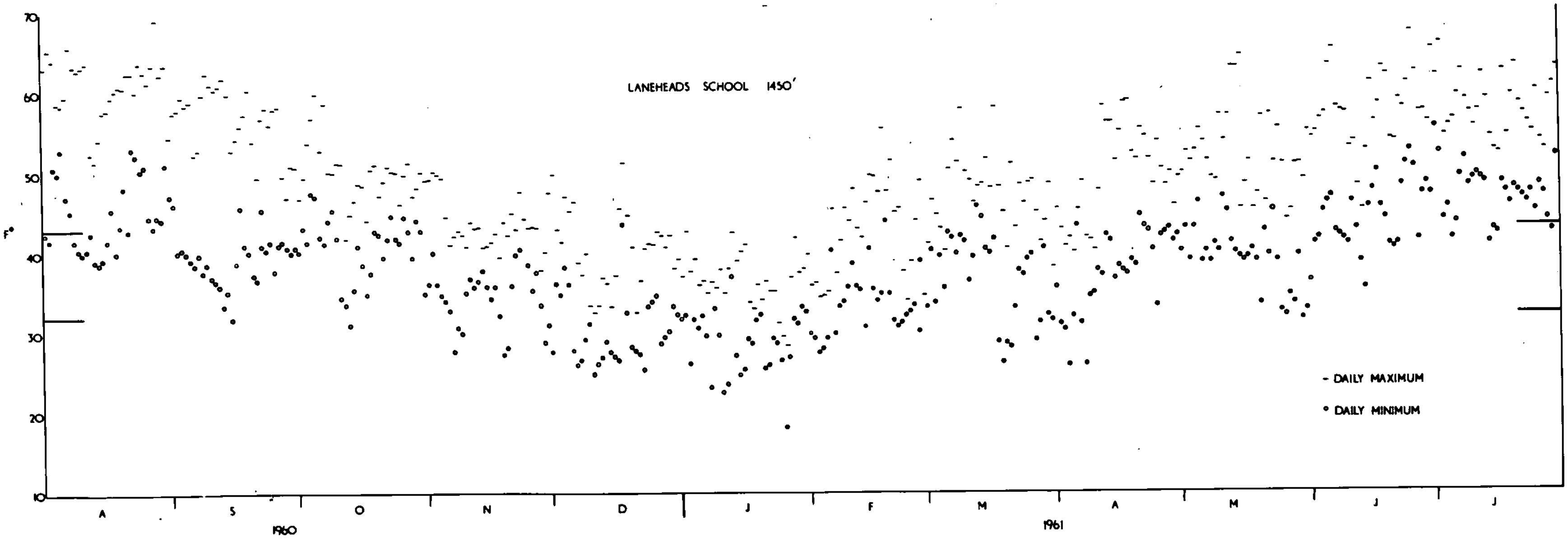


FIG. 36

an overall temperature gradient from sub-arctic on the uplands, designated by MANLEY (1936) as "the most consistently elevated and chilly part of England", to cool temperate in the lower and more sheltered valley floor. Certainly the minimum air temperature can fall below 32°F in every month of the year. The exact nature of the gradient between these extremes awaits investigation, but it is probable that the sub-arctic effect extends significantly below 2000' into the upland tributary valleys on account of the effects of Katabatic "banking" in basin and valley sites. The incidence and severity of such sub-arctic effects on lower ground remains at present an unexplored province.

More exact conclusions can be drawn about the length of growing season in Weardale using the principles developed by MANLEY (1945) for the broader region of the Northern Pennines. Accepting ANGOT's original value of 42.8°F (6°C) as a "critical vegetative temperature", it can be shown in Weardale that increasing altitude leads to a rapid decrease in the length of the actual growing season, at a rate of ten days per 250 ft. rise (fig. 37). The sharp rate of decrease constitutes a prime ecological control in Weardale with important effects on vegetative growth, land potential and pedogenic processes; it emphasises, above all, the altitudinal zonation of the biotic environment.

The altitude-growing season relations are, furthermore, not improved if one takes soil rather than air, temperatures into account. The figures for Lanehead School are the only data for the area (fig. 38) and they show a similar trend to the mean air temperatures (fig. 35) with a characteristic time-lag. This lag is primarily due to

# ALTITUDE - GROWING SEASON RELATIONS

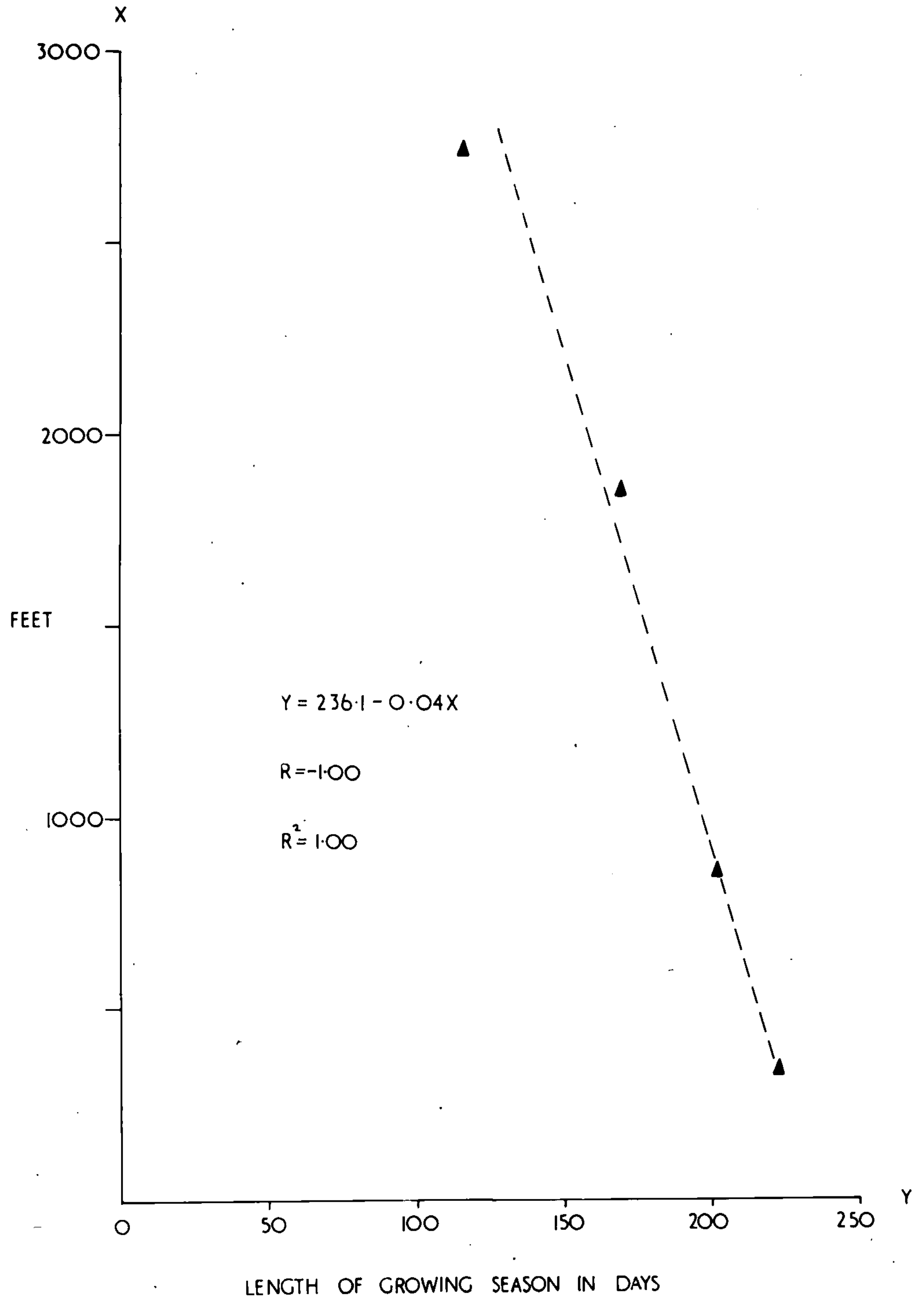


FIG. 37

## SOIL TEMPERATURES

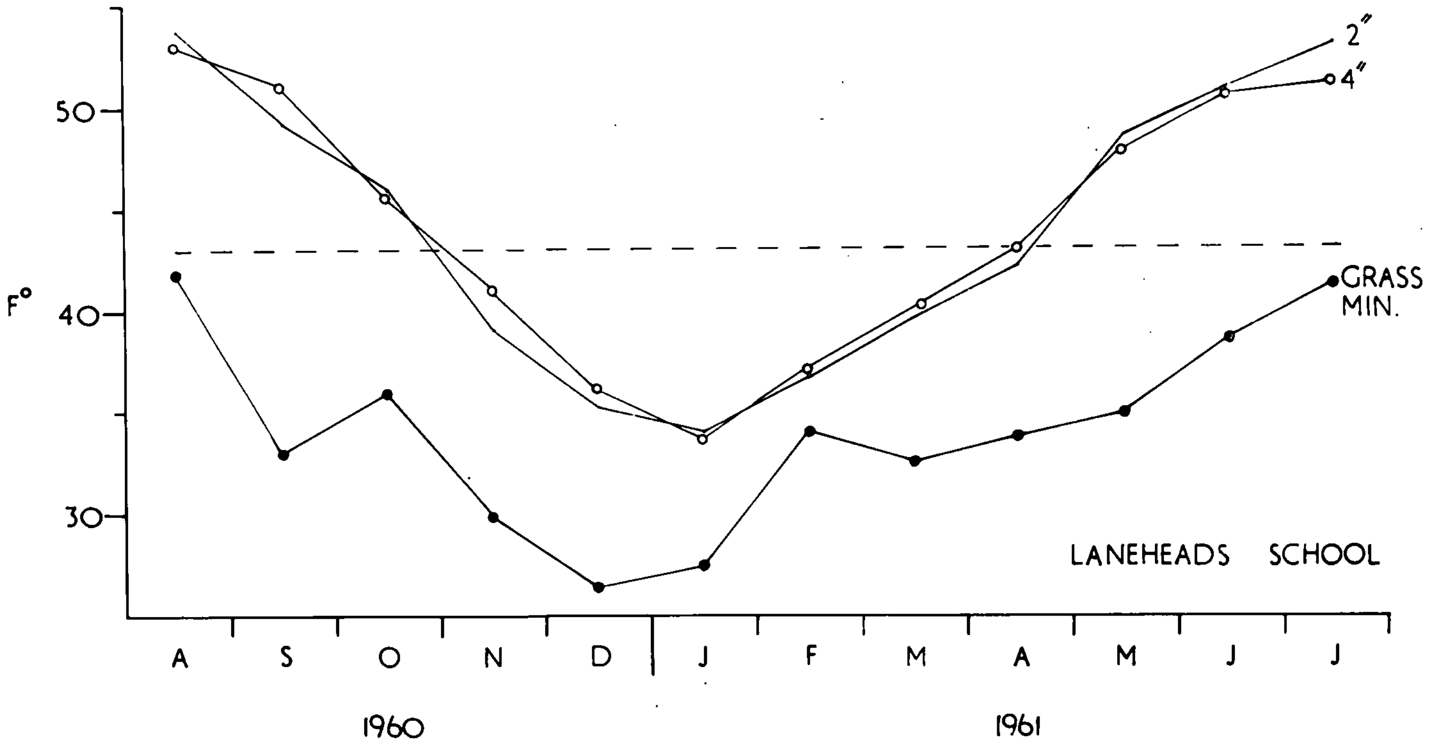


FIG. 38

the wetness, and hence coldness, of the soil in spring, with the consequent delay in reaching effective growing temperatures.

A further ecological inference concerns the height of the natural tree line under the prevailing climatic conditions. Until the results of the Forestry Commission's experimental and commercial planting in Killhope Burn and Wellhope Burn become available, the general census of opinion favours a treeline at about 2000' (MANLEY 1942). This accords with a prehistoric treeline during Zone VI as suggested by DIMBLEBY (1957). Exposure and windiness are added to temperature to arrive at this estimate. However, in the survey area at Chapel Fell and to the south west on Cross Fell (LEWIS 1904) there is evidence in the form of buried trees to suggest that during post-Glacial times trees occurred as high as 2500 feet, a situation which has to be borne in mind when assessing the prehistoric and historic development of soils in the area.

Indeed, a major consequence of the rapid change of climate with altitude and the overall marginality of the Weardale climate is that normal variations in the lapserate in the lower layers of different air masses influence the climate to a considerable degree. In the words of MANLEY (1942), "even in a lifetime's experience we have witnessed variations which on the one hand would almost permit tree growth at the highest limits known since glacial times, and on the other hand would almost permit snow drifts to remain throughout the year." The relevant conclusion is that the climate of the North Pennines just on and above the treeline is subject to considerably greater changes in the short term than that of the lowlands.

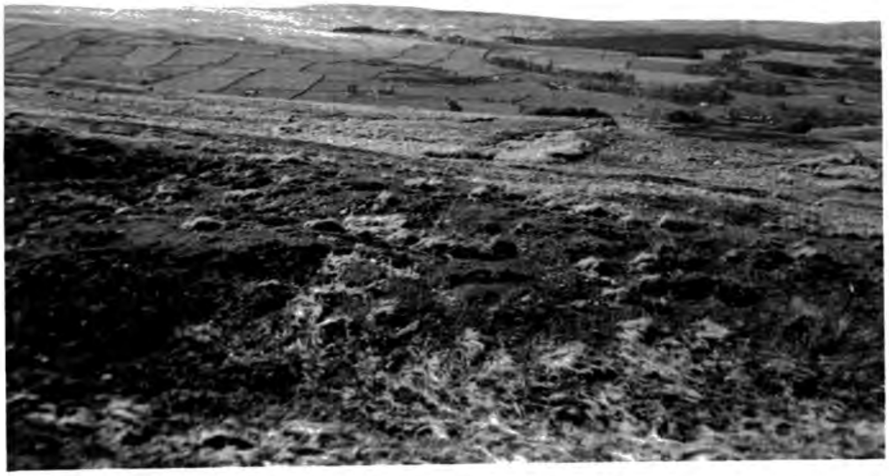


Plate 22. The ecological balance disturbed. Contemporary soil erosion in *Nardus* grassland. (84/935355)

Plate 23. The land-use pattern in the Upper Dale at 1500'; unenclosed moorland, relapsed enclosures, and improved pasture for hay. (84/835405)

Plate 24. Experimental forestry planting at 1900' on Killhope Moor. (84/815438)

# PART 2

# THE SOILS OF UPPER WEARDALE: classification, characteristics and distribution

# Chapter 5

## Soil Investigations

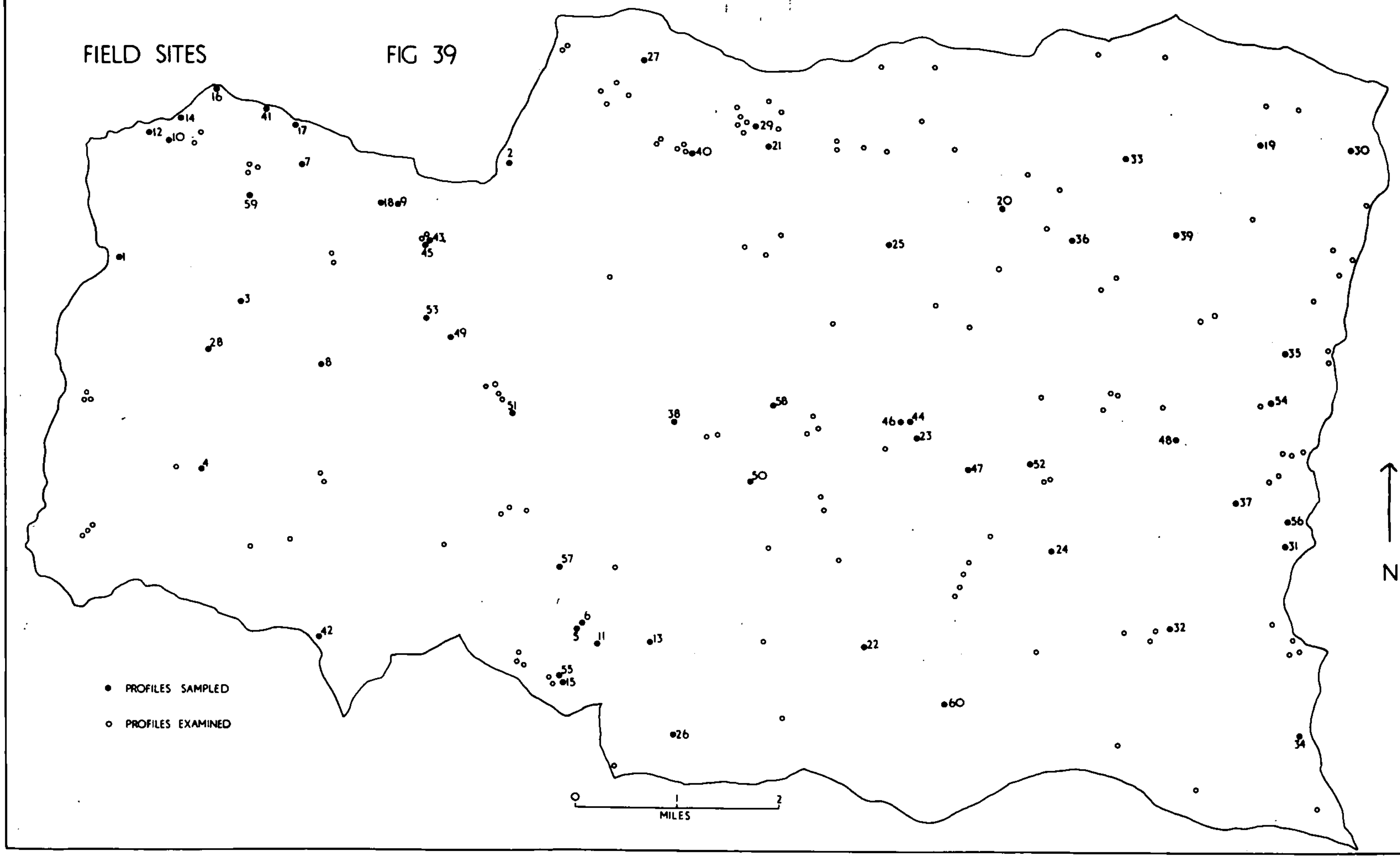
The investigation of the soils of Upper Weardale is presented with two main aims. The first is to describe, classify and map the distribution of soils in the study area and hence compile a soil inventory for this upland tract. Using conventional methods of field analysis and description, supplemented by routine and diagnostic laboratory analyses, a soil map has been prepared and detailed data compiled on the properties of the soils. This aim is similar to that upheld by the Soil Survey of England and Wales, and of Scotland (AVERY 1955; GLENTWORTH AND MUIR 1967).

The second aim is to provide a long-needed study of pedogenesis in an unstudied area of Upland Britain. This necessarily incorporates a wide range of source material, employing the results of the routine field and laboratory examinations, but also calls for more detailed laboratory analysis of trace element distributions, micromorphological features, and clay analyses. The aim here is to use such data as is relevant in assessing the character and degree of soil processes and the relations between soils and their pedogenetic factors.

### 5.1 Soil Mapping

The initial aim of the work was to produce a map of the distribution of soils on a scale of 1:25,000. This involved field analysis by profile pits, and natural and man-made exposures. Numerous screw auger inspections were used to check the delimitation of boundaries between the cartographic units. Figure 39 shows the distribution of the field sites.

FIELD SITES FIG 39



During the preliminary reconnaissance of the area it was observed that certain profile characteristics are generally associated with a particular surface topography or slope facet, and thus the mapping was initially approached by assessing the nature of the particular geomorphic surface (i.e. altitude, degree of slope, kind of slope, relative position, extent). This is a line of enquiry used most successfully by LOVEDAY (1958) in the Southern Chilterns and since outlined by CURTIS et al. (1965).

The second stage was to examine the soils on the geomorphic facet to determine whether there was any objective consistency in the macromorphology of the profile, as had been indicated during the reconnaissance. The results of this enquiry show that the value of topo-boundaries varies considerably from locality to locality. In areas of sharp topographic change over quite short distances, e.g. valley-sides, topo-boundaries do, in fact, delimit areas of soil showing a considerable degree of uniformity in a number of characters. Topo-boundaries thus can often be used as boundaries of soil mapping units. In areas of more gentle slope or on slopes of considerable extent, there are striking anomalies, and considerable variation within facets ruled out any simple and general slope-soil correlations.

Several features explain this inter-facet variation in Upper Weardale. A prime influence on soil character is, of course, parent material and profile drainage status. Certainly the use of the soil series concept has much to recommend it in the area, implying, as it does, "a geographic concept, defined as a landscape unit with a limited range of parent materials" (AVERY 1956).

The characters which are used to distinguish soil series are those which are related in their occurrence to landform.

This approach to soils is in contrast to that involving a stricter adherence to an established soil taxonomic scheme whereby profiles, regardless of their position in the landscape, are considered in relation to ideal conceptions. The taxonomic conceptions are favoured because of their insistence on soil processes and the resultant process profile (e.g. KUBIENA 1953; FITZPATRICK 1966). In practice both approaches are more complementary than many would admit and it takes little effort to relate particular series to a central taxonomic concept.

In the present study, with its emphasis on pedogenesis, the accompanying soil map on the 1:25,000 scale is presented in the form of taxonomic conceptions at the sub-group level (fig. 40). This means of showing soil distributions is preferred to the delimitation of soil series for several reasons. As indicated by JENNY (1941), NIKIFOROFF (1949), and BUTLER (1959), the nature of a soil is dependent on a variety of factors besides its position in the landscape and these factors vary independently of the landscape. Thus in Upper Weardale a major difficulty is to be found in the complex bioclimatic character of the area. The form of surface vegetation association has a strong influence on soil processes. This manifests itself in a close correlation between present vegetation and present process and, more subtly, in the existence in certain profiles of features associated with a previous vegetative cover. The marginality of the Pennines seems to intensify the contrasts between pedogenic processes operating under different types. The fact that the vegetation cover is so dynamic and so influenced by human as well as natural conditions needs a full emphasis. The soil is a multivariate ecosystem in its own right, and not a function of the bivariate controls of parent material and drainage. The work of RYAN and WALSH (1966) serves the useful function of emphasising this approach.

A second disadvantage of the unthinking use of soil series in upland areas is that it presupposes a knowledge of parent material origin which may not always be available. In upland areas of incised relief, superficial deposits and weathered rock materials are most accurately viewed as features with continuous variation in properties. The definition and mapping of soil parent materials depend very heavily on subjective and often emotive interpretation given by the individual worker. The terms 'weathered regolith', 'solifluction deposit', 'till', 'drift', and 'moraine', introduced in Chapter 3, at best represent geomorphic concepts. That they should be used with complete faith as mappable criteria as a basis for soil classification is doubtful. Soil parent materials in upland regions should not be viewed with the "unrealistic discreteness" of MILLER (1956).

This is a particularly serious difficulty in pedological work as considerable emphasis is placed on parent material identification and characterisation in conventional survey practice (e.g. MUIR 1955). Upland regions present very real problems for the pedologist on account of the lack of distinctive parent material types such as are found in lowland areas. In weardale this is Cap.
particularly the case as the Dale seems to have been

unglaciated during the last phase of the Wurm Glacial, being subject to intense congelifraction and solifluction, with a consequent mixing of slope deposits. Thus it becomes difficult to identify a 'sandstone derived deposit', 'limestone derived deposit', and 'shale derived deposit', and even more difficult to map their extent and limits. Attempts such as the one by MALING (1955) have to be treated with considerable circumspection, for even some of his more emphatic boundary limits have little statistical significance (FALCONER, private communiction).

## 5.2 Soil Classification

The system of classification used for showing the distribution of soils and for the subsequent discussions on soil genesis and process is presented in table 7. Basically, the seven major divisions recognised subdivide into thirty sub-groups, which form the central units of study. This system compares closely with usage employed in the memoirs of the Soil Survey of Great Britain, and the properties and genesis of the various sub-groups are discussed in the ensuing chapters.

In order to help correlation with conventional Soil Survey practice, the relationships between the divisions, subsoil texture, and parent material are presented in table 8. Although the detailed nature of the study leads to fine subdivisions in the categories (seven divisions and thirty sub-groups including the sub-peat division), it is hoped that this table will prove useful in future correlation with the mapping and classification of soils in other parts of the Pennines, particularly with respect to the work of ASHLEY in Northumberland, HALL in Lancashire, and MATTHEWS in the West Riding of Yorkshire. The area is less easily comparable with that of BRIDGES (1966).

## TABLE 7. TAXONOMIC UNITS

| DIVISION | MAJOR SOIL GROUP | SUB-GROUP |
|---|---|---|
| ORGANIC SOILS | a. Bog Peats<br>b. Flush Peats | Blanket peat<br>Basin peat<br>Lime flushes<br>Iron flushes<br>Peaty flushes |
| SUB-PEAT SOILS | a. Podzolic sub-peat soils<br>b. Gleyed sub-peat soils | Sub-peat podzol<br>Sub-peat podzol with pan<br>Sub-peat gley<br>Sub-peat gley with pan |
| GLEY SOILS | a. Ground-water Gleys<br>b. Surface-water Gleys | Non calcareous Gleys<br>Peaty Gleys<br>Calcareous Gleys<br>Non calcareous surface water gleys<br>Peaty gleyed podzols |
| LEACHED SOILS | a. Podzols<br>b. Brown Earths | Iron podzol<br>Humus-Iron podzol<br>Podzols with gleying<br>Acid Brown Earth<br>Imperfectly drained Acid Brown Earth<br>Podzolised Acid Brown Earth<br>High Pennine Brown Earth |
| CALCAREOUS SOILS | | Rendzinas<br>Brown calcareous |
| ALLUVIAL SOILS | | Fine Alluvial Soils<br>Coarse Alluvial Soils<br>Sandy Alluvial Soils |
| RANKER SOILS | | Whin Rankers<br>Sandstone Rankers<br>Ironstone Rankers<br>Spoil Rankers |

## TABLE 8. RELATIONSHIPS BETWEEN TAXONOMIC UNITS AND PARENT MATERIAL

| DIVISION | PARENT MATERIAL |
|---|---|
| ORGANIC SOILS | Blanket peat<br>Flush peat<br>Basin peat |
| SUB-PEAT SOILS | Clay; solifluction deposits from Carboniferous shale<br>Clay to clay loam; solifluction deposits from Carboniferous shale and sandstone<br>Loam; solifluction deposits from Carboniferous sandstone<br>Coarse loam; over Carboniferous sandstone |
| GLEY SOILS | Clay; till<br>Clay; solifluction deposits over Carboniferous shale<br>Loam; solifluction deposits from Carboniferous sandstone and shale<br>Loam; solifluction deposits over clayey till<br>Clay; solifluction deposits from Carboniferous sandstone and shale<br>Loam or clay; riverine alluvium |
| PODZOLS | Sand to coarse loam; over coarse-grained Carboniferous sandstone<br>Sand to coarse loam; solifluction deposits from Carboniferous sandstone<br>Loam; solifluction deposits from Carboniferous sandstone and shale<br>Sand to coarse loam; tip material from Carboniferous sandstone<br>Fine sand to loam; tip material from Carboniferous sandstone and shale |
| BROWN EARTHS | Sand to coarse loam; over fine grained Carboniferous sandstone<br>Loam to coarse silt; over fine grained Carboniferous sandstone<br>Sand to coarse loam; over coarse grained Carboniferous sandstone<br>Loam; glacial till<br>Loam to coarse silt; solifluction deposits from Carboniferous shale<br>Sand to loam; solifluction deposits from Carboniferous sandstone |

| DIVISION | PARENT MATERIAL |
|---|---|
| CALCAREOUS SOILS | Carboniferous Limestone<br>Loam; solifluction deposit over Carboniferous Limestone<br>Loam to clay; solifluction deposit over Carboniferous Limestone |
| ALLUVIAL SOILS | Loam or clay; riverine alluvium<br>Loam or clay; river terrace deposits<br>Sand to coarse loam; riverine alluvium<br>Sand to coarse loam; river terrace deposits<br>Gravel; riverine alluvium<br>Gravel; river terrace deposits |
| RANKERS | Loam; over Whin<br>Sandy to coarse loamy; Carboniferous sandstone<br>Gravel; undifferentiated spoil materials<br>Loam; undifferentiated spoil materials<br>Loam (variable); over Carboniferous ironstone |

## 5.3 Soil Description and Analysis

Within the study area, the soil profile at sixty sites was examined in detail and sampled, to give a record of two profiles for each taxonomic sub-group. The exposed profile was recorded by terms defined in the Field Handbook of the Soil Survey (1960), and soil colours described by the names and symbols of the Munsell Soil Color Charts. Definitions of the standard descriptive terms are not included in this thesis.

The basic unit for field and laboratory study was the soil horizon. Each horizon was given a designation, using the Canadian system (see Appendices II & V), and the macromorphology of each horizon was described in the field. Subsequent sampling was then carried out for laboratory analysis. Laboratory analysis included mechanical analysis, determin ation of exchangeable cations and cation exchange capacity, soil reaction, loss on ignition, content of calcium carbonate, and percentage carbon and nitrogen. Studies on trace element contents, microfabric, and mineral assemblages of particular horizons were also compiled. All analytical methods are outlined in Appendix III, and the results of all field and laboratory analysis are presented in Appendix IV.

# Chapter 6

## Organic soils

The terms 'organic soil', 'peat soils', 'thin peats', 'humose soils', and 'hochmoor' are used with widely different connotations in pedological and ecological literature. In the present area, organic soils are to be equated with peats, i.e. they are derived from an accumulation of partly decomposed plant remains in an anaerobic environment. For the purposes of soil mapping and classification, a depth criterion has been chosen as a suitable definition of organic soils, and all areas whose surface peat exceeds 20" (0.5 metres) in thickness have been mapped as organic soils. This is greatly in excess of procedure in the Soil Survey of Great Britain (e.g. MUIR 1956) where 12" is used, and also the 15" of MUIR (1955) and the 16" of CLAYDEN and MANLEY (1964). Although the 12" definition is probably a useful general demarcation for questions of reclamation and management, from the point of view of pedogenesis it forms a somewhat arbitrary limit and has little intrinsic merit. In Weardale it would encompass substantial areas of peaty gleys and peaty gleyed podzols which have contrasting dynamics and origins to the peat areas proper. For this reason, the lower limit of organic soils has been raised for this study. Using this line of demarcation and adopting well-known principles previously outlined by PEARSALL (1950, 1956), GORHAM (1957), and NEWBOULD (1958), the classification and subdivision of organic soils is tabulated below.

TABLE 9. CLASSIFICATION OF ORGANIC SOILS

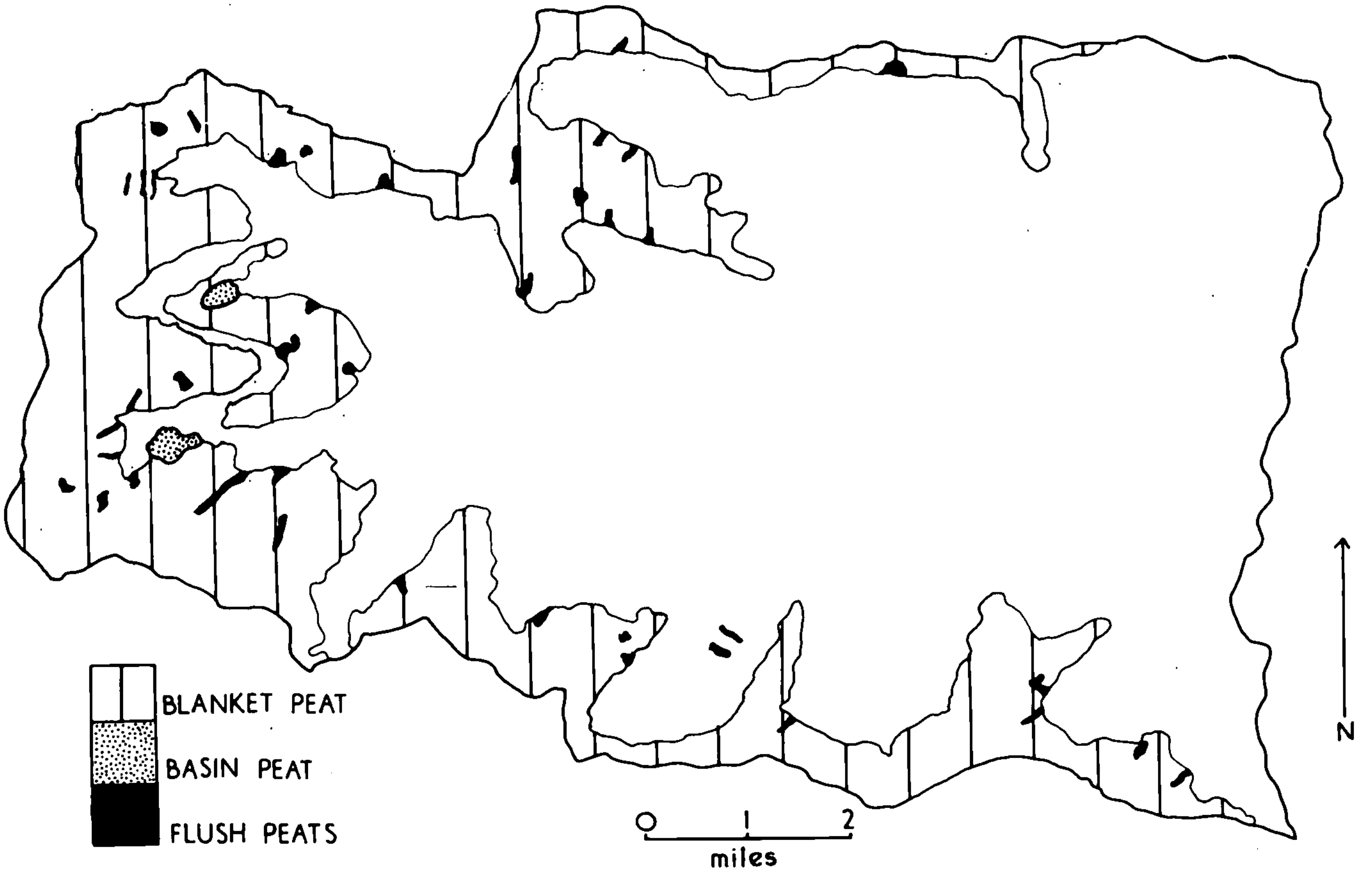
| DIVISION | MAJOR SOIL GROUP | SUB GROUP | PHASES |
|---|---|---|---|
| ORGANIC SOILS<br>(Accumulations of peat in excess of 20 inches) | a. Bog Peats | Blanket peat | a. Thin Peat (20-40") |
| | | | b. Thick Peat (> 40") |
| | | Basin peat | |
| | b. Flush Peats | Lime flushes | |
| | | Iron flushes | |
| | | Peaty flushes | |

Blanket peat is subdivided on the basis of depth to distinguish the deep accumulations which characterise several areas, from the thinner peat areas.

Fig. 41 shows the distribution of the types of organic soil. The field work entailed in the construction of this map did not include the rigorous surveying and grid design employed by National Peat Surveys (SCOTTISH PEAT SURVEY, 1964) but was carried out on the 1:25,000 scale using gully observations and frequent probes with the screw auger. Owing to the fact that several of the taxonomic units merge imperceptibly into one another (particularly in the case of peaty flushes and where blanket peat reaches the valley bottoms in the higher valleys), the boundaries must be regarded as qualitative.

DISTRIBUTION OF ORGANIC SOILS

FIG. 41



## 6.1 The Blanket Peat

The palaeoecological significance of the blanket peat has been discussed in Chapter 4. From figure 41, it can be seen that the peat cover is extensive above 1500 feet and extends up to the highest point of the area at 2452 feet at Burnhope Seat. The main core areas of peat follow the high interfluves encompassing the major valley of the River Wear and Rookhope Burn, with subsidiary north-to-south extensions between the main tributaries. Although the peat cover is characteristic of summits and flat ridges, it does in fact extend a considerable distance down the valley sides. In the higher valleys of Killhope, Burnhope, and Wellhope at the head of the dale, it reaches the valley floors. Although the nature of the basal substratum is considered more fully in Chapter 7, it is noteworthy that it occurs on materials with a considerable diversity of chemical and physical properties. Impermeable solifluction deposits form a common base, but some of the deepest deposits are in fact situated on a permeable, weathered sandstone regolith. There is no obvious correlation between peat depth and substratum permeability.

Variability in thickness is one of the most obvious characteristics of the peat, however, and this property appears to be related to the hydrologic cycle at particular peat sites. From the point of view of moisture input, the most favoured areas are the highest ridges, where precipitation is at a maximum and evaporation at a minimum. This entails the classic 'maritime sub-arctic climate' of the land over 1500 feet (see Chapter 4).

Within this broad zone, peat accumulation has been most striking where output by drainage has been at a minimum i.e. on the more gentle sites. Thus on the high, flat interfluves it is usual to find a peat cover of at least 6 feet in thickness, a maximum thickness of 8.5 feet being recorded just to the south of Killhope Law.

Profiles 1 and 2 in Appendix IV illustrate the morphological and chemical properties of two ombrogenous blanket peats. Both are extremely wet, with water exceeding the dry peat material by a factor of from seven to nine, and mineral material accounts for a maximum of 4.6% of the dry weight. Nitrogen ranges from 1.01 to 1.73% of the dry peat. The peats are extremely acid, pH values ranging from 3.4 to 4.1, a feature which GORHAM (1956, 1957, 1958) has shown to be due to sulphuric acid in the bog waters. The source of the sulphuric acid is hydrogen sulphide, formed by the breakdown of organic sulphur compounds in the anaerobic peat environment, which is oxidised to sulphuric acid when it diffuses into surface pools.

TABLE 10. MEAN ANALYTICAL VALUES OF BLANKET PEAT SAMPLES

| No. of Samples | pH | % dry weight | | |
|---|---|---|---|---|
| | | $H_2O$ | Ash | N |
| 7 | 3.7 | 832 | 3.3 | 1.43 |

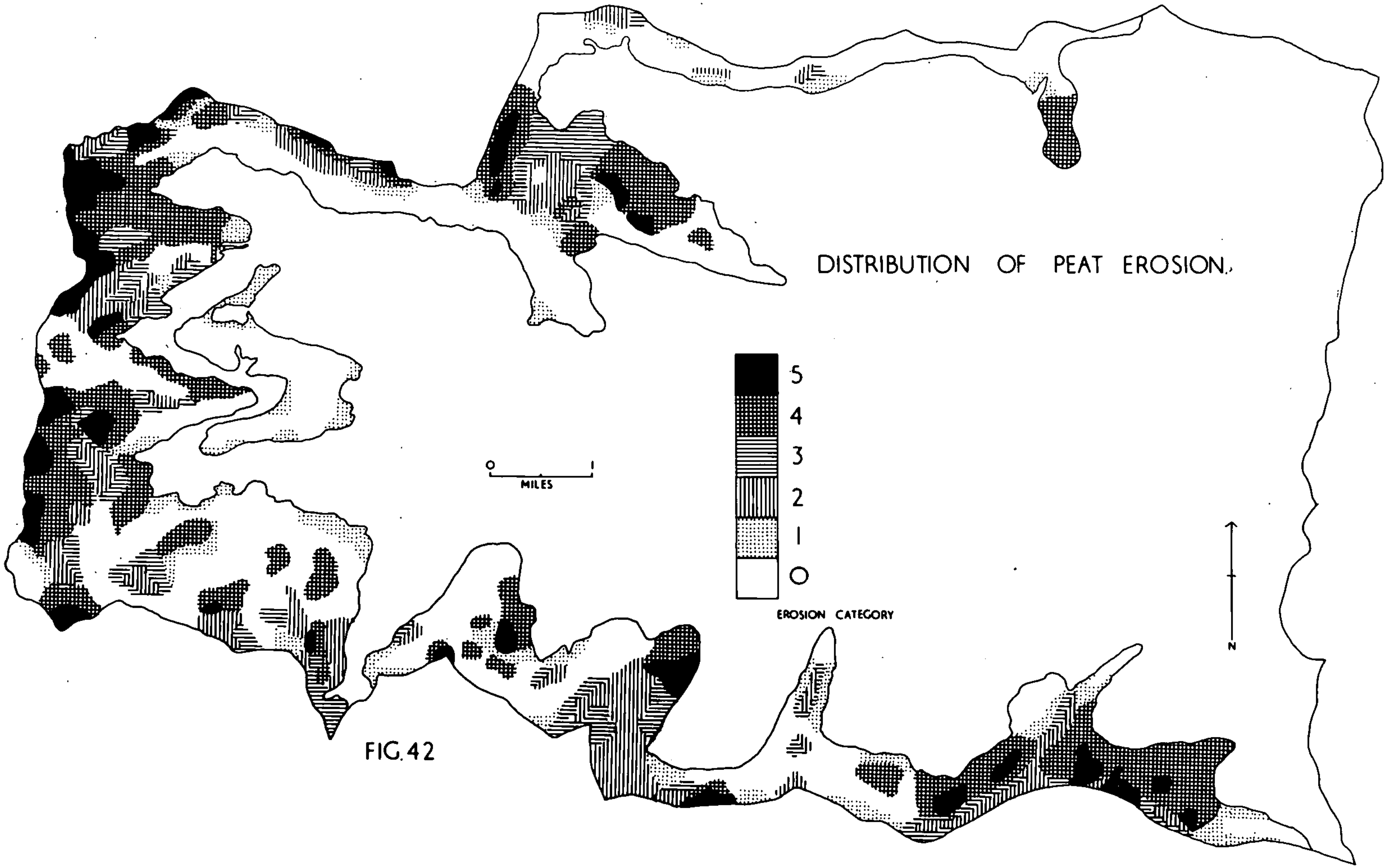
The above figures for average analytical values are similar to average North British and Scottish figures quoted by GORHAM (1961), except for the water content as a percent of dry weight which is considerably below GORHAM's figure of 1170. This is probably a reflection of the drainage conditions at the two sites studied.

The blanket peat areas of Weardale clearly offer considerable scope for future research. Apart from their importance as palaeo-ecological indicators, much data remains to be collected on such features as surface morphology, stratification and structure, horizontal and vertical variation in chemical characteristics, and chemical analyses of precipitation input and drainage output. Only with such data at hand can questions of reclamation and land-use planning be rationally assessed.

## 6.2 Erosion of the Blanket Peat

Extensive areas of blanket bog erosion or "hagging" have long been noted by naturalists in the Northern Pennines, but the comprehensive studies of BOWER (1959, 1960, 1960b, 1961) have provided the first maps of its distribution and extent. Using criteria of site conditions and gully frequency, she distinguishes three main categories of peatland dissection - 'type 1', 'type 2', and 'unaffected' - and further subdivides 'type 2' by means of a gully interval rating.

Within the watershed of Weardale, field mapping of erosion allowed a finer scale of the classification of erosion types than BOWER's use of aerial photographs allowed. The following table defines the simple ranking categories used, and fig. 42 shows their distribution. Within the erosion complexes, the main erosive agents are



DISTRIBUTION OF PEAT EROSION.

FIG. 42

Plate 25. Isolated 'peat haggs' on Burnhope Seat (84/792380)

Plate 26. Severe peat erosion by gullying and mass movement on Burnhope Moor. (84/835370)

TABLE 11. CATEGORIES OF PEAT EROSION

| BOWER's Degree of Dissection | Ranking | Characteristics |
|---|---|---|
| Unaffected | 0 | Undissected; but erosion within or beneath peat |
| Type 2 | 1 | Occasional Gullies |
| | 2 | Frequent Gullies |
| | 3 | Very Frequent Gullies |
| Type 1 | 4 | Discrete mounds with branching gullies |
| | 5 | Isolated mounds with broad inter-mound flats |

water, mass movement, wind and frost and the chief processes at work appear to be those previously documented by LEWIS (1904), CRAMPTON (1911), MITCHELL (1938), and BOWER (op.cit.).

Of more particular interest within Upper Weardale is the distribution of erosion types and the light it sheds on the changing processes from place to place. This seems necessary in the light of BOWER's (1961) general statement that although "on first sight of a small area, erosion may seem overwhelmingly influenced by landforms and geology, further enquiry over a large area..... reveals the overall significance of climate."

Although the scarcity of past and present climatic data means that qualitative judgements have to be relied upon in assessing the importance of the climatic factor, certain features of the distribution of erosion types appear to be causally connected with the distribution of climatic elements. The overall regional trend of increasing climatic severity with increasing altitude is reflected in the more advanced state of erosion in the higher peat areas. As is indicated on the distribution map, erosion of an 'advanced' character is generally confined to the higher interfluvial areas, for the most part over 2000'. The higher rainfall totals, the greater frost incidence, and the greatly increased wind speeds in these exposed locations undoubtedly increase the rate of erosion. This is particularly interesting in relation to CONWAY's (1954) statements that at high altitudes peat is deeper because it has accumulated for a longer period and probably more rapidly than the thinner peats of lower altitudes. Thus high altitude peats may be at a more advanced state in a natural growth cycle the end point of which, as several people believe, is the onset of erosion.

It is dangerous to equate stage with age, however, and in the study of erosion on a local intensive scale, factors of site supercede the more general factor of climate. /S Only in these terms can certain important anomalies be explained i.e. the relative lack of severe erosion on the highest posts of the watershed at Burnhope Seat.

The effects of topography and human interference appear to be of particular importance in determining the distribution of erosion types. In the absence of data on hydrological conditions at the peat surface, within the peat body, and on the peat-mineral soil interface, as well as engineering studies on the peat mass and its underlying foundations, these effects too can only be judged by observation and relatively simple analysis. Numerical analysis of the complex bog system, using techniques favoured by KULCZYNSKI (1949), offers a favourable field for ecological research in the Pennines.

Analysis of erosion category and slope reveals no simple relation between slope and erosion type in Weardale, although several interesting observations can be made from the slope-erosion category scattergram. Severe erosion of categories 4 and 5 is more common on flat sites, although not exclusively so as suggested by BOWER (1961). This association is most probably derived with the hummock-pool complex which the peat surface shows on flat sites, the development of an intricate gully system also depending on the more gentle runoff from these areas. Categories 1 and, to a lesser extent, 0, also favour flatter localities. In such areas, peat erosion is minimal, with only occasional intrapeat channels or widely spaced gullies. The trigger mechanism of erosion does not appear to have been released. The widest location is found for categories 2 and 3, where the usual form of erosion is by means of the widening and headward extension of straight and parallel gullies. These categories are most common on slopes over $5^{\circ}$, where, in fact, gully frequency is a function of slope. Mass moved peat erosion is again dependent on slopes. There are no signs of dramatic 'bog-bursts' in Weardale, although numerous small slumps and slides can be seen along gully sides and exposures.

The biotic factor remains as one of the imponderable 'possibilities' in assessing the trigger action for erosion - a rather elusive third alternative to ideas on climatic change and a natural growth-decay cycle. Burning, overgrazing, and draining are widespread human activities in the North Pennines, and all undoubtedly stimulate the degree of erosion - burning and overgrazing by removing the surface vegetation cover, and draining by canalising

# RELATIONS BETWEEN SLOPE AND EROSION CATEGORY.

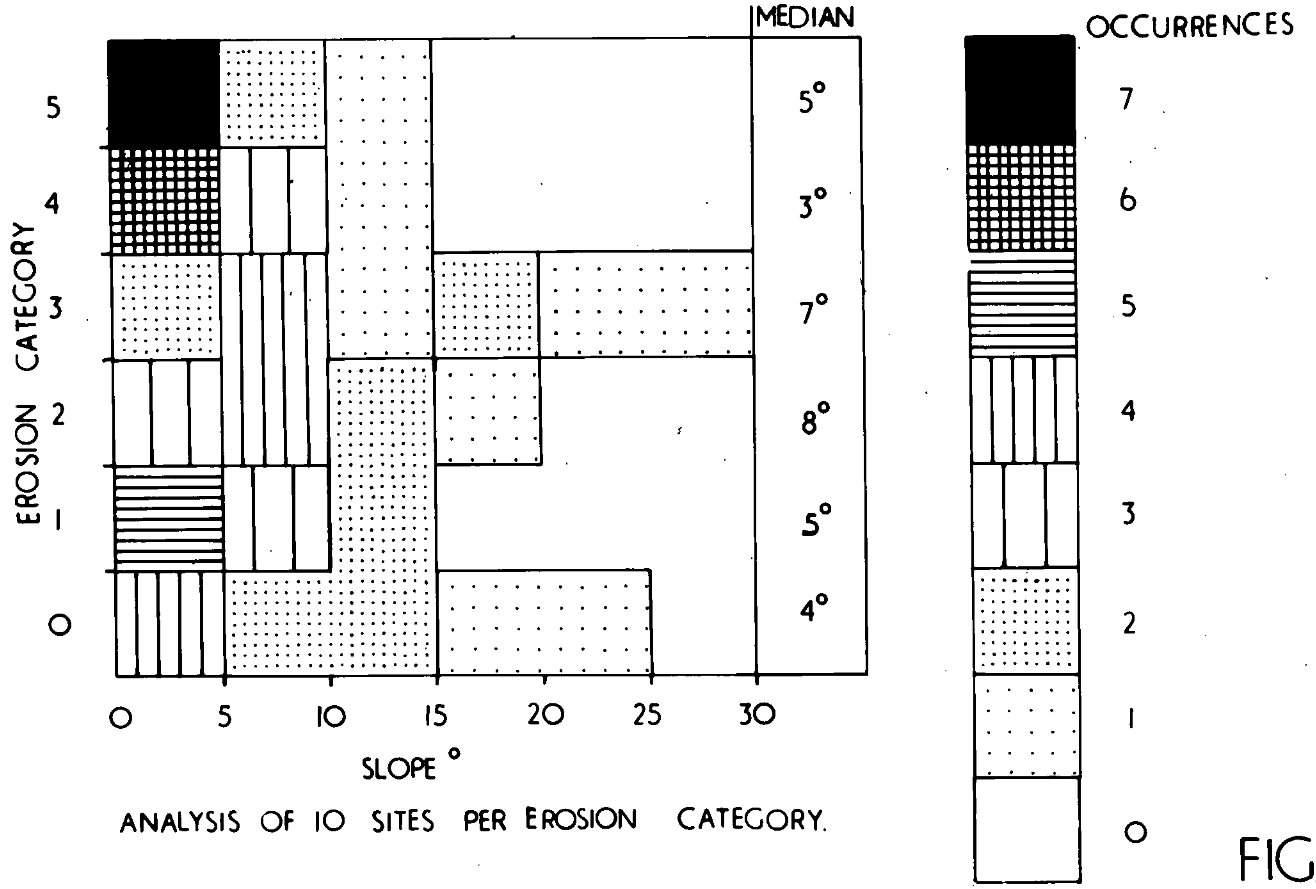


FIG. 43

and tapping water flow. The net result is to convert a stable blanket bog ecosystem into an unstable system, which is then open to erosion and irreversible degeneration. Owing to the absence of quantitative experimentation the full effects of biotic activities cannot be precisely assessed.

### 6.3 Basin Peat

Basin peat in shallow peat-filled hollows probably occurs in several areas within the area of blanket peat, but the difficulties of locating and defining such deposits are considerable. In Weardale two areas of topogenic peat in valley bottoms have been located, in the valleys of Wellhope Burn and Burnhope Burn. In each case colluvial deposits have dammed natural outflow in concave basins, which have since been filled by peat.

Studies of the details of the stratigraphy of these two deposits have been made by WARDHAUGH (private communication), who recognises a tripartite subdivision of each section, corresponding to the classic open water, fen, and bog developmental stages. The Wellhope Bog has a maximum depth of 5.3 feet whilst that for Burnhope is 6.5 feet.

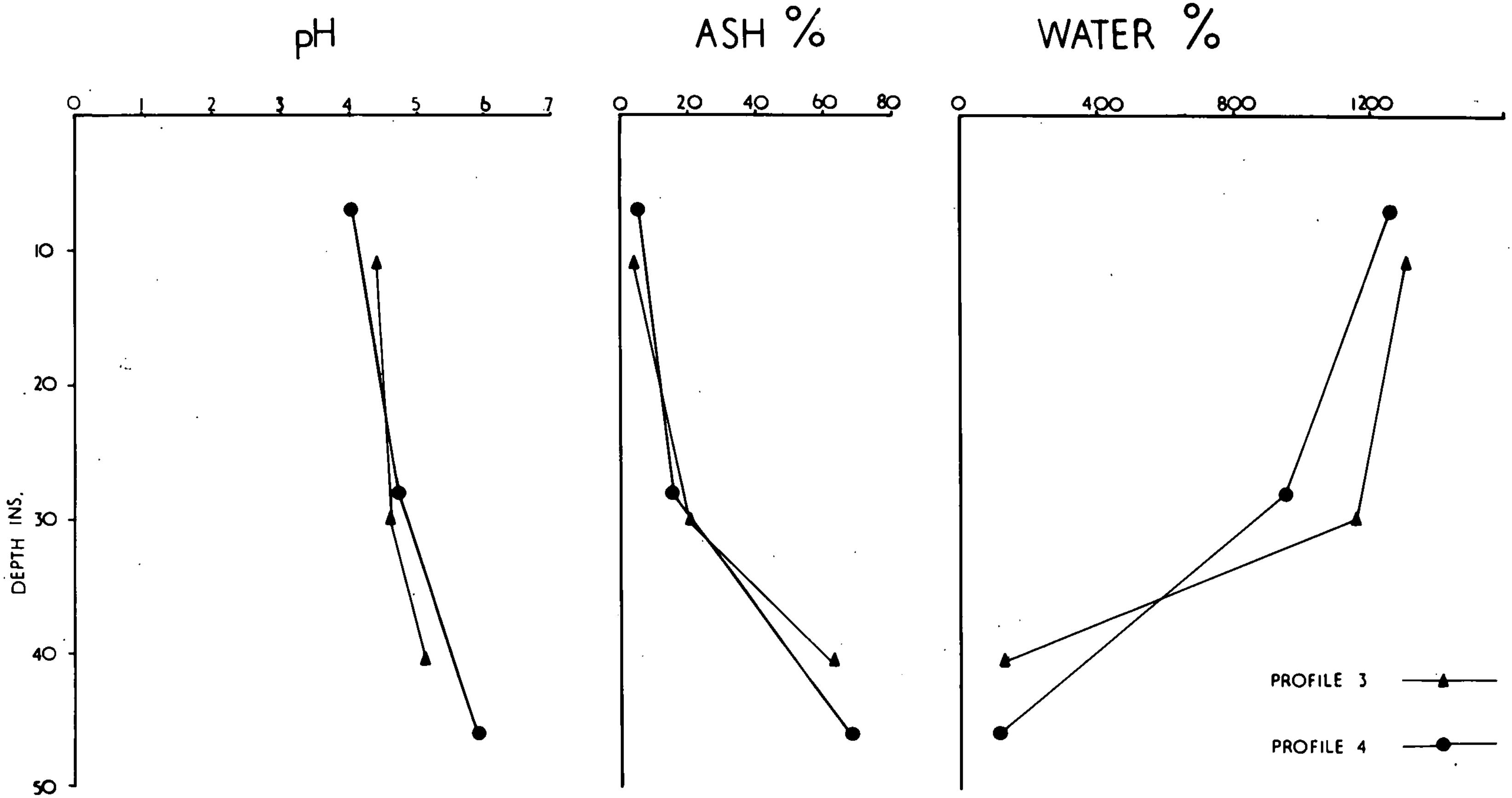
The descriptions of surface vegetation and the macromorphology of the upper sections of the basin peat show that it has already developed to the raised moss stage with a surface vegetation little different from that of the blanket peat. In analytical characteristics, too, there are close similarities. The striking differences are firstly, the much higher water content of the basin peat surface (1286%dry weight against 832) and its slightly higher pH (4.2 compared to 3.7). Both of these differences are related to the receiving position of basin peat sites with continual influxes of surface- and ground-water and their contained bases. It is thus doubtful whether the surfaces are exclusively ombrogenous.

Perhaps the most striking characteristic of the basin peats, however, is the vertical succession shown by the profiles and the way this is reflected, in physical characteristics. The aquatic stage - fen stage - ombrogenous stage sequence is mirrored in decreasing pH, increasing water content and decreasing ash content. No significant trends are shown in nitrogen values. The changes of these characteristics with depth are graphically shown in figure 44. The trends and values shown compare closely with figures for other Northern England sites, for example in the Lake District (TANSLEY 1939).

## 6.4 Flush Peats

Flush types are notoriously difficult to classify on account of their considerable variety in detail (MUIR & FRASER 1940; PEARSALL 1950) and their extremely small extent. The term 'flush' is generally used to a small area where a distinctive vegetation is formed by the movement of free water through and over the soil surface; no attempt can be made to give more than a general outline of the different types.

The tripartite subdivision into peaty, lime, and iron flushes is a reflection of the chemical characteristics of the flush water. Thus the source of water and hence its location plays an important role in determining the distribution of the different flush types. The chemical characteristics of the flush water not only determine the



VERTICAL CHANGES IN THE CHARACTERISTICS OF BASIN PEATS. FIG. 44

chemical medium of the flush for plant growth, but also have indirect influences on the luxuriance of plant growth, the rate of decomposition, and the build-up of humose peat. Thus all areas within a flush zone in Weardale do not have a continuous thickness of peat over twenty inches, but for mapping purposes they have been included within the flush type.

Peaty flushes are the commonest type of flush in the area. They are widely scattered within the wet-heath and moorland associations, and also are found commonly at a peat-edge location. Decomposition of organic matter is limited, and peaty humus accumulation takes place, particularly where drainage water is confined to the surface of the peat, is held up in a peat hagg or is concentrated on emerging from the peat. Sphagnum, Juncus squarrosus and effusus, Carex spp., and Narthecium ossifragum are common ecological indicators.

Profiles 5 and 6 show the variability which can be found over quite short distances within a flush zone, the profiles being located within three yards of each other. Compared to the surrounding ombrogenous peat the pH and ash contents are slightly, but not significantly, higher. The peaty flush is predominantly a humose, waterlogged and acid medium throughout.

Lime flushes are of particular importance throughout the Pennines due to the presence of various limestone strata throughout the geological succession. They are especially common where spring water emerges from the limestone, particularly the Great Limestone, and flows over the surface of the blanket peat. Thus very distinctive local habitats are created with distinctive calcophile floras. Indeed, the main interest to date in these flush zones has concerned the structure of the plant communities and their relations with the sub-alpine marshes of the Alps and Scandinavia; the work of PIGOTT (1956) in neighbouring Teesdale is particularly well known in this respect.

In Upper Weardale some of the finest examples of calcareous flushes have been disturbed by mining and forestry activities, particularly in the burns of Killhope and Wellhope. The pale green areas of Philonotis are still conspicuous, however, and provide indicators of more eutrophic conditions. The flush water is mildly calcareous (35 p.p.m. $Ca^{++}$ on average) with a pH just below neutrality. Generally a thick (> 20") layer of humose silt overlies a water-saturated and anaerobic blue-grey slope deposit.

Iron flushes cover a much smaller area and are generally more localised than the other two main types. They are particularly associated with Killhope Burn where several such flushes are maintained by waters from ironstones and iron-bearing shales. It is probable that mining disturbance here has brought much iron-rich mineral material into the soil water zone. They are particularly characteristic in peat areas of marked surface micro relief, either naturally or by erosion, where waters charged with soluble ferrous iron compounds issue from the anaerobic blanket bog and became oxidised along drainage courses. A thick 2.5 YR 4/4 Reddish brown deposit of ferric oxides stains the surface of the drainage channel and the surrounding vegetation. It is difficult to think of a characteristic

Plate 27. Iron flush deposit on Killhope Moor. (84/806436)

flora in such a poor medium for plant growth, and species are generally those of the surrounding blanket bog, with Juncus and Carex spp. more commonly represented.

PUUSTJARVI (1952) has worked on oily 'rimpis' in Finnish mires and regards "oily" and brown stainings as colloidal isoelectric precipitates. However the eutrophic nature of his sites (mean pH 6.3) contrast markedly with the dystrophic iron flushes in Weardale.

## 6.5 Peat Water Analyses

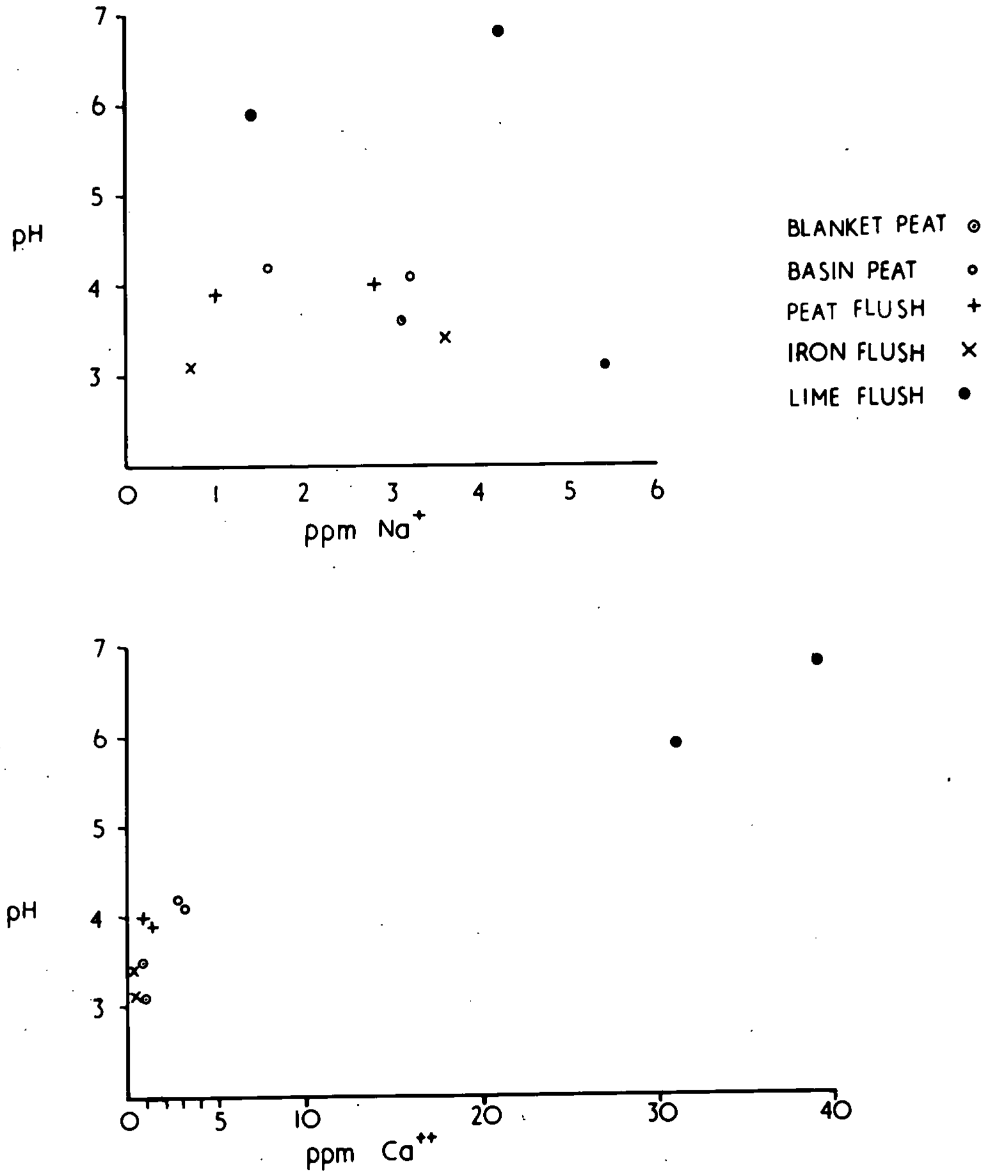
TABLE 12. ANALYSIS OF PEAT WATERS

| Profile | pH | p.p.m. Ca | Mg | Na | K |
|---|---|---|---|---|---|
| | | Ca | Mg | Na | K |
| 1. Blanket Peat | 3.1 | 1.0 | 0.4 | 5.4 | 0.1 |
| 2. " " | 3.5 | 0.8 | 0.4 | 3.1 | 0.2 |
| 3. Basin Peat | 4.2 | 2.8 | 1.5 | 1.6 | 0.3 |
| 4. " " | 4.1 | 3.1 | 0.7 | 3.2 | 0.2 |
| 5. Peat Flush | 4.0 | 0.9 | 0.5 | 2.8 | 0.1 |
| 6. " " | 3.9 | 1.3 | 0.4 | 1.0 | 0.1 |
| 7. Iron Flush | 3.4 | 0.2 | 0.6 | 3.6 | 0.2 |
| 8. " " | 3.1 | 0.2 | 0.1 | 0.8 | 0.4 |
| 9. Lime Flush | 5.9 | 3.2 | 1.8 | 1.4 | 0.5 |
| 10. " " | 6.8 | 3.8 | 1.4 | 4.2 | 1.0 |

The above results show the ionic composition of peat water samples collected at the indicated profile sites. Although the results have to be interpreted with caution owing to the fact that the ionic composition of peat waters has a marked dependence on weather conditions (GORHAM, 1955) and on peat micro relief (GORHAM 1950), nevertheless some interesting trends are shown.

Potassium contents are uniformly low as are magnesium values except for the lime flushes and, to a lesser extent, the basin peats. Sodium values are extremely variable, probably reflecting atmospheric rather than ground water conditions. There certainly appears to be no obvious relation between sodium and pH (figure 45). Calcium values, however, increase with increasing pH. Calcium values, in fact, offer a good ionic indicator of the genetic environment. The extremely low values for blanket peats, peaty flushes, and iron flushes increase slightly in the basin peats, and then increase significantly for the lime peats.

DRAINAGE WATER ANALYSES. FIG. 45



# Chapter 7

# Sub-Peat Soils

## 7.1 Introduction

Soil profiles with a significant (> 20") thickness of peat are classified and mapped as Organic Soils, incorporating similar concepts, but a different criterion of peat thickness, to the Soil Survey of Great Britain. In addition considerable emphasis has been placed on the properties of mineral material beneath the peat cover to investigate its diagnostic importance in the pedology of the area. The prefix 'sub-peat' refers to such profiles beneath the peat and typifies that zone of altered mineral material situated beneath the peat and above the parent material on which the peat rests. In this respect it is used with a meaning similar to that of PROUDFOOT (1958).

Sub-peat profiles have been completely neglected in the Pennine Uplands. TOMKEIEFF (1927) commented on the sub-peat weathering of granite in the Cheviot Massif, CLAYDEN and MANLEY (1964) describe sub-peat sections on Dartmoor, and PROUDFOOT (1958) has analysed sub-peat profiles in an archaeological context in Co. Antrim. On the whole, however, difficulties of mapping and interpretation have precluded detailed studies. Their interest is pedological and only marginally agronomic, and obvious site problems make field study difficult.

In the present study sub-peat profiles have only been examined under ombrogenous blanket bog. In three small areas, in Killhope Burn, in Wellhope Burn, and on Chapel Fell, gully dissection of the peat cover has allowed numerous profiles to be examined particularly as the gullies commonly extend down to bedrock. The fact that a linear gully system flows at right angles to the slope has meant that transects have been possible in both localities, traversing a range of geologic strata, superficial deposits and slope conditions. The converse disadvantage of a possible gully effet on the profiles has had to be ignored, most sections being thoroughly cut back before study. The samples collected from the sites have been analysed as though they were samples from surface mineral soils.

## 7.2 Morphology

The most striking morphological contrasts in sub-peat profiles are the incidence and intensity of gleying and the presence or absence of a thin iron pan. Profiles 11 and 12 show continuous gleying from the peat/soil interface into the underlying parent material, whilst profiles 13 and 14 have thin iron pans in addition to the profile gleying. Profiles 15 and 16 have an imperfectly drained status with only intermittent and slight visual signs of gleying, whilst profiles 17 and 18 are similarly podzols but with well marked iron pans. In these last two examples gleying only occurs locally above the pan. Thus, using the visual differentiae of hydromorphism and iron pan, a preliminary sub-division of sub-peat soils might be:

TABLE 13. TYPES OF SUB-PEAT PROFILE

| DIVISION | MAJOR GROUP | SUB-GROUP |
|---|---|---|
| SUB-PEAT SOILS | i) Gleys | i) Gley<br>ii) Gley with pan |
| | ii) Podzols | iii) Podzol<br>iv) Podzol with pan |

## 7.3 Chemical Characteristics

In order to understand the dynamics of features found in profiles beneath the peat, the profiles described have been analysed for iron and trace element contents using methods outlined in Appendix III. The results are presented in Table 14.

Although absolute values between profiles are variable, all profiles show similar trends with depth. Immediately beneath the peat occurs a zone of relative loss of iron and other trace elements, doubtless due to intense leaching below the basal layer of peat. This is an invariable feature beneath blanket-bog, and also corresponds to the horizon of minimum pH. With increasing depth, pH values rise, as do the contents of trace elements. Iron pans obviously stand out as zones of intense enrichment, whilst more diffuse accumulations occur in the non-pan varieties. Although there is no sign whatever of this accumulation in profile morphology, the analytical results suggest similar processes in all profiles.

## 7.4 Interpretation

The interpretation of the evolution of sub-peat profiles is a relatively complex matter, however, and one must be aware of several possible processes and developmental sequences which can operate within the soil.

From field evidence and mechanical analyses, the intensity of gleying is dependent on the texture and structure of the parent material. The heavy solifluction deposits from Carboniferous shale and from a mixture of shale and sandstone are typical parent materials for Sub-Peat Gleys. The compaction and firm consistence of these deposits generally give pale gley colours throughout,

# TABLE 14. IRON AND TRACE ELEMENT VALUES OF SUB-PEAT PROFILES

| PROFILE | Sample No. | Depth Ins. | pH | % Loss on Ignition | Deb's Iron % | ppm Pb | ppm Zn | ppm Cu |
|---|---|---|---|---|---|---|---|---|
| 11 | 033 | 0-3 | 3.6 | 43.2 | 0.4 | 032 | 013 | 010 |
| | 034 | 3.12 | 3.9 | 19.1 | 1.3 | 146 | 074 | 019 |
| | 035 | 12-18 | 4.1 | 6.1 | 2.4 | 188 | 063 | 036 |
| | 036 | 18-22 | 4.8 | 1.9 | 1.6 | 204 | 084 | 041 |
| 12 | 037 | 0-4 | 4.5 | 32.3 | 0.6 | 022 | 008 | 002 |
| | 038 | 4-10 | 5.1 | 3.4 | 1.8 | 074 | 094 | 012 |
| | 039 | 10-22 | 4.8 | 2.1 | 2.4 | 096 | 062 | 024 |
| | 040 | 22-28 | 5.2 | 1.3 | 1.8 | 132 | 032 | 020 |
| 13 | 041 | 0-4 | 4.5 | 11.4 | 0.9 | 000 | 000 | 014 |
| | 041P | 4-4¼ | - | - | 5.6 | 048 | 090 | 036 |
| | 042 | 4¼-18 | 4.6 | 3.2 | 2.1 | 024 | 050 | 018 |
| | 043 | 18-28 | 5.1 | 1.9 | 1.7 | 056 | 062 | 026 |
| 14 | 045 | 0-12 | 4.8 | 1.6 | 0.2 | 132 | 012 | 002 |
| | 045P | 12-12½ | - | - | 6.3 | 248 | 036 | 008 |
| | 046 | 12½-28 | 5.0 | 0.3 | 3.1 | 230 | 020 | 006 |
| 15 | 047 | 0-4 | 4.8 | 11.9 | 0.4 | 004 | 036 | 024 |
| | 048 | 4.7 | 5.0 | 7.8 | 0.8 | 136 | 064 | 040 |
| | 049 | 7-14 | 5.1 | 3.6 | 1.3 | 230 | 058 | 064 |
| 16 | 050 | 0-6 | 4.2 | 4.9 | 0.3 | 104 | 004 | 023 |
| | 051 | 6-10 | 4.6 | 0.8 | 0.6 | 182 | 010 | 042 |
| | 052 | 10-22 | 5.0 | 0.2 | 0.9 | 162 | 046 | 038 |
| 17 | 053 | 0-6 | 3.5 | 5.8 | 0.3 | 064 | 006 | 020 |
| | 053P | 6-6¼ | - | - | 4.2 | 258 | 142 | 042 |
| | 054 | 6¼-9 | 3.7 | 2.4 | 2.3 | 164 | 084 | 034 |
| | 055 | 9-18 | 4.0 | 0.9 | 1.7 | 132 | 062 | 040 |
| 18 | 056 | 0-11 | 4.6 | 7.3 | 0.6 | 036 | 012 | 032 |
| | 057 | 11-14 | 4.9 | 3.4 | 1.3 | 084 | 024 | 026 |
| | 057P | 14-14¼ | - | - | 8.4 | 138 | 104 | 144 |
| | 058 | 14¼-29 | 5.3 | 3.5 | 4.2 | 092 | 082 | 064 |

with both coarse and fine mottles around included stones. Loams and coarse loams from weathering products and solifluction deposits derived from Carboniferous sandstone show the characteristic sub-peat bleaching of the podzol profile. Variations in topography and drainage only marginally influence these soil-parent material correlations.

The influence of structure is even more clearly demonstrated in Sub-Peat Gleys with pan. Here a situation similar to that noted by CLAYDEN and MANLEY (1964) on Dartmoor is observed, where a definite structural interface marks the position of the panning. The olive grey horizon immediately below the peat is separated by the pan from a massive and compacted substratum. The lack of obvious sheathing and platiness suggests that the explanation of FITZPATRICK (1956) may need modification for the origin of the dense subsoil, and one is reminded of the work of VAN DER MAREL (1949) who emphasises the translocation of alumina in podzolisation and the formation of boehmite ($Al_2O_3.H_2O$) in podzolic subsoils. ROMANS (1959) has noted the indurating power of alumina moved in this way. It is clear, however, that the maximum zone of iron build-up coincides with a definite physical interface.

In terms of present processes only, it is possible to suggest two mechanisms operating to produce the eluvial/ illuvial sub-peat profile. On freely draining sites, the downward movement of acid waters from the peat produces impoverishment and podzolisation within the mineral material, to give bleaching profiles similar to those earlier noted by ENDELL (1911), SMIRNOV (1915), BLANCK AND RIESER (1925), and TOMKEIEFF (1927). Thus the hydrology of the blanket peat influences directly the dynamics of the underlying strata, in contrast to the suggestions of PROUDFOOT (1958) for Co. Antrim. VAN HEUVELN, ET AL. (1960) substantiate the percolation of humic acids below peat.

In gleyed profiles the movement of trace elements may be the result of processes originally suggested by MUIR (1934) and since experimentally verified by BLOOMFIELD (1951). As a result of gleying immediately beneath the peat, iron is reduced and mobilised, to be re-precipitated lower down.

Owing to the ecological history of Weardale and the fact that sub-peat soils have been interpreted elsewhere as fossil soils (PROUDFOOT 1958; DIMBLEBY 1962), it is necessary to consider the significance of the profiles in a palaeo-pedological setting. The basal peat on the Weardale Fells started to accumulate at the Boreal-Atlantic transition (c.5500 B.C.) on parent materials previously affected by frost weathering and leaching for several thousand years. How far does the pre-peat pedology give relict features to the soils under review? How far advanced was the gley-podzol dichotomy?

With the onset of peat forming conditions, surface anaeobism and loss of iron in the manner suggested by MUIR (1934) would necessarily follow. However, sub-peat gleys show consistently more intense leaching than normal peaty gleys (see Chapter 8). How far is this a reflection of the length of time of a blanket-peat cover (c.7000 years), or how far is it a function of the thickness of the overlying peat? The fact that these factors are so obviously correlated increases the difficulty of interpretation. As a working conclusion it must

Plate 28. Sub-peat gley formed in clayey slope deposit derived from weathered shale. (84/805438)

Plate 29. Sub-peat podzol with thin iron pan in Wellhope Burn.
(84/821408)

be accepted, however, thick peat induces intense leaching in underlying mineral soils, a rate of loss of elements which increases with peat thickness and time.

# Chapter 8

# Hydromorphic Soils

## 8.1 Definition

The most dominant characteristics of the soils of Upper Weardale are morphological features associated with hydromorphism in the soil profile. In addition to the exclusively organic profiles previously discussed, anaerobism in essentially mineral soils produces both a wide suite of 'Gley' soils and a number of podzol and brown earth profiles which have to be qualified by the suffix,'with gleying'. Reduction, both complete and intermittent, leads to the common occurrence of all those morphological features normally associated with poor soil drainage which have been concisely described by CROMPTON (1952).

For purposes of classification and mapping the criterion used to differentiate between, for example, a gleyed brown earth and a true gley soil is that proposed by CROMPTON (1952), whereby all soils with a definite horizon showing permanent waterlogging are gley soils, while those which merely show blotching or mottling are classed as brown earths. This usage is in keeping with the concept of the hydrologic soil association of GLENTWORTH AND DION (1950) with its insistence on progressive and continuous change under varying soil drainage conditions.

Another conventional practice which has been used to simplify the environmental relations of gley soils is the taxonomic subdivision, at major soil group level, into those soils dominated by ground water conditions and those dominated by surface water. In an ideal situation the distinction between these two genetic groups can highlight striking differences in the controls of gleying i.e. whether they are geomorphically or pedologically controlled, and it has traditionally proved to be a subdivision with important ramifications both for pedogenesis and also for problems of land-use.

TABLE 15. CLASSIFICATION OF GLEY SOILS

| DIVISION | MAJOR SOIL GROUP | SUB-GROUP |
|---|---|---|
| Gley Soils | a. Ground-water Gleys | Non calcareous Ground-water Gleys<br>Peaty Gleys |
| | b. Surface-water Gleys | Calcareous Surface-water Gleys<br>Non calcareous surface water gleys<br>Peaty gleyed podzols |

Notwithstanding the apparent logic of the scheme of classification and the striking morphological and analytical differences between modal profiles in each sub-group, it involves several arbitrary features which can give rise to difficulty in the definition of boundaries. On the Division level, the distinction between the imperfectly draining soil and its impeded counterpart has been previously referred to. The criterion of CROMPTON (1952) is generally satisfactory, particularly on relatively homogeneous parent materials, but difficulty was experienced on slope deposits and tills with significant stone contents; such deposits generally have a very variable fabric with consequent high internal variations in colour and porosity. It sometimes proves extremely difficult to distinguish between mottling, blotching, and speckling inherited from the parent material and similar morphological features produced by the contemporary pedogenic process of gleying

A greater difficulty occurs at Major Soil Group level with the ground-water/surface-water distinction. To the hydrologist the distinction between the ground-water table and local-water table is simple but tenuous (SMITH, private communication). It becomes extremely difficult, without a thorough hydrophysical survey, to decide where surface-water conditions end and ground-water conditions begin. Particularly is this true on the relatively heavy textured slope- and till-deposits of Weardale. Whilst it is possible to separate the heavier textured soils, where surface-water gleying is common, together with some ground-water gleying, from the lighter-textured soils where ground-water is the only cause of gleying, intermediate topographic situations exist where it is extremely difficult to be definitive. ASHLEY (1959) has previously noted this difficulty with reference to the process he calls "lateral gleying" in similar moorland and sub-moorland soils of Northumberland.

## 8.2 Relation to Environment

The distribution of gleying in the soils of Upper Weardale is closely allied to the distribution of those soil forming factors which favour the prolonged or intermittent retention of water in the soil profile. Much of the difficulty of interpreting the relations of environment derive from the difficulty of assessing the interaction between these controlling factors and their relative importance from place to place. /S

The basic precipitation pattern of the area has already been shown to consist of a steep gradient decreasing from west to east and from high ground to low ground. Conditioned primarily by exposure and by altitude, this gradient results in a general tendency for soil drainage status to improve with lower annual precipitation - a situation common on the highland/lowland fringe where upland impedence gives way to imperfertly draining and freely draining profiles in more sheltered areas. This underlying sequence is characteristic for much of Britain and has been previously discussed by GLENTWORTH (1966) in Scotland and by BALL (1964) in Wales. The peats, peaty gleys and peaty gley podzols of moorland ridges and crests typically occupy a climatically controlled hydromorphic situation. Indirect side effects of the montane climate, notably low annual temperatures with reduced evaporation and reduced microbial decomposition of organic material, enhance the effects of high precipitation.

It would be perhaps a mistake to attempt to quantify this important climatic control. Although climate appears to have overwhelming significance and it is in high rainfall areas that, for example, one finds profile anaerobism over the widest range of parent materials, yet without data on present-day climatic parameters and without a historical record, it is difficult to be any more than qualitative about the climatic effect. How far is the present situation a legacy from past climatic history? How far is present peat erosion a climatically induced or ecologically induced phenomenon? How far did the initiation of peat growth at the Boreal/Atlantic transition trigger off an evolutionary pathway which has now acquired features of near permanency?

An assessment of parent material and topography effects on gleying is fortunately less speculative than that concerned with climate. The permeability of the parent material is an overriding consideration, particularly for surface-water gleying, and markedly determines the fate of gravitational water in the soil, whether derived from soil water movements or directly from precipitation at the surface. Parent materials of clay - clay loam texture most commonly show gleyed characteristics, and include till and slope deposits derived from shale or from a mixture of shale and sandstone. Such associations between gleying and texture are to be expected, but rather more interesting are those cases where gleying occurs in deposits of loam texture, notably colluvial and slope deposits with a high admixture of sand fraction from Carboniferous sandstone. In such deposits factors of structure, compaction, surface organic form, and sesquioxide distribution have effects on inherent permeability.

Topographic controls are similarly well documented for Britain as a whole, the applicability of the hydrologic sequence (GLENTWORTH and DION 1950) having been noted in many survey and pedology studies. Certainly in Upper Weardale the interactions of slope angle, form and length with parent material permeability most readily explain the distribution of gleying. Inherent moisture retaining capacities of soils have to be viewed in conjunction with the slope component of soil moisture movement.

In the dale, however, the effect of topography is much more complex than considerations of slope alone suggest. Apart from the effects of altitude on the regional precipitation pattern, topographic conditions influence the importance of aspect. With a clearly defined easterly drainage pattern, conditions are similar to those previously described by ASHLEY (1958) for the valley of the River Tyne. North-facing slopes show a much wider distribution of gleying (cf. CRAMPTON 1965) by their ability to lower the critical levels of rainfall, permeability, and slope wherein gleying is induced. The pronounced differential effect of insolation with aspect remains a prime consideration in relating the soils to the factors of their formation (GEIGER 1950; TAYLOR 1958).

A final variable in this multivariate situation derives from the palaeo-ecology of the area (Chapter 4). The majority of gley soils in the study area are to be found under grassland associations, whether dominated by Eriophorum, Nardus, Molinia or Deschampsia species. This is a very broad general relationship, but one which has been noted in other areas (MUIR & FRASER 1940; CROMPTON 1952; BURNHAM 1961). Bearing in mind the possible former extent of woodland in the dale and the striking changes in soil porosity and structure noted where woodland has been cleared and put down to grass (DUCHAUFOUR 1959; DIMBLEBY 1962) and vice versa (ASHLEY, 1966), the distribution of gleying has to be assessed in its contemporary context as a response to changing ecological conditions. Differences in profile morphology between soils under grassland and under woodland are particularly striking in the field and undoubtedly have a strong control over the dynamics of soil moisture.

## 8.3 Non-calcareous Ground-water Gleys

Soils of the non-calcareous ground-water sub-group typically occur in valley bottom locations. Here ground-water gleying is frequently intensified by the existence of a more impermeable layer, either beneath the solum or within it (Profiles 19 and 20). MUIR and FRASER (1940) equate this group with what previously had been designated as 'meadow soil'. As such, it is probably more correct hydrologically to distinguish between a perched-water table rather than a regional water table, but again the distinction is very difficult in the field.

Landscape location rather than soil textural characteristics determines the prominence of gleying, however, and features of waterlogging can occur even in the lightest textural types. In the study area, where valley bottom sites have generally received inwashes of both colluvial and alluvial material it is rare to find uninterrupted sandy profiles in the manner described for the 'sandy gleys' of CROMPTON and OSMOND (1954) and AVERY (1956). It is more usual to find sandy loam, loam and sandy clay loam material overlying clay loams, silty clays, and clays. The profile banding in such cases is related to colluvial phases in the geomorphic history, the heavier material being derived from a solifluction phase and the lighter material being deposited during a later alluvial phase.

The presence of these marked textural profiles makes it impossible to link these soils as the hydromorphic analogue to acid brown soils as has sometimes been done (AVERY 1956). Rather they occupy distinct, yet localised,

Plate 30. Ground-water gley profile in Rookhope Burn (84/938430)

poorly drained situations which have always probably carried grassland or wet heath. There is no evidence for differential iron translocation in their profiles and no morphological evidence for old tree root channels now serving as nuclei for ferric oxide deposition. Depositional patterns are varied but are generally associated with prismatic structure faces included stone fragments, and numerous old grass root channels.

## 8.4 Peaty Gleys

The peaty gley sub-group is by definition associated with blanket peat soils (surface peat less than 20" in depth) and commonly found on the fringes of the blanket peat area proper. It occupies relatively flat or gently sloping sites on the watershed crests and upper slopes above approximately 1100'. Land use generally is unenclosed moorland with characteristic species of Eriophorum vaginatum and Molinia, Juncus squarrosus and Sphagnum spp, although it can also occur under once enclosed pasture which has since reverted.

The dominant characteristics of the profile are the presence of a wet surface peaty humus and underlying gleyed mineral horizons and the absence of a thin iron pan (Profiles 21 and 22). The detailed character of the gleyed mineral horizons depends very much on the textural and structural properties of the slope deposit on which it has formed, but several features are general in most profiles. Mineral layers immediately below the peaty humus show marked organic stainings which give way with depth to the characteristic hues of gleying. Rusty orange mottles are most common along old root channels, structure interfaces and around included stones. Patterning thus varies between and within horizons. Again, the

Plate 31. Peaty gley soil developed on clay slope deposit with few included stones (84/893445)

Plate 32. Dried out exposure of peaty gley soil on compacted slope deposit with significant content of sandstone fragments (84/902347)

Plate 33. Peaty gley profile within the present limit of enclosure (84/845415)

Plate 33. Peaty gley profile within the present limit of enclosure (84/845415)

profile. In an evolutionary trend they are regarded as immature and will develop by further leaching into leached gley soils (DUCHAUFOUR 1965).

In the study area calcareous gley soils have developed in response to surface water conditions. Typically they have formed on heavy clay loam/clay slope deposits overlying, or immediately downslope of, an outcrop of Carboniferous Limestone (Profile 23). They are thus localised to areas with suitable surface-water hydrologic conditions near a calcareous source.

Calcareous gley soils have several features in common with other soils of the calcareous group. The surface humus form is dark in colour and is generally well humified. The cation exchange capacity is base saturated, with calcium dominating all other cations. Surface structure is angular blocky and free calcium carbonate commonly appears as concretions in the subsoil. Where the soil occurs downslope of the limestone but above the limit of contemporary improvement, a characteristic *Agrostis*-*Festuca*-*Juncus* association commonly forms the surface vegetation. Apart from the presence of lime concretions, the textural, structural, and stone content features of the subsoil are common to non-calcareous soils on a similar parent material.

Profile 24 represents a less common variety of calcareous gley. Despite the steeper slope and ligher texture of the parent material, severe gleying is so marked as to produce a peaty humus form near the surface. This is probably due to a combination of a northerly aspect, a compactly structured subsoil and frequent incursions of calcareous water in a flush-like effect.

Plate 34. Calcareous gley soil with calcium carbonate segregations (84/842423)

## 8.6 Non-calcareous Surface-water Gleys

Surface-water gleying is a common feature in Upper Weardale soils on account of the general high precipitation, the heavy textures of the slope deposit and drift parent materials, the widespread opportunity afforded by slope conditions to intra-soil moisture movements (the "lateral gleying" of ASHLEY 1959), and the predominance of grassland vegetation types. As defined in the study area the non-calcareous surface-water gley soil may be equated with the 'leached gley' of AVERY (1956).

The relationships between texture, structure, moisture retention and features of gleying have been studied intensively by DUCHAUFOUR (1959, 1961). In areas of medium to high rainfall the disposition of infiltered soil moisture depends heavily on textural and structural features of the soil. Wherever a textural or structural interface ponds up soil water near the top of the profile and wherever this impeded soil moisture cannot escape by lateral seepage or surface run-off, surface-water gleying is induced.

Within Upper Weardale a number of differing situations have arisen to give a physical interface within the solum. A common situation which derives from the complicated superficial geology of the area is for a stratification within a parent material or the superimposition of two parent materials to produce a striking textural profile (Profile 25). One of the most obvious effects of past erosion cycles within the dale is thus an indirect effect through soil texture. The situation is most common at the lower end of slopes where both depositional disturbance and lateral water influx are both at a maximum.

majority of the peaty gleys examined in the area show continuous gleying to depth due either to deep surface-water conditions or local ground-water held up in the slope deposit. In several deep exposures and sections in the slope deposits, however, there is a return to freely draining conditions at depth in the profiles particularly where a structural or textural change occurs in the composition of the parent material. In many pits, however, the peaty gleyed profile may merely show less completely gleyed horizons in the lower profile.

Several of the most interesting aspects of the peaty gley soil occur not in the upper profile, where the peat-organic staining-gleyed sequence is widespread and characteristic, but in the morphology of the sub-soil layers. In some peaty gley profiles the grey-brown colours of the ground mass are veined with a complicated network of old root channels which are outlined by iron oxides and filled with grey gleyed clay material. One interpretation of the size and frequency of such an intricate pattern would be that it represents the root system of a former forest vegetation. If this is correct surface impedence and peat growth postdates the removal of the forest and has resulted in the superimposition of surface waterlogging on a brown forest soil. The mechanics and significance of such a developmental sequence in other areas of Upland Britain have previously been noted by MUIR (1934) and DIMBLEBY (1962).

## 8.5 Calcareous surface-water Gleys

Ideally the freely drained analogue of the calcareous gley is the brown calcimorphic soil, a leached brown earth which is still calcareous throughout the

Rather more difficult sites to assess are those where the features of gleying coincide with an obvious structural interface. Where this occurs it seems possible to distinguish two main situations: those where changes in surface vegetation and land-use have been important and those where structural changes owe their origin to a physical agency.

The initial use of the term 'leached gley' by AVERY (1956) was designed to cover the first of these situations. It emphasises that the effects of gleying are largely controlled by and superimposed upon the profile morphology of what was previously a leached brown soil. Under woodland the leached brown soil commonly shows a pronounced structural break at the boundary between the A and B horizons, a break which denotes the change from a subangular blocky and porous horizon to a dense prismatic B with few pores except for occasional vertical fissures. Under conditions of woodland gleying occurs only mildly at this interface. Canopy interception and the sponge effect of the surface humus lower the net amount of water infiltrating into the soil and ensure a more gradual penetration of moisture. Within the profile water removal by roots is continual.

When the woodland is removed a radical alteration in the hydrologic balance of the cleared site is produced. More moisture is able to reach the soil surface and vegetation removals by transpiration are reduced. Cultivation and stock poaching also tend to destroy the structure of the former A horizon, thereby reducing its permeability and moisture holding capacity. Waterlogging and gleying thus become features of the A horizon. The speed at which this progression takes place is very rapid judging from present day examples (STEVENS personal communication).

Surface-water gleys in Weardale at low elevations (less than 1000') show similar profile features to those described for leached gley soils under grassland by CROMPTON (1952). A dark brown surface horizon passes into a pale grey gleyed layer with frequent ochreous mottling along the root channels. With depth, grey and bluish grey prisms become well developed with a mosaic of old root channels outlined in grey. As with several peaty gley profiles, the network of old root channels can be interpreted as a relic from the system of tree roots that once penetrated the horizon under forest conditions.

High altitude (over 1500') surface-water gleys show structural profiles which owe more to parent material geomorphic history than to vegetational history (Profile 26). The presence of compacted horizons in their lower profiles is not reflected in mechanical analysis data alone. The origin of high bulk densities in subsoil horizons remains a controversial topic in pedology (GLENTWORTH & DION 1950; FITZPATRICK 1956; ROMANS 1962). In Upper Weardale periglacial sheathing has affected areas of upland regolith (vide Chapter 3) but the diagnostic features of relic permafrost are not characteristic of upland sloping sites. Here compaction is more probably associated with the nature of the soil-water system at the time of its deposition (LAMBE 1960) or subsequently during a solifluction phase. As such, induration owes more to geomorphic rather than pedogenic processes.

Plate 35. Surface-water gleying (84/938366)

Plate 36. Detail of surface-water gleying with the gley/non-gley interface highlighted by ferric oxides (84/938366)

The importance of inherited parent material properties is also emphasised by the complete absence of clay movement in the profile as has been noted in lowland surface-water gleys (e.g. BURNHAM & MACKNEY 1964). The clay B/clay A index remains near unity and visible clay cutans are not seen.

The chemical characteristics show that leaching in surface-water gleys is only slightly less intense than in the acid brown earth. Reaction values are of the order of 5.0 to 5.5, with variable degrees of base saturation. A notable feature of surface-water gleying is the fact that a distinct iron profile can often be detected, owing to the reduction and removal of iron largely as more soluble ferrous compounds and complexes.

TABLE 16. DEB IRON CONTENTS OF PROFILE 25

| Depth " | % $Fe_2O_3$ |
|---|---|
| 0-4 | 7.4 |
| 4-8 | 9.3 |
| 8-15 | 14.3 |
| 15-25 | 10.4 |
| 25-32 | 10.1 |

## 8.7 Peaty Gleyed Podzols

The genesis of peaty gleyed podzols, or thin iron pan soils as they are sometimes termed (FITZPATRICK 1966) has received considerable attention since the early observations of MUIR (1934), which have recently been expanded by CROMPTON (1952, 1956) and CRAMPTON (1963). ATKINSON (1963) and MAKIN (1963) have also commented on the micromorphological and chemical characteristics of thin iron pan soils.

Peaty gleyed podzols in Weardale occupy moderately sloping sites immediately adjacent to the blanket peat deposits on watershed crests. Typically they are associated with the upland climates of high precipitation (generally over 45 inches) and low mean annual temperatures, where the rainfall-evaporation balance is such as to maintain a continuously waterlogged surface. This moorland and moorland-edge location corresponds to the earlier observations of GLENTWORTH (1954), MUIR (1955), MITCHELL and JARVIS (1956), RAGG (1960), and BALL (1960). Within the high rainfall zone of Weardale the peaty gleyed podzol occurs over a wide range of parent materials, being found on all but the most impermeable superficial deposits. Parent material base status is probably a more obvious control than permeability with the commonest parent material being slope deposits with a high proportion of included Carboniferous Sandstone fragments.

Although many speculative theories have been advanced to explain genesis of peaty gleyed podzols, MUIR's (1934) initial observations offer the most likely explanations for their formation. The mechanism of surface anaerobism and reduction appears particularly to be associated with unenclosed vegetation of <u>Eriophorum</u> or <u>Eriophorum</u>-Wet Heath association, associations which favour the retention of water at the surface.

The profiles of peaty gleyed podzols contain evidence of peat accumulation, gleying, and podzolisation, the latter process being reflected in the deposition of a thin iron pan. The thin iron pan forms at the junction of surface anaerobic and subsoil aerobic conditions (profiles 27 and 28). The mineral soil is overlain by

Plate 37. The thin iron pan of the peaty gley podzol (84/876449)

layers of amorphous or fibrous peaty humus which is always wet except for exceptionally dry summers. The surface peat does not usually contain any significant amounts of mineral material.

The mineral layers beneath the peat are generally patchily stained with organic material and merge into a dull grey gleyed horizon. The gleyed horizon is sharply terminated by a thin iron pan with a mat of roots concentrated on its surface. The pan itself is from $\frac{1}{4}$" to $\frac{1}{8}$" thick and consists of an upper black half and a lower reddish brown portion. It is continuous and of consistent hardness, but it traces an erratic course with marked wavy irregularities. It passes without a break through included Carboniferous Sandstone stones.

The position of the pan in the profile marks a profound break in profile morphology. The grey upper horizons with obvious waterlogging, give way to freely draining conditions with yellowish red hues. Ferric iron oxides stain the mineral material immediately below the pan. Iron staining is frequently associated with old root channels and structure faces. It is rare to find live root penetration below the level of the pan.

TABLE 17. CHEMICAL DATA FOR PROFILE 28.

| Depth ins. | Clay % | Org. C % | pH | Clay Analyses | | |
|---|---|---|---|---|---|---|
| | | | | $S_1O_2$ | $Fe_2O_3$ | $S_1O_2/Fe_2O_3$ |
| 10-14 | 26.1 | 3.1 | 4.5 | 57.8 | 4.2 | 13.8 |
| 15-23 | 12.4 | 2.6 | 4.5 | 63.6 | 10.4 | 6.1 |

The chemical characteristics of Profile 28 illustrate the acidic, base deficient and podzolised character of the peaty gleyed podzol, particularly as the texture of this profile is nowhere lighter than loam. The translocation of iron is clearly shown by the silica and iron analysis of the clay fraction.

MAKIN (1963) has admirably summarised the literature of iron pan formation with all the attendant controversies it has stimulated. Whilst there is little difficulty in accepting MUIR's developmental sequence, two problems remain, firstly, the polygenetic character of the peaty gleyed podzol and, secondly, the exact nature of the interface of iron deposition.

Traditional pedological theory would support the view that the peaty gleyed podzol is the result of the superimposition of iron pan and hence surface water gleying on a previous podzolised brown soil or acid brown soil (JONASSEN 1950; DIMBLEBY 1954, 1962; PROUDFOOT 1958; DUCHAUFOUR 1960). Archaeological and palynological evidence (e.g. CRAMPTON 1963; ROMANS ET AL 1966) has been used to reconstruct pictures of soil history which invoke the sudden onset of soil degradation through podzolisation in response to vegetation change. This degradation has been variously ascribed to disforestation and the subsequent development of surface peat and also to the abandonment of prehistoric agricultural land. Whether such severe ecological changes are entirely responsible, or whether climatic deterioration too had a marked effect (STEVENS AND CARLISLE 1959; DURNO 1959) is very difficult to assess.

In Upper Weardale the peaty gleyed podzols occupy high level flanking sites, sites which climatically favour the MUIR (1934) developmental sequence. There is no evidence of prehistoric agriculture as has been shown by DIMBLEBY (1962) for the North York Moors, but forest clearance certainly may have had an important pedogenic effect. The lack of brightly coloured ochreous B horizons in the subsoils of peaty gleyed podzols does not refute a brown earth origin, as soil erosion coincident with forest clearance could have completely removed the B horizon of the brown earth or alternatively, as has been suggested for Dartmoor by CLAYDEN and MANLEY (1964), the brown earths may have been at an early stage of development. The latter conclusion is not borne out by the findings of DIMBLEBY (1962), however.

A fascinating feature of the peaty gleyed podzols in Upper Weardale is the substantial degree of irregularity in course which the thin iron pan can show. A wealth of theorising exists in soils' literature to explain deposition in terms of sub-surface aerobism (MUIR 1934), ground water discontinuities (MORISON and SOTHERS 1914; GALLAGHER and WALSH 1943), pan migration (CROMPton 1952), pH gradients (BETREMIEUX 1954), or microbial concentrations (NIKIFOROFF 1937). More recognition is probably given today, however, to the effect of physical interfaces within the profile causing band-like iron deposition. Whether such textural, structural, and porosity changes are associated with laboratory experiments (FOLKS and RIECKEN 1956; WURMAN et al. 1959) or with field observation (FOX 1941; DEB 1950; DIMBLEBY 1952; FITZPATRICK 1956), the evidence for the importance of a physical cause appears to be mounting.

Profiles 27 and 29 illustrate the differing aspects of this problem. In the Rookhope Head profile, the horizons below the pan are marked by platy structures and increasing induration despite the increase in coarse sand. It is probable that at the time of pan formation this may have marked the junction of non-indurated solum with indurated material below. This has previously been demonstrated for several Scottish sites by ATKINSON (1963). Profile 28 presents a contrast and illustrates the fact that there may be as many explanations for iron pan formation as there are separate environments. Here the major physical change is the fall in clay content below pan level due to the colluvial accretion of fines over weathered sandstone material. Clearly in this polygenetic profile the pan has formed at the area of contact where fine material passes abruptly to coarse, a situation which is in accord with the pedological experiments of HENIN and BETREMIEUX (1948) and TURC (1958).

Field analysis of Weardale thin iron pan soils reveals that the initial observations of MUIR AND FRASER (1940) on pan depth still have much to recommend them. They regard pan depth as a function of such factors as drainage, texture and surface erosion. Analysis of pan depth at twenty five profile sites reveals that pan depth in Upper Weardale is extremely shallow, a situation which corresponds to MUIR and FRASER's findings on Clashindarroch rather than on the Balloch. The result is to some extent surprising considering the porosity and acidity of the Carboniferous Sandstone contribution to many of the parent materials of thin iron pan soils.

TABLE 18. DEPTH OF IRON PAN BELOW MINERAL SOIL

| DEPTH ins. | FREQUENCY |
|---|---|
| 0-2 | 6 |
| 2.1-4 | 11 |
| 4.1-6 | 3 |
| 6.1-8 | 2 |
| 8.1-10 | 2 |
| 10.1-12 | 1 |

Median depth = 3.9"

It does illustrate the significance of surface creep and soil loss on upland sites. Whether it is possible that erosion is accelerated by the presence of thin iron pan remains an unanswered problem, but it is certainly probable that in places erosion has removed the surface horizons of peaty gleyed podzols, including the thin iron pan.

## Chapter 9

## Podzolic Soils

### 9.1 Podzolisation in Upper Weardale

Soils whose profiles show the classic features of podzol development are much less extensive in Upper Weardale than soils with hydromorphic characteristics. This is mainly due to factors of the post-glacial history of the area, the widespread drainage impedence resulting a from the character of the dominant parent materials, and the general high rainfall of the Dale.

The role of surface vegetation and humus form on the processes of base leaching, mineral decomposition and differential translocation of break-down products has always been suspected, but has only recently been characterised. The works of BLOOMFIELD (1953 et seq.), SWINDALE and JACKSON (1956), COULSON et al (1960) and DUCHAUFOUR (1960) have emphasised the role of organic components such as polyphenols and plant acids in transporting free and liberated sesquioxides down the soil profile. Although many aspects of this role have yet to be clarified, a tentative conclusion has beendrawn by both BLOOMFIELD AND COULSON et al. that the reactivity of organic extracts seems to be greater under fresh and actively decomposing plant debris i.e. under a mor or moder-like mor humus than under a hydromor or peaty humus. Whilst other factors are undoubtedly involved in intensity considerations of podzolisation, the coincidence of intense podzolisation with acid mor humus in Upper Weardale is particularly striking. Sites with some variety of heathland, either dry *Calluna-lichen* heath or *Calluna*-*Vaccinium* or even *Calluna*-Mixed Wet Heath or Calluna-Moorland, are the main areas of podzolised soils. Recent forestry plantings in Killhope Burn and Wellhope Burn have not yet been established for long enough to allow podzolisation to take place.

So striking is the Calluna-podzol correlation that divergencies from it, as at the head of Rookhope Burn and on watersheds to the south of Stanhope, raise interesting questions. In both cases mature podzols are found under Nardus grassland with few ericoid species. One partial explanation for this is that vegetation change has occurred quite recently. As has previously been noted, a comparison of LEWIS's (1904) vegetation map reveals that this has happened, particularly with respect to a decline in pure Calluna heath. Land-use practices, especially sheep grazing, have favoured the replacement of Calluna by grassland species.

Other instances occur, however, where grassland is documented for over sixty years, and on such sites the existence of a podzol under grass raises an old pedological controversy. Although grass often brings about a build-up of fertility in soil, the evidence in Upper Weardale would suggest that podzols can exist under grassland, despite the fact that podzolisation is more intense and more acid under heath. DIMBLEBY (1962) considers that leaching in a cool, moist climate is such that grass roots are unable to return sufficient nutrients to the surface to counteract it. HANDLEY (1954), too, points to the possibility of there being mor- and mull-producing grasses, owing to different levels of polyphenol content, and CASE (1963) has demonstrated by pollen analysis that a shallow podzol can develop under a grass cover.

It is difficult to isolate the single effect of surface humus on the intensity of the podzolisation processes in the area, however, as the factors controlling podzolisation are to some extent mutually dependant. Thus plant habitat from the point of view of drainage status is strongly interconnected with profile drainage and parent material permeability; the basicity of the plant habitat and the chemical environment of the pedogenic processes is greatly influenced by the chemical nature of the parent material. Thus podzols are typical of parent materials derived from Carboniferous sandstone rocks. On upland watersheds above the level of drift and solifluction deposits they are generally formed directly from the regolith of sandstone strata with only minor traces of contaminant material. On slope flanks within the solifluction zone they develop only on coarse loamy solifluction deposits derived from Carboniferous sandstone or on loamy solifluction deposits derived from Carboniferous sandstone and shale where profile drainage is free. With increasing fines content of the parent material, drainage and chemical factors give rise to soils of the gley or brown earth group. Podzolic soils are limited to areas of favourable surface humus, free profile drainage, and a siliceous parent material.

Although podzolic soils will form under the climatic conditions of the Dale wherever one gets the simultaneous occurrence of the above pedogenic factors, the implications of post-glacial ecological change in the area make it imperative to regard podzolisation in terms of soil history as well as in terms of contemporary process.

Although the glacial and late-glacial history of Upper Weardale must remain tentative and therefore speculative (see Chapter 2), the sequence of vegetation change and evidence of podzols beneath peat suggests that the podzolisation process was active on favourable sites during the Boreal Period. ROMANS (1962) has reached a similar conclusion from field observation in the Eastern Grampians. The subsequent peat formation during the climatic optimum did not cover the entire drainage watershed, and particularly in the east, both north and south of Stanhope, outcrops of Upper Carboniferous sandstone show no evidence of a former peat cover. Although peat removal has been more widespread than is perhaps generally realised (HORNUNG, private communication, who would disagree with PEARSALL 1950), there is no evidence for the existence of a former peat cover. Thus podzolisation may have proceeded unchecked on such sites since Boreal times.

Without a complete record of the vegetation history for podzol sites it is difficult in the study area to assess the palaeopedology of podzolic soils. Evidence of the onset of podzolisation is notoriously conflicting, with different emphasis being stressed by different workers in different areas. DIMBLEBY (1962) would favour the trigger mechanism to be one of disforestation by prehistoric cultivation whilst DUCHAUFOUR (1960) stresses the distinction between 'le podzol atlantique' and 'le podzol boreal', depending on contemporary climate, suggesting that the former owes its features to the Atlantic climate, with a phase of lessivage impoverishing the soil and preparing the way for podzolisation.

The relevance of this idea to the fluctuating post-glacial climatic history of upland Britain has never been made clear.

The lack of buried profiles in Weardale precludes the use of methods of palaeo-chronology which might give absolute datings for podzolic profiles, such have been so successfully employed by ROMANS (1956) and FITZPATRICK (1966). This lack is even more serious due to the lack of extensive prehistoric settlement in the North Pennine Uplands in the manner of the North York Moors (DIMBLEBY 1962) and Dartmoor (FOX 1943 ). Prior to widespread late-Mediaeval and late-Tudor enclosure of the valley sides of the Dale (ROBERTS private communication), human interference was restricted to hunting and pastoral activities during Mesolithic and later times. The lack of evidence for early cultures except for finds of microlith tools, as for example on Chapel Fell (MOORE, private communication) and Eastgate (PROUDFOOT, private communication), means that an accurate chronology cannot be established. Clearly there is a strong need here for intensive studies of pollen evidence as has been done by DURNO (1961) and others. This would enable more exact evidence to be gained on the spread of ericoid species and perhaps highlight the relative influences of climatic deterioration and human culture. In the light of present profile morphology, the podzolic soils can be subdivided as follows:

| DIVISION | MAJOR SOIL GROUP | SUB-GROUP |
|---|---|---|
| Leached Soils | a. Podzols | Iron Podzols<br>Humus Iron Podzols<br>Podzols with gleying |

## 9.2 Iron Podzols

Iron podzols (profiles 29 and 30) are particularly characteristic of free-draining and moderately sloping sites where the soil has developed directly from siliceous Carboniferous Sandstone. Vegetation is mainly Calluna-mixed grass heath, often with a high admixture of grassland species.

The surface organic horizons are generally variable in thickness but are notably thicker than other quoted examples of iron podzols. The $A_e$ horizon is strongly developed and changes abruptly at about 15 inches into the iron cemented B. Induration is a common feature at depth in the unaltered parent material. In most cases, however, it appears to be a feature of the parent material and not a modification by periglacial (FITZPATRICK 1956) or sesquioxidic agencies (GLENTWORTH 1954; ROMANS 1959).

Iron oxide determinations on the horizons of profile 29 illustrate the dominant process of iron translocation in these soils.

TABLE 19. ANALYTICAL DATA FOR PROFILE 29 (IRON PODZOL)

| Depth ins. | Clay % | pH | Loss on Ignition % | Free Iron Oxides |
|---|---|---|---|---|
| 0-3 | - | 4.4 | 93.2 | - |
| 3-5 | - | 3.8 | 42.1 | - |
| 5-14 | 3.8 | 4.0 | 6.2 | 0.6 |
| 14-16 | 9.5 | 4.9 | 7.9 | 4.1 |
| 16-23 | 8.4 | 5.1 | 3.4 | 2.4 |
| 23-32 | 8.0 | 5.2 | 2.6 | 2.0 |

Plate 38. Iron podzol under Calluna - Grass Heath vegetation. Developed on permeable sandy loam colluvium with many sandstone fragments. Compacted shale at the base (84/914439)

## 9.3 Humus-Iron Podzols

Humus-iron podzols in Upper Weardale are more common than iron podzols. Their profiles show an accumulation of colloidal organic matter and sesquioxides in the B horizon with weak cementation and horizon panning. Profile 31 shows the development of an ortstein-like layer particularly well.

TABLE 20. ANALYTICAL DATA FOR PROFILE 31 (HUMUS IRON PODZOL)

| Depth ins. | Clay % | pH | Loss on Ignition % | Free Iron Oxides % |
|---|---|---|---|---|
| 0-2 | - | 3.5 | 94.0 | - |
| 2-5 | - | 3.7 | 56.5 | - |
| 5-7 | 2.4 | 3.8 | 8.0 | 0.4 |
| 7-10 | 7.1 | 4.1 | 5.7 | 0.6 |
| 10-13 | 3.4 | 4.4 | 18.9 | 2.2 |
| 13-20 | 11.3 | 4.8 | 6.4 | 3.6 |
| 20-26 | 11.4 | 4.9 | 2.6 | 1.4 |
| 26-37 | 11.6 | 4.9 | 3.0 | 1.0 |

Profile 31 is developed under a Calluna-Grass Heath association with a very varied botanical composition; it is highly probable that the original dominant Calluna is being replaced by Nardus, Deschampsia flexuosa, and occasional Juncus squarrosus. Despite the presence of occasional rushes at the surface, the profile shows all signs of free drainage. The surface humus horizons have developed under acid, base-deficient conditions with good aeration, with strong contamination of charcoal from previous burning. The eluviated and structureless $A_e$ horizons have a low organic matter content, but overlie a dark brown highly organic layer which is moderately cemented. The amount of free iron oxide in the $B_h$ horizon is lower than in the underlying $B_{Fe}$, although in this example the content of $MnO_2$ in the $B_h$ horizon is high (approx. 5%). The clay content of the profile shows a relative increase in the $B_{Fe}$, a feature which ROBINSON (1949) would regard as being a result of normal mechanical eluviation in the podzol profile.

Although the podzolic process has probably stimulated more literature discussion than any other single pedogenic process in Britain, explanations for the contrasts between iron podzol and humus-iron podzol profiles remain tenuous and vague. Several workers (DUCHAUFOUR 1956; MACKNEY 1961) invoke an evolutionary sequence of successive degradation involving the succession brown earth iron podzol humus iron podzol. DUCHAUFOUR's study derives from podzolisation under coniferous forest in the Vosges mountains, whilst MACKNEY's work stems from a succession under oakwood, the humus-iron podzol being produced under ensuing heath land. The latter is in agreement with SCHEYS, DUDAL and BAEYENS (1956) that the development of iron podzols is associated with deciduous woodland, whilst the development of humus-iron podzols is a response to a change to heath vegetation. Other workers (e.g. FITZPATRICK 1966 ) have sought to explain the distribution of the humus-iron podzol in terms of present site and soil drainage status.

Within the study area humus-iron podzols do not appear to occupy drier positions and hence it is more feasible to think in terms of an evolutionary sequence rather than present site conditions. Both sub-groups of podzol occupy freely draining sites, both have similar pH values, and both can occur under a mixed Calluna-Grass Heath vegetation. However, under acid grass heath it is possible to find an iron podzol whereas under pure

Plate 39. The humus-iron podzol under Grass Heath (84/985372)

Plate 40. Horizontal variation in the podzol profile (84/985372)

Calluna heath only a humus- iron podzol is found. As some Calluna heaths have recently changed to mixed Calluna-Grass Heath, the presence of an illuviated humus layer may be a pedological indicator of a former vegetative cover.

The precise role of Calluna in mobilising colloidal organic material in this way has never been stated but it appears to take place after the translocation of inorganic sesquioxides. SINGH (1956) and EVANS and RUSSELL (1959) suggest that organic material may be sorbed by clay in the B, whereas STOBBE and WRIGHT (1959) visualise a filtering effect due to reduced permeability. Other workers (GALLAGHER and WALSH 1943) believe that organic matter is precipitated in the B by sesquioxides, following the classic ideas of MATTSON (1930 ). Whatever the exact nature of the mechanism, interaction between the organic and inorganic phases under an acidic Calluna vegetation is dearly involved.

## 9.4 Podzols with Gleying

The sub group of'podzols with gleying' has been mapped in several areas to include podzolic soils with imperfectly draining features in the eluvial horizon. CRAMPTON (1963, 1965) has studied such profiles in the uplands of South Wales, suggesting the term 'loamy podzols' in view of their heavier textural properties than the normal freely-draining podzol.

The podzols with gleying in Upper Weardale exist as discontinuous areas adjoining the freely draining podzol. Profile textures show a significant admixture of shale-derived slope deposit material; profile 34 shows a high content of silt sized material. Mottles

Plate 41. Podzol with gleying developed on shale-derived slope deposit (84/982346)

associated with gleying are distinctive characteristics of the $A_{eg}$ horizon and diffuse organic matter stainings are common. The thin iron pans described by CRAMPTON have not been observed.

It is convenient to regard 'podzols with gleying' as intergrades between the podzol and peaty gleyed podzol sequence such as was envisaged by MUIR (1934). The reduction of iron in the acid environment of the $A_e$ horizon can either be non biological (BLOOMFIELD 1953, 1954) or microbial (BLOOMFIELD 1950; BETREMIEUX 1954), the latter explanation being favoured by most workers at the relatively organic rich humus-mineral interface. The high water holding capacity of the root mats of Calluna and Calluna-Grass heath vegetations on loam parent materials has been long recognised (MUIR 1934; RENNIE 1953), and anaerobic conditions can be produced and confined to the topmost mineral layers. The factors involved are probably very complex, involving aspect and slope (GEIGER 1950; TAYLOR 1958), but CRAMPTON and WEBLEY (1954) assume that the onset of gleying in podzols equates with heathland maxima in the vegetation history. It is probable that eluvial horizon gleying occurs in wider range of root mat forms than CRAMPTON (1963) will admit.

The data for the distribution of free iron oxides

TABLE 21. ANALYTICAL DATA FOR PROFILE 34

| Depth ins. | Silt % | Clay % | Loss on Ignition % | pH | Free Iron Oxides % |
|---|---|---|---|---|---|
| 0-3 | - | - | 74.2 | 3.5 | - |
| 3-4 | - | - | 79.8 | 3.5 | - |
| 4-9 | 35.3 | 16.9 | 6.8 | 3.7 | 0.2 |
| 9-23 | 25.4 | 19.8 | 6.9 | 4.3 | 5.3 |
| 23-39 | 30.2 | 16.3 | 4.1 | 4.5 | 1.1 |

in 'podzols with gleying' shows a more intense impoverishment of the eluvial horizon and a higher concentration in the illuvial horizon than is found in other podzolic types. A likely inference arising from this is that gleying in the eluvial horizon produces reducing conditions which cause depletion additional to the podzolisation loss. Under the combined influences of acidity and anaerobism, the solubility of iron is enhanced, and increased mobilisation of iron is produced by the direct influence of anaerobic conditions or the indirect effect resulting from anaerobic organic decomposition. SMIRNOVA and GLEBOVA (1958) have found that the highest levels of mobile sesquioxide occur at the wettest times of the year, which, according to IARKOV (1954) and LOSSAINT (1959) is due to the formation of active organic compounds by anaerobic decomposition. SERDOBOLSKII (1950) has shown that iron mobility at a constant pH tends to be a function of redox potential, a statement which would adequately provide a mechanism for MUIR's (1934) developmental sequence.

# Chapter 10

# Brown Earths

## 10.1 Introduction

Since the original statement on braunerde by RAMANN (1905), investigations on the properties and genesis of brown earths have revealed the importance of far more processes in their formation than was earlier considered. The recent paper by BALL (1966) highlights the differences in terminology and interpretation which are still current, particularly with respect to intergrade profiles.

In the present study, weight has been given to the criteria of ROBINSON (1949) and especially AVERY (1956) in recognising and demarcating brown earth profiles. In addition to the requirement of a comparatively uniform brownish colour, the dominant process operating in the profile is one of complete leaching, resulting in the complete absence of free carbonates and a moderately acid reaction in the topsoil (pH 4.5-6.0) which tends to decrease with depth. The surface humus form is either mull or mull-like moder, so that there is no breakdown of clay minerals and differential movement of breakdown products in the profile.

The traditional classification of the brown earth group in Britain into 'low base status' and 'high base status' varieties (CLARKE 1941) has now been to some extent superceded by the concepts of DUCHAUFOUR (1951) and AVERY (1956) on the basis of profile process. The terms 'leached brown soil' (sol brun lessive) and 'acid brown soil' (sol brun acide) have now a wider currency in pedological writing (e.g. MACKNEY and BURNHAM 1964).

Sols lessives are not found in Upper Weardale, but the term sol brun acide is retained to characterise the sub-group of acid brown earths, even though in some examples surface applications of lime have increased the colloidal base status.

An important feature of acid brown earths is their free-draining characteristics; in a normal brown earth there are no signs of drainage impedence in the profile. In Weardale, however, brown earths developed on heavy till and slope deposits commonly show ochreous mottling in the B horizon and features of imperfect drainage are inherited from the properties of the parent material. Such profiles have been designated as 'sol brun acide with gleying'.

The gradational changes between brown earth and podzol have received an increasing amount of attention in recent years. The term 'podzolised sol brun acide' is used in this study in compliance with the usage of MACKNEY and BURNHAM (1964), and as such these soils are considered as part of the Brown Earth group, rather than with the Podzolic Soils as BALL (1966) would suggest. The use of the term 'podzolised sol brun acide' instead of 'brown podzolic' is also a particular preference.

Much of the confusion and disparate terminology within the brown earth group might have been avoided if, as DECKERS and VANSTALLEN (1955) note, more sub groups had been recognised by pedologists. With this though in mind, a High Pennine Brown Earth has been tentatively recognised and mapped on the basis of profile features and genetic processes. This is a high altitude brown earth which superficially resembles sol brun acide but which owes its morphology to slightly different processes.

TABLE 22 CLASSIFICATION OF BROWN EARTHS

| DIVISION | MAJOR SOIL GROUP | SUB-GROUP |
|---|---|---|
| Leached Soils | b. Brown Earths | Acid Brown Earth<br>Acid Brown Earth with gleying<br>Podzolised Acid Brown Earth<br>High Pennine Brown Earth |

## 10.2 Acid Brown Earths

Although DUCHAUFOUR's (1959) concept of acid brown earth involves its formation mainly on sloping sites, in Weardale soils with similar characteristics are developed over a wide range of topographic situations. They also cover a wide altitudinal range, from 700 to 1500 feet, and are clearly associated with medium and medium-to-light parent materials. The group is found on colluvial and drift parent materials, generally with significant sand contributions from sandstone parent rocks, but the profiles can also contain an appreciable proportion of clay (e.g. profile 35).

In view of the vegetational history of the dale, the natural vegetation of the acid brown earth group can be considered as oak or oak-birch woodland. At present, however, enclosure has produced a grassland vegetation with *Agrostis* and *Festuca* species, whilst the unenclosed portions are associated with grass heath species, especially *Agrostis stolonifera*, *Agrostis setacea*, *Festuca ovina*, *Anthoxanthum odoratum*, *Festuca ovina* and *Potentilla erecta*, with occasional *Pteridium aquilinum* and rare *Calluna vulgaris*. Heavily grazed unenclosed moorland and enclosed pastures of side slopes are the characteristic locations.

The acid brown earth under acidic grassland has an acid mull or acid moder surface horizon consisting of a very dark humose loam in which the grit and quartz particles are bleached. This merges into a dark brown loam layer, generally 6" thick, which has a pronounced friable consistency. This in turn merges into a yellow brown or strong brown B horizon of variable depth, but often compact. Stones are common throughout the profile. The dominant features of the profile are its uniformity and lack of illuvial horizons; its friable nature throughout, and the acid mull or moder surface humus.

Acid brown earths are acid throughout, but the pH values can show considerable variability from one site to another. Profile 35 shows a relatively uniform pH gradient from the surface to depth (pH 5.2 to 5.3) whilst profile 36 shows a surprisingly high surface pH which decreases with depth (pH 6.5 to 5.6). Base saturations for both profiles follow this trend in pH.

As the major criterion of the characteristics of the acid brown earth is the lack of eluviation-illuviation processes, free iron oxides were determined on profiles 35 and 36. The results point to the general lack of an iron profile in these soils, in comparison with podzolic soils.

TABLE 23. FREE IRON OXIDE CONTENTS IN ACID BROWN EARTHS

| PROFILE 35 | | PROFILE 36 | |
|---|---|---|---|
| Depth ins. | $Fe_2O_3$ % | Depth ins. | $Fe_2O_3$ % |
| 0-2 | 0.4 | 0-6 | 1.2 |
| 2-8 | 0.6 | 6-12 | 1.5 |
| 8-15 | 0.8 | 12-19 | 1.8 |
| 15-28 | 0.7 | 19-31 | 0.9 |

Plate 42. Acid brown earth profile upgraded by improvement and management for stock (84/984396)

Recent work by SCHWERTMANN (1964) and McKEAGUE and DAY (1966) on free and inherited iron oxides in soil profiles highlights the importance of distinguishing between dithionite-(DEB) and oxalate-extractable iron in soils. The latter extracts only amorphous products of recent weathering and is hence a useful index in distinguishing between iron released by *in situ* weathering and iron translocated down the profile. The results for acid ammonium oxalate extraction for profiles 35 and 36 are tabulated below.

TABLE 24. OXALATE-IRON VALUES FOR ACID BROWN EARTHS

| PROFILE 35 | | PROFILE 36 | |
|---|---|---|---|
| Depth ins. | Iron Oxides % | Depth ins. | Iron Oxides % |
| 0-2 | 0.21 | 0-6 | 0.38 |
| 2-8 | 0.19 | 6-12 | 0.41 |
| 8-15 | 0.23 | 12-19 | 0.35 |
| 15-28 | 0.22 | 19-31 | 0.33 |

The data further confirm that little or no translocation of iron is taking place.

## 10.3 Acid Brown Earths with gleying

Acid brown earths with gleying have identical morphological features to the freely draining soil except that features of gleying become visible in the lower B horizon. The gleying rarely becomes intense, but usually appears as a network of ochreous mottling.

The main reason for the incidence of the hydromorphic features is the physical constitution of the superficial deposits making up the parent material. The distribution of these soils bears little relation to the distribution of precipitation totals, and the typical lowlying

Plate 43. Acid brown earth with subsoil gleying.
Parent material a clay loam slope deposit with included Carboniferous sandstone fragments (84/987380)

location on lower slopes and valley side benches emphasises the importance of soil moisture movement downslope. Features of subsoil gleying become prominent where the clay content of the parent material exceeds 20%. This is less than GLENTWORTH's (1967) average for 'brown forest soils with gleying' in Scotland, chiefly on account of the compacted and slightly indurated parent material structures in the till and soliflucted till deposits of Weardale. A prime principal of ROMANS (1959) work on pore space in soil profiles has been the recognition of the importance of structural as opposed to textural influences on porosity. It is interesting that ASHLEY (1957) refers to the contiguous area of Southern Northumberland as being covered by Carboniferous Drift of 'heavy' and 'light' texture and notes that 'slightly gleyed brown earths' are characteristic of the heavier variety. Whilst the term 'Carboniferous Drift' is too vague to be useful on a small scale, the textural distinction does emphasise the importance of gleying on heavier parent materials.

Dithionite-extractable and oxalate-extractable iron oxides show no translocation of iron by podzolisation processes. The only trend in the content of iron appears in the gleyed portions of the lower B where the effects of in situ weathering are probably increased by the oxidation of ferrous-iron to give the hydrated ferric oxides of mottles.

TABLE 25. IRON OXIDE VALUES FOR ACID BROWN EARTHS WITH GLEYING

| | PROFILE 37 | | | PROFILE 38 | | |
|---|---|---|---|---|---|---|
| Drainage | Depth ins. | Dithionite Iron % | Oxalate Iron % | Depth ins. | Diphionite Iron % | Oxalate Iron % |
| Freely Draining | 0-3<br>3-9<br>9-13 | 1.4<br>1.2<br>1.1 | 0.41<br>0.53<br>0.61 | 0-9 | 1.6 | 0.26 |
| Slightly Gleyed | 13-24 | 1.6 | 0.65 | 9-18<br>18-25<br>27-37 | 1.8<br>1.4<br>1.9 | 0.38<br>0.41<br>0.43 |

## 10.4 Podzolised Sols Bruns Acides

Although iron and humus-iron podzols are typical soil forms developed from Carboniferous sandstones and thin colluvial material overlying Carboniferous sandstones, several distinct localities exist in the Dale where a sandy loam slope deposit over a sandstone outcrop gives rise to a soil of the Brown Earth group (profile 40). Alternatively the slope deposit may have a significant admixture of shale as well as sandstone fragments (profile 39).

The morphological features of such brown earth profiles have several similarities to soils previously described as 'acid brown earths'. The A horizon is from 5 to 9 inches thick and typically dark brown in colour. Bleached quartz grains are common but no distinctive eluvial zone is visible. The A horizon has a merging boundary with the underlying B horizon which has a very striking reddish brown/reddish yellow

Plate 44. Podzolised acid brown earth over sandy loam slope deposit derived from Carboniferous sandstone. Weathering shale at the base (84/898443)

Plate 45. Podzolised acid brown earth on slope of 12°. Mixed grass heath vegetation (84/982354)

coloration due to free ferric oxides. Beneath this distinct horizon of iron enrichment, one passes abruptly into the paler colours of the parent material.

The analytical data for profile 40 indicate that there is a distinct iron profile in this soil, with an impoverishment of iron in the A horizon and a distinct accumulation in the B. After peroxidation of the A horizon, the pale colours of the residue also highlight the surface loss of iron which is to some extent masked in the field by the organic fraction. The Deb iron results show that although iron translocation is significant,

TABLE 26. ANALYTICAL DATA FOR PROFILE 40

| Depth ins. | pH | % Clay | % Iron Oxides |
|---|---|---|---|
| 0-3 | 4.3 | 13.6 | 1.5 |
| 3-9 | 4.5 | 15.7 | 1.8 |
| 9-15 | 4.8 | 12.0 | 2.3 |
| 15-21 | 4.9 | 14.7 | 2.5 |
| 21-31 | 4.8 | 11.6 | 1.8 |

| Depth ins. | CLAY ANALYSIS* | | | | | |
|---|---|---|---|---|---|---|
| | % $SiO_2$ | % $Fe_2O_3$ | % $Al_2O_3$ | mol. $SiO_2/R_2O_3$ | mol. $SiO_2/Al_2O_3$ | mol. $SiO_2/Fe_2O_3$ |
| 0-3 | 51.9 | 17.8 | 22.4 | 2.61 | 3.94 | 7.76 |
| 3-9 | 50.3 | 19.9 | 22.5 | 2.43 | 3.80 | 6.73 |
| 9-15 | 49.1 | 20.4 | 23.3 | 2.30 | 3.58 | 6.41 |
| 15-21 | 45.5 | 22.4 | 26.4 | 1.90 | 2.93 | 5.40 |
| 21-31 | 50.7 | 16.7 | 25.5 | 2.38 | 3.38 | 8.08 |

* Kindly performed by Mrs. M. Kaye, Department of Geology, University of Durham.

it has not been taken to completion, and the silica/sesquioxide ratios for the clay fraction indicate that podzolisation has taken place with breakdown of the clay and the preferential movement of breakdown products.

In Upper Weardale 'podzolised sols bruns acides' occupy site conditions which are transitional to podzols on the one hand and acid brown earths on the other. They are thus intergrades with features of both major soil groups, a characteristic which is further reflected in their morphological and chemical characteristics. There is an obvious problem of classification here and in the present work the term 'podzolised sol brun acide' is preferred to BALL's (1966) term of 'brown podzolic'. This would place the soils in the major group of Brown Earth rather than Podzol and thus conforms to the conventions of MACKNEY and BURNHAM (1964) and CRAMPTON (1963).

Although 'podzolised sols bruns acides' are not areally extensive in Weardale and have not in fact been recognised by ASHLEY (1966) in neighbouring Northumberland, they occupy an important intergrade position. They are found at high altitude and therefore high rainfall sites on siliceous parent materials under Calluna-Mixed Grass Heath associations. The freely draining nature of the sites thus enables podzolisation to take place, and thus the main point of pedological interest is the lack of the eluvial A - illuvial B horizonation typical of the modal iron podzol. The description of 'concealed podzols' by MUIR and FRASER (1940) aptly sums up their essential characters. The genesis of these soils has been the cause of much speculative pedological literature during the last twenty years, and it seems apposite to consider the relevance of some of the more tenable ideas in the context of the Upper Weardale sites. As there is no evidence for faunal churning in the soil, prehistoric cultivation of crops, and the content of soil silica being too low to produce an $A_e$ horizon, these theories have to be initially dismissed. The prime feature of the sites of the soils is their sloping nature (5-15$^o$) and hence their genesis must be dependant to some degree on slope processes.

ROBINSON ET AL (1950) have proposed the term 'truncated podzol' to soils with sesquioxide-rich sub surface horizons on steep slopes in Wales, assuming that the $A_e$ horizon of such soils has been eroded under the impact of human interference. More modern interpretations would question this view and certainly in Upper Weardale there is no evidence for the presence of a former widespread $A_e$ horizon in present 'podzolised sol brun acide' sites and no substantiating evidence that a podzol ever occupied such sites.

The importance of the sloping and freely draining site has been interpreted in a slightly different manner by CROMPTON (1960) who, using concepts such as 'richness of weathering' and 'intensity of leaching' derived from POLYNOV (1937), regards them as 'strongly leached brown earths' with a sesquioxidic residue due to the solution and removal of bases and silica. In his view podzolisation is not occurring, but rather the dominant process is one of strong leaching under conditions of weak weathering. CROMPTON (1960) thus regards the prime pedogenic process to be one of intense soluviation of soluble salts, bases, and silica, to give a sequence of pedogenesis with affinities to that of areas of tropical weathering; PERRIN (1965) agrees that the preferential mobilisation of silica may be more important than hitherto admitted.

Analytical data for the silica content of the clay fraction, however, (table 26) shows that silica values are proportionately highest in the A horizon which, being the horizon of lowest pH and highest organic matter content, ought to the horizon of maximum loss of silica. The characteristic trend of the $SiO_2/R_2O_3$ values would suggest incipient podzolisation rather than a form of 'tropical weathering'.

The fact that steeply sloping sites over a base-deficient parent material are such a characteristic location of these soils would suggest that processes of downslope movement and soil creep are operative in surface horizons, with consequent mixing and masking of the eluvial/illuvial sequence. MUIR (1935), in fact, used the term 'creep soils' and expanded the concept in his later work (MUIR & FRASER 1940). Although he was essentially describing Brown Earths with little podzolisation, soil creep has been shown by YOUNG (1960) to be of universal importance. YOUNG (1960) has shown that soil creep falls off rapidly below a depth of 10 cm. and in the upper 10 cm. of the solum averages 0.62 cm./year for a 7° slope. Such movement seems sufficient to explain the 'crypto podzolic' character of these soils.

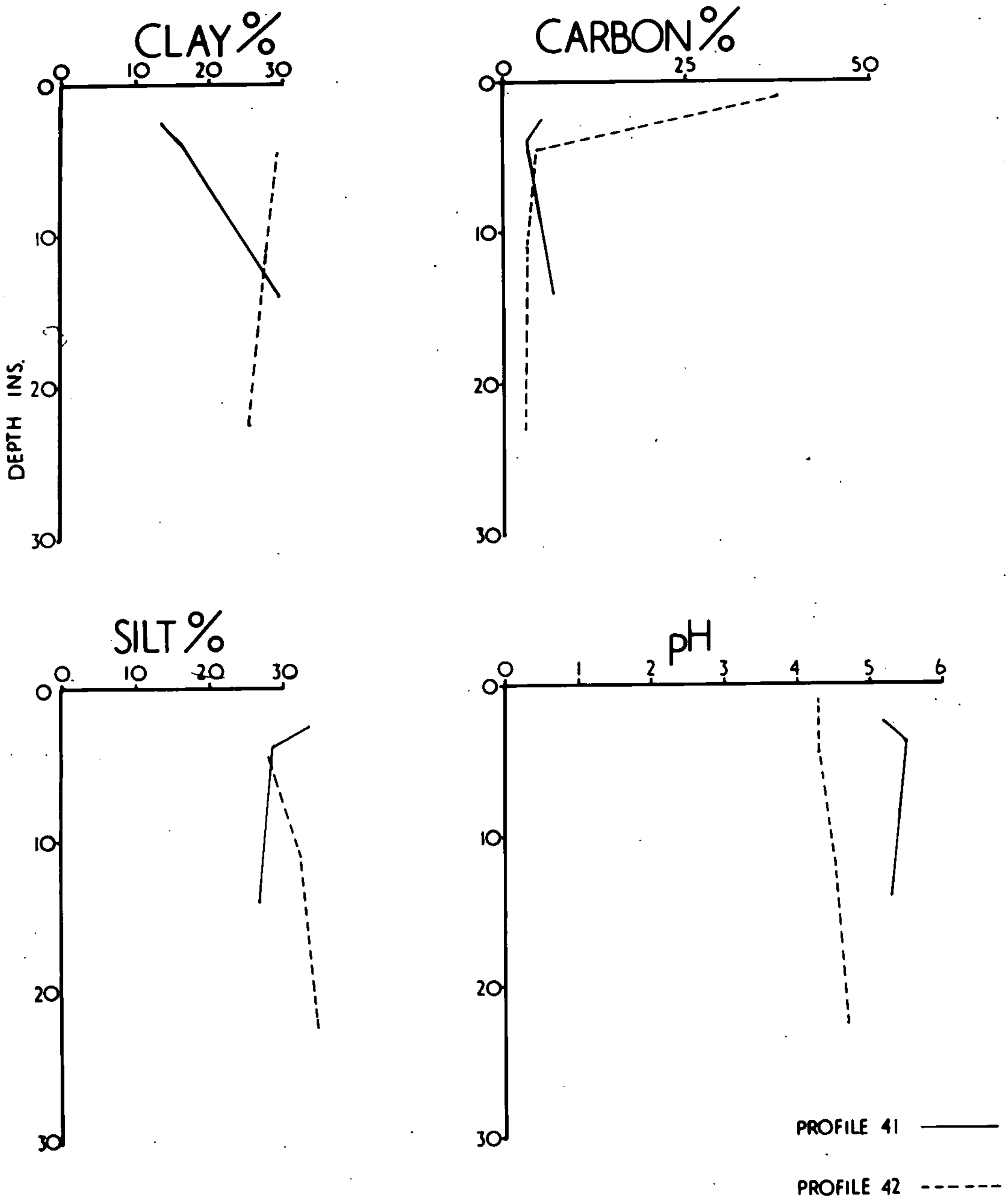
## 10.5 High Pennine Brown Earths

The term 'High Pennine Brown Earth' is used within Upper Weardale to denote areas within and fringing the main zone of blanket peat where brown mineral soils are found. The term is used tentatively for a range of areas where free or imperfectly draining soils with dark surface horizons and brown subsoils are found. Profiles so designated show a range of characteristics (profiles 41 and 42) and the mapping unit is therefore best regarded as a 'soil complex' with many local modifications dependant on local site conditions.

The prime characteristic of the location of these soils is their high altitude. The lowest height at which they have been mapped is 2050' on Middlehope Moor and thus the soil zone corresponds to the 'sub alpine podzol zone'... 'of variable profile morphology' of ROMANS ET AL (1966). The term 'High Pennine' rather than 'sub-alpine' is preferred in the present context.

Analytical data for profiles 41 and 42 are presented in figure 46, which illustrates the contrasting physical and chemical characteristics of these soils. Both absolute values and profile trends for such critical data as clay and silt contents, carbon percentage and pH show such dissimilar characteristics that this subgroup needs to be viewed in a tentative manner, local site conditions and site histories probably having a great influence on soil character from place to place.

Profile 42 is developed on a superficial deposit largely derived from shale with only a minor sandstone admixture. It is a leached soil, with no free calcium carbonate or limestone fragments and shows a distinct stone profile with a maximum concentration of stones occurring at a depth of from 2 to 7 inches. The increasing content of fines below this stony horizon is



ANALYTICAL CHARACTERISTICS OF HIGH PENNINE BROWN EARTHS.

FIG. 46

characteristic of upland regolith material on Carboniferous Sandstone (Chapter 3). Furthermore the presence of a friable silty loam beneath an indurated silty loam is suggestive of the work of CORTE (1962) and ROMANS ET AL (1966) on silt translocation and enrichment under the influence of freezing and thawing in the profile. Neither granules nor cappings of silt material could be distinguished under the hand lens, and it is probable that solifluction and erosion on the site has disturbed any late-Glacial legacies which ROMANS (op cit) and his co-workers have distinguished on stable sites in montane Scotland.

Certainly profile 41 is characteristic of an extremely unstable site. Here the profile examined occurs within a grass heath vegetation which appears formerly to have been peat covered. The configuration of drainage lines and of the residual hummocks of peat suggests that the former peat cover has been stripped by stream erosion. Hence the present solum was originally a sub-peat substratum which has been disturbed since the onset of erosion by fluvial action and solifluction. The thin slope deposit contains a much higher proportion of sandstones than profile 41 and is consistently lighter in texture.

It is somewhat surprising that despite lighter texture and higher sandstone content the pH values for profile 41 are uniformly higher than for profile 42. A possible cause of this apparent anomaly might be found in the contrasting pressure of sheep grazing on these two sites. Field trials on the Moorhouse Nature Reserve have shown that where sheep are excluded by fencing from grassy areas within the blanket peat zone rapid leaching impoverishes the base of the soil (HORNUNG; private communication) owing to the lack of nutrients being returned in the animal droppings. Differences in grazing intensity between areas of'High Pennine Brown Earth' are thus important in explaining differences in base status between individual sites.

# Chapter 11

# Calcareous Soils

## 11.1 Introduction

Although several bands of limestone outcrop within the Middle and Upper Limestone Groups in Weardale, the distribution of calcareous soils is not as extensive as the solid geology map would suggest. In many areas limestones have been covered with superficial colluvium, till or alluvium; this occurs particularly over the lower outcropping limestones of the Middle Limestone Group. In such situations acid brown earths or poorly draining soils are found, depending on the permeability characteristics of the superficial deposits.

Calcareous soils are chiefly associated with the outcrops and structural benches formed by limestones of the Upper Limestone Group. Within this group the thickness and importance of the Little and Felltop Limestones varies greatly from place to place, and on these strata only scattered and small areas of calcareous soils are found. On the other hand, the consistency of outcrop of the Great Limestone, forming a largely continuous topographic bench, is remarkable and forms the most typical area of calcareous soils.

Although pedologists are generally agreed that calcareous soils are soils showing incomplete leaching of carbonates, more detailed classification within the division has led to a variety of proposals for nomenclature (KUBIENA 1953; AVERY 1956, 1963; DUCHAUFOUR 1965). This may in part be due to the extreme variability within small areas which calcareous soils show, a variability which would probably lead to the designation 'limestone soil complexes' on a 1" map.

Within Weardale only two sub-groups of calcareous soil have been recognised, the rendzina and the brown calcareous soil (the brown calcimorphic soil of AVERY 1963). Boundaries between the two groups are merging, as are the boundaries between these calcareous soils and contiguous acid brown earths, peaty gleys, and peaty gleyed podzols. DUCHAUFOUR (1965) recognises these transitions as evidence of a developmental sequence beginning with bare limestone, passing through phases of 'rendzina de pelouse', 'rendzina noire forestiere', 'sol brun rendziniforme', and 'sol brun calcaire', and ending with a soil of the brown earth group.

This concept of sequential change is certainly relevant to Upper Weardale. There are very close relationships between the rendzina, brown calcareous, and acid brown soils, relationships which take the form of property changes within the sequence. Variations occur in depth of solum, in the form of the surface humus and its degree of mixing with the mineral soil, in soil structural characteristics, and in chemical properties as one moves along the bare limestone to acid brown earth sequence.

## 11.2 Properties

The rendzina soil is the shallowest and simplest calcareous soil found in the area. It consists of a very thin solum resting directly on solid limestone, with a typical AC form (profiles 43 and 44). The shallow nature of the soil is very often a result of the shedding position of the site where present day erosion is continually removing soil material (profile 43). In other instances previous human activity in the form of mining or quarrying has led to accelerated erosion caused by trampling and digging and the removal of solum material (profile 44).

The vegetation of rendzina soils is a *Sesleria* facies of the *Agrostis-Festuca* community and this facies can be used as a reliable indicator of this soil type. The soil material is dark brown to black in colour with a high content of organic matter. Values for organic carbon average between 15 and 20 percent and the C:N ratios show it to be well humified. The difficulty in removing this organic matter by hydrogen peroxide pretreatment points to the intimacy of the clay-humus complex. The dominance of calcium on the exchange complex is typical of such calcic mull surface horizons, as is also the well developed and stable fine to medium crumb structure. Fragments of underlying limestone are present in the surface turf layer and the fine earth fraction is calcareous to the surface. The soil reaction is just below neutrality.

The rendzina profile shows a very sharp junction between the A horizon and the underlying limestone. There is no well marked horizon of weathered limestone rubble such has been reported for the Chalk limestones of Southern England. The underlying limestones are hard and probably weather only slowly. Signs of limestone weathering are often observed beneath rendzina soils, however, particularly in the form of clints and grykes. Thus the depth of rendzinas varies according to the morphology of the underlying bedrock. Shallow phases, from 3 to 6 inches deep overlie clints, whilst deeper rendzinas, from 6 to 9 inches deep, cover hollows and grykes. BULLOCK (1964) in his study of Carboniferous Limestone soils in the Malham district of Yorkshire refers to this profile as the 'clint rendzina'. However, his clint rendzinas (Mean pH 4.8; 0.4% $CaCO_3$) appear to be much more heavily leached than Weardale varieties.

The brown calcareous soil is a deeper limestone soil than the rendzina. The vegetation is again an Agrostis-Festuca association, but not generally the Sesleria facies of the community.

The most striking characteristic of the brown calcareous profile is the development of a $B_m$ horizon between the humic surface and the underlying limestone, thus giving an A $B_m$ C profile (profiles 45 and 46). The surface A horizon is a humic loam and is similar to the calcic mull of the rendzina. It is nearly neutral in reaction and calcium dominates the exchange complex. The mull humus is dark and well humified. Fibrous roots and earthworms again promote a stable crumb structure.

A sharp change occurs in the profile at about 9 inches. The $B_m$ horizon is paler in colour and noticeably heavier in texture than the A horizon. Composed of clay loam material, it is angular blocky in structure and shows more compaction than the A horizon. Occasionally this can lead to the formation of faint mottling in the horizon (profile 46).

The change to the underlying limestone in the brown calcareous profile provides a contrast to the rendzina. Beneath the brown calcareous soil there is usually a narrow zone of shattered limestone, approximately 2 inches thick. Within this zone the limestone bedrock is fractured into flat pieces parallel to the bedding planes. Roots and patches of soil material frequently penetrate the horizontal partings as far as the underlying solid bedrock.

Plate 46. Brown calcareous soil exposed over the Great Limestone at Green Quarry (84/851422)

Plate 47. Brown calcareous profile at Height's Quarry (84/925390)

The pH values compare closely to those of the rendzina soils. Within the brown calcareous profile slight gradients can exist, although the significance of these is not known; it is seen to increase with depth in profile 45 and to decrease in profile 46. Calcium carbonate contents again resemble those for the rendzina, although in this case there is a slight but noticeable decrease with depth. This is a trend contrary to the usual leading gradient in soils and is probably a result of earthworms and soil fauna circulating fine calcium carbonate.

Just as the limestone surface morphology greatly affects the depth of rendzinas, hummock and hollow systems can also cause variations in the depth of brown calcareous soils. Variations in depth from 12 to 30 inches are common within the sub-group. Also where rendzinas and brown calcareous soils form a 'limestone soil complex', a rendzina occupies a clint and a brown calcareous soil the corresponding gryke if the hollow is deep enough and contains $B_m$ material.

With increasing thickness of solum over limestone, the brown calcareous soil gives way to an acid brown earth. This change, which seems to occur whenever superficial material exceeds about 30 inches, is strikingly reflected in a change to a _Nardus_ - _Agrostis_-_Festuca_ association. This is associated with the development of a thin, acid humus form which can be sharply differentiated from mineral material below. The microtopography of superficial material over limestone generally shows sharp breaks, and hence when used with vegetation indicators, provides a relatively straightforward method of mapping the boundary between calcareous and non-calcareous soils in the field.

## 11.3 Soil Genesis

The distinctive nature of the influence of underlying limestone on calcareous soils can readily be appreciated from the field and chemical analyses of their profiles. The structural characteristics, the humus forms, the biological fertility, the calcium ion dominance on the exchange sites, and the presence of calcium carbonate all distinguish the limestone soil group from other soil formations in the Dale. Despite the fact that ASHLEY (1956) does not recognise any soil series developed on Carboniferous Limestone, the group represents an important element in the pedological pattern in the study area.

The distinctive floristic and biotic features of upland limestone areas have long held the interest of botanists and ecologists. It is only relatively recently that pedologists have shown a similar interest (PIGOTT 1962; BULLOCK 1964). This is no less surprising on account of the substantial advances being made by karstic geomorphologists (SWEETING 1966).

The most pressing pedological problem concerned with the limestone soils of Upper Weardale lies in the origin of their parent materials. The prime considerations here are how far the present parent material over limestone is residually derived from the underlying limestone and, conversely, to what extent transported material makes a contribution to the soil body. A subsequent problem, provided a non-sedentary component is proved, is to determine the origin of the transported material, i.e. whether it is derived from alluvial, glacial, colluvial or aeolian activity.

As has been pointed out by several workers (e.g. PERRIN 1956) the insoluble residue of most limestones is small. Taking 15% as an average figure for the content of insoluble material in the Great Limestone and SWEETING's (1966) estimate of limestone lowering as a reasonable figure (24 inches in 12000 years), hypothetically it would require the weathering of 100 inches of limestone to produce the solum of profiles 45 and 46. Moreover, this would require 50,000 years to complete, even at the present rate of dissolution. Even after allowing for the very tentative nature of some of the assumptions of this calculation, it emphasises the large scale landscape reduction and the long length of time necessary to produce an <u>in situ</u> profile over limestones.

In order to investigate the contribution of extraneous material on the brown calcareous profile, a number of analyses have been performed on samples from profiles 45 and 46. In detail, attention has been directed towards the nature of the insoluble residue of the Great Limestone after dilute acid treatment and the degree of similarity between this residue and the overlying mineral horizons. By concentrating on the single lithological stratum one has avoided any further complication due to the large amount of variation in properties between the different limestones of the Dale. The fact that the properties of the same limestone stratum differ from one outcrop to another has also to be borne in mind. The limestones of the North Pennines differ so very greatly in their content of impure bands, of corals, and of mineral suites in the insoluble residue that one has to be very careful before making generalisations. The presence of more easily weatherable shale bands and of Lithostrotion corals near the top of the limestone member of the cyclothem (JOHNSON 1963) presents very real difficulties in assessing how far the limestone soils are developed from the limestone at present forming the underlying solid rock.

Previous work on the origin of soils over the Carboniferous Limestone of the Pennines has been restricted to two main areas, the Derbyshire Dome which has been studied by PIGOTT (1962) and the Malham district of Yorkshire (CROMPTON and BULLOCK 1961;BULLOCK 1964). The results of both studies suggest that only rendzinas have developed from the underlying limestone, the brown calcareous soils having received extraneous contributions from transported material. Whilst the detailed results from these areas can conveniently be borne in mind in assessing the origin of the calcareous soils of Weardale, it must be pointed out that the North Pennine area presents important contrasts to the South and Central Pennines. The work of PIGOTT, CROMPTON and BULLOCK is principally relevant to extensive outcrops of Carboniferous Limestone on plateaux surfaces. The more restricted linear outcropping along the valley sides in Weardale forms a distinct contrast to this. Also, it is probable that the Pleistocene Chronology has been markedly different in its legacies in different parts of the Pennine Chain. It is significant that the study area of PIGOTT lies well to the south of SISSONS (1964) glacial limit for the York Readvance. The study area of CROMPTON and BULLOCK may have been unaffected by the York Readvance and almost certainly was outside the limit of the Lammermuir Readvance.

Laboratory investigations on the brown calcareous soils over Great Limestone indicate that the extraneous contribution to the soil material is significant. Counts carried out in triplicate on the fine gravel fraction (2mm.-6cm. diameter) show that the combined value for sandstone, shale, ironstone and coal fragments exceeds that for limestone fragments in both profiles. Within this overall trend the increasing frequency of limestone gravel with depth suggests the increasing influence of the limestone bedrock, and the lessening of the effect of transported material. Similar counts for the rendzina profiles show that limestone always makes up the bulk of the gravel fraction (usually over 70%), but signs of contamination in the form of sandstone, shale and coal fragments still occur.

TABLE 27. GRAVEL COUNTS FOR BROWN CALCAREOUS SOILS

| Profile | Sample | Limestone | Sandstone | Shale | Coal | Ironstone |
|---|---|---|---|---|---|---|
| 45 | 170 | 45 | 29 | 8 | 16 | 2 |
| | 171 | 53 | 27 | 11 | 9 | - |
| 46 | 172 | 31 | 41 | 18 | 9 | 1 |
| | 173 | 47 | 38 | 19 | 6 | - |
| | 174 | 59 | 25 | 5 | 10 | 1 |

(Nearest whole number means of three determinations)

Heavy mineral analyses of the fine sand fractions of the brown calcareous soils are presented in Table 28. Although no statistical significance can be attached to the profile trends shown, the richness in heavy minerals in the fine sand fraction of the soil horizons is in

TABLE 28. HEAVY MINERAL ANALYSIS OF BROWN CALCAREOUS SOILS

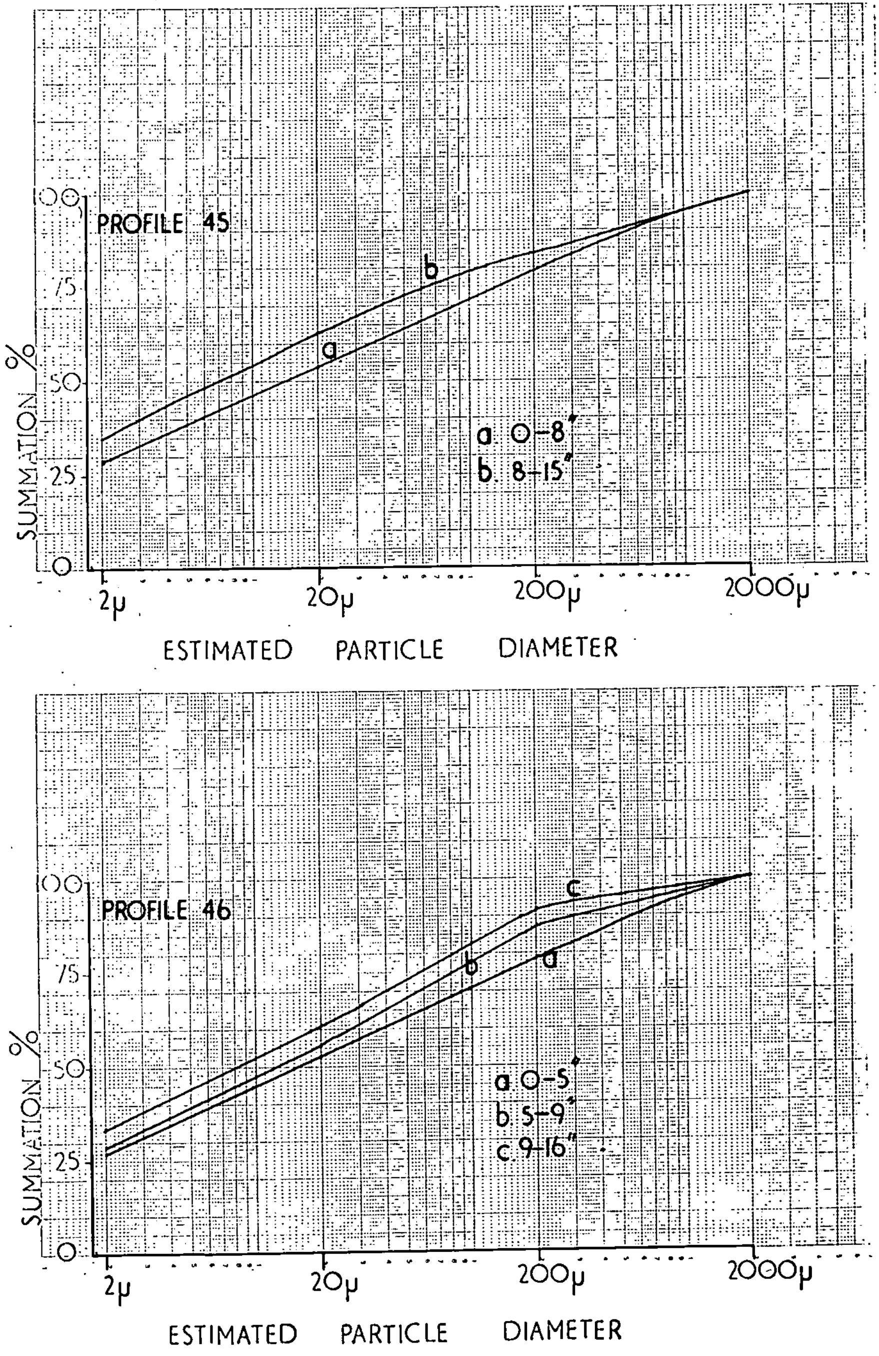
| | | FLUORITE | ZIRCON | TOURMALINE | STAUROLITE | APATITE | OPAQUES |
|---|---|---|---|---|---|---|---|
| Profile 45 | Depth " | % Frequency Occurrence | | | | | |
| | 0-5 | 10 | 5 | 5 | 10 | 15 | 55 |
| | 6-10 | 5 | 10 | 5 | 10 | 20 | 50 |
| | 11-15 | 15 | 5 | 10 | 15 | 10 | 55 |
| Profile 46 | Depth " | | | | | | |
| | 0-5 | 20 | 5 | 5 | 15 | 20 | 35 |
| | 6-10 | 15 | 10 | 10 | 10 | 15 | 40 |
| | 11-15 | 15 | 5 | 5 | 5 | 15 | 55 |

direct contrast to the paucity of heavy mineral suites in the Great Limestone. Inspection of the heavy mineral yield of dilute acid extracts of the Great Limestone from the profile sites was restricted due to the extremely deficient crop obtained. Occasional grains of biotite and limonite were the only minerals recovered. The variety and richness of the heavy mineral yield from the overlying soil againssuggests substantial contamination, possibly from the shale members of the Yoredale series. Heavy minerals thus reinforce the fine gravel evidence for the transported nature of the solum material.

A major conclusion of the work of PIGOTT (1962) and BULLOCK (1964) is that calcareous soils in the Pennines show evidence of significant loessal additions of wind deposited material. The quoted evidence for this is based on the stratification of brown calcareous profiles, with material of silt loam grade overlying a clay loam in situ weathering product derived from the limestone itself. This interpretation is reinforced by mechanical analysis data which show, in PIGOTT's profiles at least, as much as 70% of the mineral material concentrated within the 2µ to 60µ range. PERRIN (1956) and AVERY ET AL (1959) also suggest the possibility of loessic additions on the Chalklands of South-East England.

The identification of wind blown material on particle size evidence alone is full of pitfalls, however. PIGOTT (1962) himself uses no less than three different grades at different stages in his argument, whilst RUSSELL (1944) suggests an entirely different category. (10-50µ). Unless there is very firm supporting evidence of a wind blown source (e.g. the conditions of SWINEFORD and FRYE 1951), the dominance of particular size grades has to be interpreted with care.

The particle size distribution curves for profiles 45 and 46 are shown in figure 47. Although brown calcareous profiles in the field show a striking colour change with depth from a dark brown surface to a grey brown or yellowish brown subsoil, this is not reflected in striking changes in mechanical composition and is probably more a reflection of their organic matter contents. With depth, soil texture increases from loam to clay loam with little evidence of sorting. The evidence rather points towards a thin glacially-derived deposit considerably modified by frost disturbance, solifluction and sheet washing. The values for the 2-60µ fraction of the various horizons of the brown calcareous soils range from 37 to 44 percent. This is a large contribution but not one which is statistically



DISTRIBUTION OF PARTICLE SIZES IN BROWN CALCAREOUS SOILS.

FIG. 47.

significant compared to published data on loess and compared to the range in values which slope deposits in Weardale show. Material derived from the frost weathering of minerals also contains significant silt sized grains (see Chapter 3 and DOUGLAS and TEDROW 1960), and shale outcrops have been observed to yield large volumes of 2-60μ material (LUGN 1962). Until significant evidence is produced to the contrary, there is little basis on which to construct a hypothesis of aeolian action.

In a further attempt to distinguish the origin of the transported material the clay fraction of profile 45 was analysed by X-ray methods to detect any variation within the solum.

TABLE 29. X-RAY IDENTIFICATION OF CLAY MINERALS IN PROFILE 45*

| | 0-8" | 8-15" |
|---|---|---|
| Kaolin | Little | - |
| Mica | Moderate | Moderate |
| Chlorite | Little | - |
| Vermiculite | Very Little | Very Little |
| Montmorillonite | - | - |
| Quartz | Little | Moderate |

These results show that although clay mica is uniformly dominant, as it is in the majority of slope deposits in the area, the surface horizon is slightly richer in clay species, a situation which could reflect the greater importance of transported material in the surface layer. The subsoil horizon, however, has significantly more finely divided quartz. Unfortunately the insoluble residue of the limestone produced no detectable material, but the quartz peak at 8-15" is significant in relation to PIGOTT's

* Data kindly supplied by Mrs. M. Kaye, Department of Geology, University of Durham.

(1962) statement that the bulk of the clay-sized particles in limestone is quartz. It would appear that the contribution of weathered material from limestone thus increases with depth, a feature which has previously been suggested by the gravel analysis.

## Chapter 12

## Alluvial and Ranker Soils

### 12.1 Alluvial Soils

Soils developed on river alluvium are traditionally viewed as forming soil complexes. The characteristics of these complexes are governed by the aggradational features of the floodplain on which they occur. In the valley of the Upper Wear alluviation has led to the deposition of a wide suite of particle size fractions, giving quite distinctive and contrasting types of alluvial soil. Along the present floodplain of the river it is possible to distinguish 'Fine' and 'Sandy' Alluvial Soils, whilst the post-Glacial terrace of the River Wear (see Section 3.24) forms the site of the 'Coarse' Alluvial Soil. The chief contrast here is between the clays, silty clays and sandy loams of the present flood plain, and the stony loams and stony sandy loams of the river terrace deposits.

The Fine Alluvial Soils (profiles 47 and 48) are characteristically stone-free and of heavy texture. Banding within the solum is directly related to alluvial rather than pedogenic processes, and the texture within the solum is nowhere lighter than silty clay loam. Structures are usually well developed. The topographic location of these profiles makes them liable to intermittent flooding throughout the year and additions of further alluvial material. The drainage status of the profile is characteristically imperfect with ochreous mottling a common feature. In areas of permanent soil hydromorphism a ground-water gley soil is formed.

The Coarse Alluvial Soil has a more freely draining profile, owing to the higher content of alluvial gravels and to its higher topographic position above the limit of present flooding (profiles 49 and 50). The profiles show no signs of mottling and have textures which are not heavier than loam.

The Sandy Alluvial Soil is similar in texture to the above, but is stone-free except for occasional included rounded pebbles. These areas can still be flooded after heavy rain. At a depth of 17-24" the texture of the sandy alluvial soil becomes heavier to give an imperfectly draining sandy clay loam with a compact massive or prismatic structure. Whether such material represents an earlier phase of deposition of fines or whether it is in fact interdigitated colluvial material is an unanswered question.

As a whole the alluvial soils show little horizon development that can be ascribed to pedogenic processes. The uniformity of their profiles is only relieved by depositional horizons related to the depositional environment, by occasional signs of gleying, and by the accumulation of organic material at the surface to give an organic matter profile.

On the recent alluvium of the river floodplain the lack of pedological horizons is in no way surprising. On the more elevated and older deposits of the river terrace, however, such a situation needs more explanation, as freely draining properties may have existed here for a considerable time. Although ASHLEY (1961) suggests the rather dubious correlation between a similar terrace in the West Allen valley and an 'interglacial(?)'

Plate 48. The junction of the river gravels of the pre Mesolithic terrace and the underlying glacial till. Interface etched by iron and manganese deposition (84/891381)

raised beach at Easington on the Durham coast, there is certainly archaeological evidence that the terrace is pre-Mesolithic in date. ASHLEY (1961) also talks of the soils in the area being "as well developed and seemingly as old as anything surveyed in the area" (i.e. South Northumberland).

Determinations of total iron, Deb's iron, and amorphous iron on these terrace soils have failed to reveal any pedologic processes which might support such a claim. With minor variations the profile trends are uniform and do not point to any iron mobilisation (table 30).

TABLE 30. IRON DETERMINATIONS ON COARSE ALLUVIAL SOILS

| PROFILE 49 | | | | PROFILE 50 | | | |
|---|---|---|---|---|---|---|---|
| DEPTH | TOTAL | DEB's | AMORPHOUS | DEPTH | TOTAL | DEB's | AMORPHOUS |
| 0-5" | 1.3 | 0.7 | 0.41 | 0-3" | 2.0 | 0.9 | 0.56 |
| 5-15" | 1.6 | 0.8 | 0.32 | 3-11" | 1.9 | 1.0 | 0.62 |
| 15-32" | 1.5 | 0.8 | 0.40 | 11-35" | 1.8 | 0.8 | 0.60 |

figures in percentages

## 12.2 Ranker Soils

The ranker profiles within Upper Weardale show a similar lack of horizon development. The profile form is represented by a thin A horizon overlying solid rock.

It is possible to classify the ranker soils according to the nature of the underlying solid rock on which they have formed. Thus Whin rankers, Ironstone rankers, and Sandstone rankers are distinguished comparatively easily in the field. In the case of Tip rankers, the parent material consists of a wide suite of spoil and mining debris which has been abandoned and is in various stages of re-colonisation by plants.

As a whole the sites of ranker soils represent areas of extreme instability where bare rock has been exposed by the removal of the superficial material. This has particularly ocurred where mining and quarrying activity has stripped off the overburden, and such areas of interference form the characteristic location of the ranker profile. A major difficulty which is introduced into any study of them is that it is thus almost impossible to assess the origin of the solum material and to judge whether it is relict debris, relict superficial deposit, or <u>in situ</u> weathered material.

Notwithstanding the complications introduced by contamination, analytical data suggests that the nature of the underlying rock has a significant influence on the thin A horizon (profiles 53-58).

TABLE 31. CHEMICAL CHARACTERISTICS OF RANKER SOILS

| | pH | % Base Saturation | % Deb's Iron |
|---|---|---|---|
| Whin Ranker | 6.5 | 86 | 4.2 |
| Ironstone Ranker | 5.8 | 19 | 8.4 |
| Sandstone Ranker | 4.6 | 6 | 1.3 |

Mean Values

Although the sites are not strictly comparable from the point of view of altitude, aspect, and leaching intensity, it is interesting to note how closely the chemical characteristics of the underlying rock are mirrored in the fine earth sample.

The soils designated as Tip Rankers form a rather special sub-group within the division of ranker soils. Spoil heaps and tailings from past mining activity have given the Dale a legacy of tip material in the form of spoil and waste. Very often the tip material comprises an easily recognisable area associated with a disused mine adit, quarry or building complex. In such instances the tip rankers can be identified and described with little difficulty (profiles 59 and 60).

Documentary evidence on the extent and intensity of the mining influence (RAISTRICK and JENNINGS, 1965) suggests that superficial disturbance, often in the form of reconnaissance activity, has been far more widespread than previously recognised. Without definite landscape or buried artefact evidence for past human activity, many field situations arise where the influence of mining has to be presumed and used as a basis for speculation. Generally 'gaugue' material and coarse tip (profile 59) gives less difficulty than fines (profile 60).

From the point of view of profile form, the physical characteristics of the tip material govern to a large degree the general trend of pedogenesis which is triggered off. The texture, structure, compaction and stratification of tip dominates the macromorphology of the profile. Profile 59 represents a distinctly stratified and coarse deposit with excessive drainage. Iron and lead analyses carried out on the constituent horizons show variations which reflect the geochemistry of the tip material and thus throw little light on the pedogenic effects of leaching in the profile. The lead profile in particular reflects the distribution of galena waste in the soil material.

TABLE 32. ANALYTICAL DATA FOR PROFILE 59

| Depth " | pH | DEB's IRON % | p.p.m. Pb |
|---|---|---|---|
| 0-6 | 5.2 | 1.9 | 870 |
| 6-17 | 4.3 | 4.1 | 2340 |
| 17-28 | - | 1.2 | 1860 |
| 28-38 | 4.9 | 2.6 | 920 |

Plate 49. The tip landscape at Broad Meres (84/827429)

Plate 50. Tip ranker beneath old, burnt *Calluna*
(84/848424)

Profile 60 shows contrasting features. Here the mounds of tip material occur on a site which was last worked in 1923 (DUNHAM, private communication). The site is now covered by an almost pure association of Calluna vulgaris which is maintained by burning for grouse. At the time of sampling (1965) the heather had been recently burned, the surface being composed of unaffected stocks and a layer of charcoal fragments.

The shale fragments which make up the parent material at this site have a platey structure which becomes more compacted and massive with depth. Thus despite the high values for silt and clay in the mineral material, there are no signs of gleying in the profile. Speckling on peds appears to be inherited from the shale fragments.

In order to assess the degree of pedogenesis in this soil, free iron oxide determinations were made on successive zones beneath the surface humus layer. The results are presented in Table 32.

TABLE 32. FREE IRON OXIDE VALUES OF PROFILE 60

| Zone | Depth " | % $Fe_2O_3$ |
|---|---|---|
| 1 | 2-5 | 1.4 |
| 2 | 5-8 | 2.3 |
| 3 | 8-11 | 2.9 |
| 4 | 11-14 | 2.5 |
| 5 | 14-17 | 2.4 |
| 6 | 17-21 | 2.6 |
| 7 | 21-24 | 2.2 |

The results for zones 2-7 cannot be used statistically to illustrate any profile trend and probably represent values for the natural variability of the tip material.

Zone 1, however, shows a significantly lower iron content indicating iron mobilisation at the base of the acid mor humus. Thus although leaching cannot be observed in the field it has resulted in a distinct iron profile. If the profile has undergone uninterrupted leaching for 42 years, it is perhaps surprising that the effects of leaching have not been even greater than this. Unless some more recent unrecorded interference has taken place it must be inferred that weathering of the iron rich shale material too has been intense and has compensated somewhat the normal leaching losses. Views similar to this (CROMPTON 1960) have already been discussed in the context of podzolised brown earths (Chapter 10).

# Chapter 13
# Conclusions

## 13.1 Introduction

The chief aim of the present work has been to describe and interpret the different types of soil which have formed in a North Pennine Dale. Field and laboratory analyses have been used in conjunction with background information to provide accounts of the genesis of the soil profiles in so far as this is possible in the light of present information.

Perhaps the most important conclusion which derives from the present work concerns the very variety and multiplicity of soil profiles which occur - a variety which is evident from the 2½" soil map and which becomes immediately apparent after reconnaissance soil investigations. This pedological variety is, of course, dependant on intricate variations in the factors of soil formation from place to place - changes in the characteristics of the atmospheric and soil climates, changes in the nature of the soil parent material, changes in slope form, present and past ecology, and in human influence. These influencing factors have, in turn, determined the intensity and importance of those pedogenic processes operating in the study area, particularly the development of surface humus form, the amount of gleying, the degree of leaching, and the occurrence of podzolisation.

As interest is increasing in the pedology of the Uplands of Britain, it seems relevant to highlight some of the specialised problems of the Weardale survey which need to be tackled by soil scientists before a complete understanding of upland pedology can be achieved.

It is MARSHALL (1964) who recounts the greatest compliment he ever received as being "I like your work because there I find research problems on every page."

A major field of study for the future in upland areas in general and Weardale in particular concerns the definition of the soil parent materials. Soil surveys and pedological studies rely so heavily on the characterisation of parent materials that it seems imperative to have intensive site studies to cover the extreme variability which upland superficial deposits show. This work would complement studies recently completed or at present in preparation (e.g. RAGG and BIBBY, 1966; FALCONER, in preparation; HORNUNG, in preparation; STEVENS, in preparation) and would involve detailed heavy and clay mineralogical analyses and the compilation of data on the property parameters of superficial deposits. Generalised groupings of parent materials, which might be useful in soil survey practice (e.g. MUIR, 1955), tend to break down in detail in part because of the significant areal complexity of parent materials and in part because of the continuing lack of an authoritative statement on the Glacial and Late-Glacial evolution of British uplands. The Pleistocene legacy in the Pennines remains a matter of controversy and speculation for Pleistocene geomorphologists.

A further line of enquiry which would amply repay study in the North Pennines is the investigation of peat and soil deposits, principally by techniques of pollen analysis, to establish a post-Pleistocene ecological chronology for particular sites. The problem of site and soil history is a recurrent one in the investigation of soil profiles in the field. Palynological data for areas of the North Pennines not covered by blanket peat are extremely scanty, chiefly on account of the lack of extensive signs of prehistoric occupance. The contrasts between Weardale and both the North Yorkshire Moors (DIMBLEBY 1962) and DARTMOOR (SIMMONS 1964) are startling.

### 13.2 Soil Manganese

In the field of soil analysis per se, whilst the mobilisation and deposition of iron remains a prime feature of Weardale soils and can therefore be used as an important chemical index of pedogenesis, other metallic constituents of the soil profile are worthy of study for the light they throw on past and present pedogenesis. In particular a striking characteristic is the presence of deposits of manganese oxides at some position in the profile.

Although advances have been made in recent years in determining the chemistry of manganese (HEM, 1963, 1964; TAYLOR et al, 1964), pedological discussions on manganese in soil have remained almost entirely descriptive (COMMONWEALTH BUREAU OF SOILS 1966). Manganese has several theoretical advantages for pedologists. It is a transition element, with multiple valency like iron, and responds to the laws of an Equilibrium System, particularly with respect to pH, Eh, drainage status, and leaching intensity. Like iron, it can be mobilised by organic chelates, and its activity in soils corresponds to the requirements of GOLDSCHMIDT's (1958) "enrichment principle", whereby ions released from the weathering of parent material are translocated and redistributed within the solum according to the pedogenic environment.

Significant accumulations of manganese in Weardale soils are found in two contrasting profile positions. The largest recorded accumulations of manganese dioxide occur in the illuvial $B_h$ of the humus-iron podzol, whilst it is also characteristic of gley soils.

Deposition in the illuvial zone of the humus-iron podzol usually occurs in the form of a distinct band overlying the zone of maximum iron accumulation but coincident with the zone of maximum deposition of illuviated organic matter. The depositional layer can be in the form of a diffuse zone (plate 51) or a thin wavy pan sufficiently impermeable to cause profile gleying (plate 52).

TABLE 33. MANGANESE ANALYSIS OF PROFILE 31

| Depth ins. | pH | Loss on Ignition | ppm MN |
|---|---|---|---|
| 0-5 | 3.6 | 83.2 | 20 |
| 5-10 | 4.0 | 6.0 | 0 |
| 10-13 | 4.4 | 18.9 | 5100 |
| 13-20 | 4.8 | 6.4 | 50 |
| 20-26 | 4.9 | 2.6 | 20 |

Table 33 shows the form of the manganese profile for Profile 31, a trend which shows a surface accumulation of manganese by plants and the considerable deposition in the illuvial zone. The amount of manganese in the $B_h$ is even larger than figures quoted for some of LAG's (1960) manganese ortsteins.

Manganese dioxide in gleyed profiles has a contrasting form to the above. Black nodules of manganese dioxide are characteristic and are widely scattered throughout the whole profile. Like iron mottles they appear to represent micro areas of manganese oxidation dependant on gradients of oxidation-reduction potential within dominantly reducing horizons. Sampling and analysis on the basis of horizons therefore fails to give any significant manganese profiles.

Whilst manganese accumulations in gley profiles are related to present day conditions of the soil chemical environment, the panning of manganese in the humus-iron podzol presents similar difficulties of interpretation to those previously discussed for iron pan soils. That the mobilisation and deposition is related to the eluviation-illuviation dynamics of the profile, particularly with respect to the movement of humic substances, is clear, but it is very difficult to account for both the richness of manganese and its accumulation at that particular profile position. Interpretation of manganese accumulations is, even more than with iron, complicated by its properties of antrocatalysis, co-precipitation, and inter-ion effects. Manganese is, in addition, a conservative feature of profiles, a permanently acquired characteristic which can act as an index of palaeopedological conditions.

In profile 31 the band of manganese dioxide points to a very strong interface within the profile. It is impossible to assess whether this interface was originally chemical or physical, but once established it has been picked out by initial deposition which has gradually built up to alter the pedology of the profile. The source of manganese is again a problem. The weathered sandstone parent material is notably deficient in this element; it is probable that an upslope MN-rich shale statum may be the source of MN-rich drainage waters, but this could not be located in the field. The need, already stressed by LAG (1960), for more work on soil manganese is clearly indicated.

Plate 51. Diffuse Manganese dioxide deposition in the Bh of the humus-iron podzol.

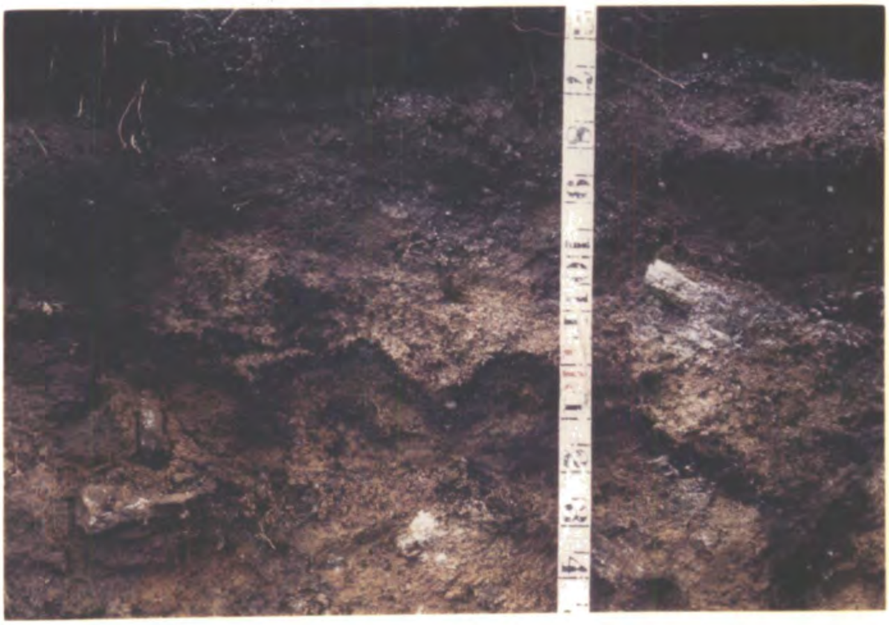


Plate 52. Manganese dioxide deposition in the form of a pan.

## 13.3 The effect of slope

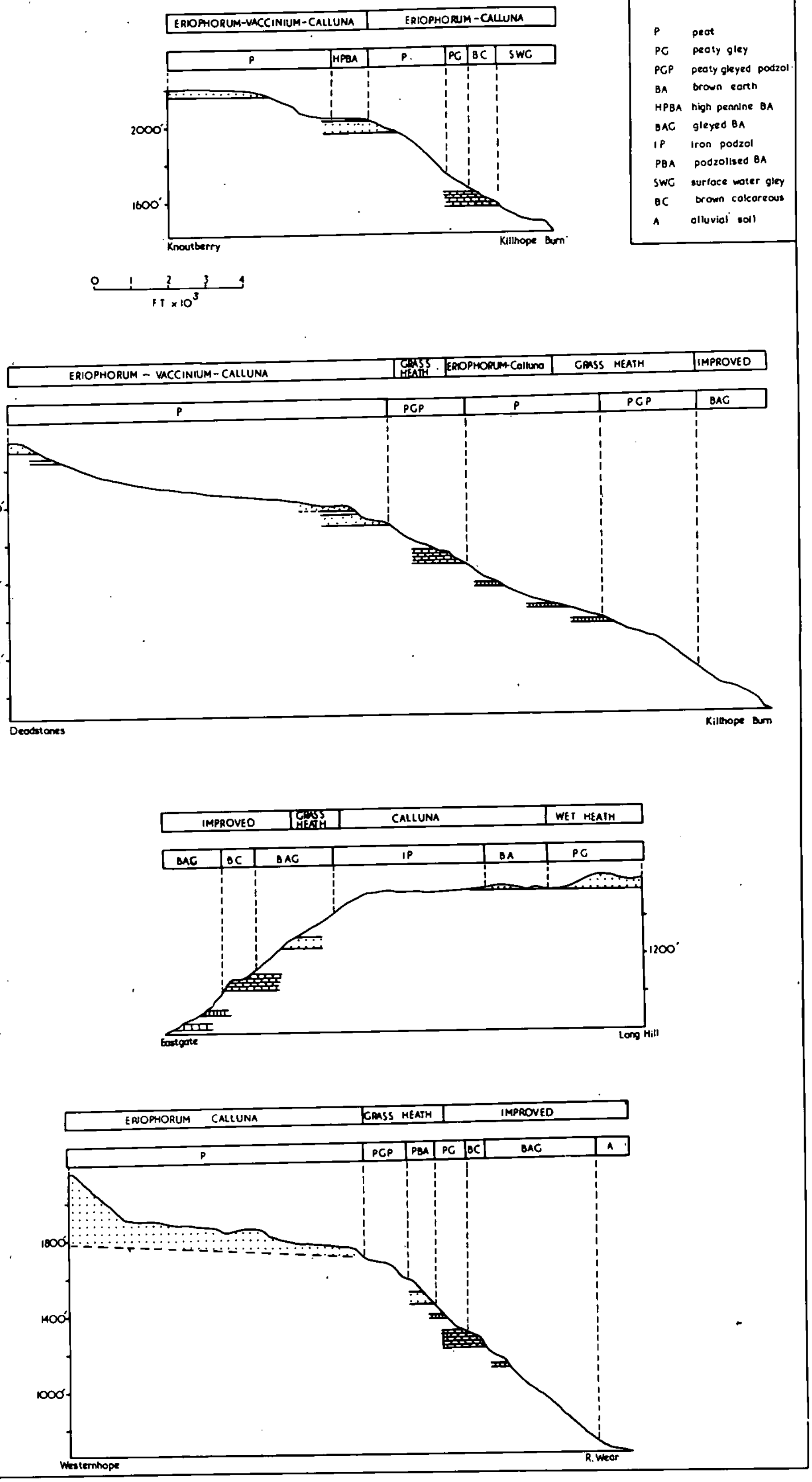
Perhaps the most obvious morphological feature affecting the soils of British Uplands and particularly the incised valley of the River Wear, is the prime geomorphological character of slope. Since the importance of slope was emphasised by GLENTWORTH and DION (1950), it has been given a prime place in British pedology. Its importance has been recognised, but the effect of slope on profile properties has never been precisely determined. Many studies of upland pedology have in fact excluded sloping sites from their analysis (e.g. ROMANS ET AL, 1966) and others have been content to give a generalised account of the relationships between slope and soils (e.g. HALL 1967).

The determination of slope sequences provides valuable data on the coincidence of soil and morphological features. Fig. 48 shows four such transects in Weardale. Changes in degree of slope play a direct role in the differences of drainage characteristics of the soils on the slope, although differences in parent material too have an important influence. The lack of data on the correspondence between slope and soil which some geomorphologists bemoan (SAVIGEAR 1967) is mainly due to the interaction between the different factors of soil formation. Sequences of soil against slope are sequences of the totality of a particular profile form against only one of its influencing factors. The soil is so much a multivariate system that the influence of any one pedogenetic factor is best analyses by means of a particular property parameter.

Two situations arose during the present investigations where it was possible to attempt to clarify the effect of slope on soil properties in relation to the movement

# SOIL SLOPE SEQUENCES.

FIG. 48



ionic and colloidal material under the influence of a slope gradient. In these investigations laboratory analyses were used to trace the movement of both soil moisture and soil colloids downslope, a feature often generally postulated for upland British sites on profile evidence alone.

The first investigation was situated on the western side slopes of Rookhope Burn in the vicinity of the old lead workings of Breckensike Level. Here a regular slope trends in a northwesterly aspect at approximately 9° and is characterised by peaty gleys and surface-water gleys on undisturbed ground, and tip rankers on the mounds of spoil material. The Rookhope Burn crosses the area from north-west to south-east in the north-east portion and a lead-fluorite oreshoot crosses the area in a similar direction in the south of the study area (fig. 49).

The aim of the investigation was to determine the amount of downslope movement of lead from the vein source by chemical analysis. A grid sampling design was adopted with samples taken from the corner of each 100 metre square. Sample sites falling on spoil heaps and mine reservoirs were ignored. Samples were taken in cores from the mineral soil immediately below the surface humus form, and duplicate laboratory determinations carried out on each core. The results of the assays are presented in Table 34 and figure 50.

TABLE 34. LEAD ANALYSIS AT BRECKENSIKE LEVEL. ppm Pb

| | A | B | C | D | E | F | G | H | I |
|---|---|---|---|---|---|---|---|---|---|
| 1 | 439 | 364 | 421 | 236 | 194 | 207 | 392 | 140 | 93 |
| 2 | 513 | 732 | 219 | 431 | 136 | 104 | 214 | 82 | 84 |
| 3 | - | - | 627 | 218 | 234 | 206 | 206 | 46 | 26 |
| 4 | - | - | 831 | 326 | 197 | 308 | 362 | 306 | 94 |
| 5 | - | - | 946 | 469 | 242 | 236 | 436 | 424 | 123 |
| 6 | 943 | 984 | 1086 | 981 | 632 | 641 | 324 | - | 264 |
| 7 | 631 | 832 | 1231 | 980 | 884 | 837 | 638 | - | 397 |
| 8 | 246 | 324 | 436 | 1093 | 1034 | 924 | - | 936 | 306 |
| 9 | 237 | 216 | 196 | 236 | 426 | 306 | 324 | 1124 | 932 |

# BRECKENSIKE LEAD SURVEY

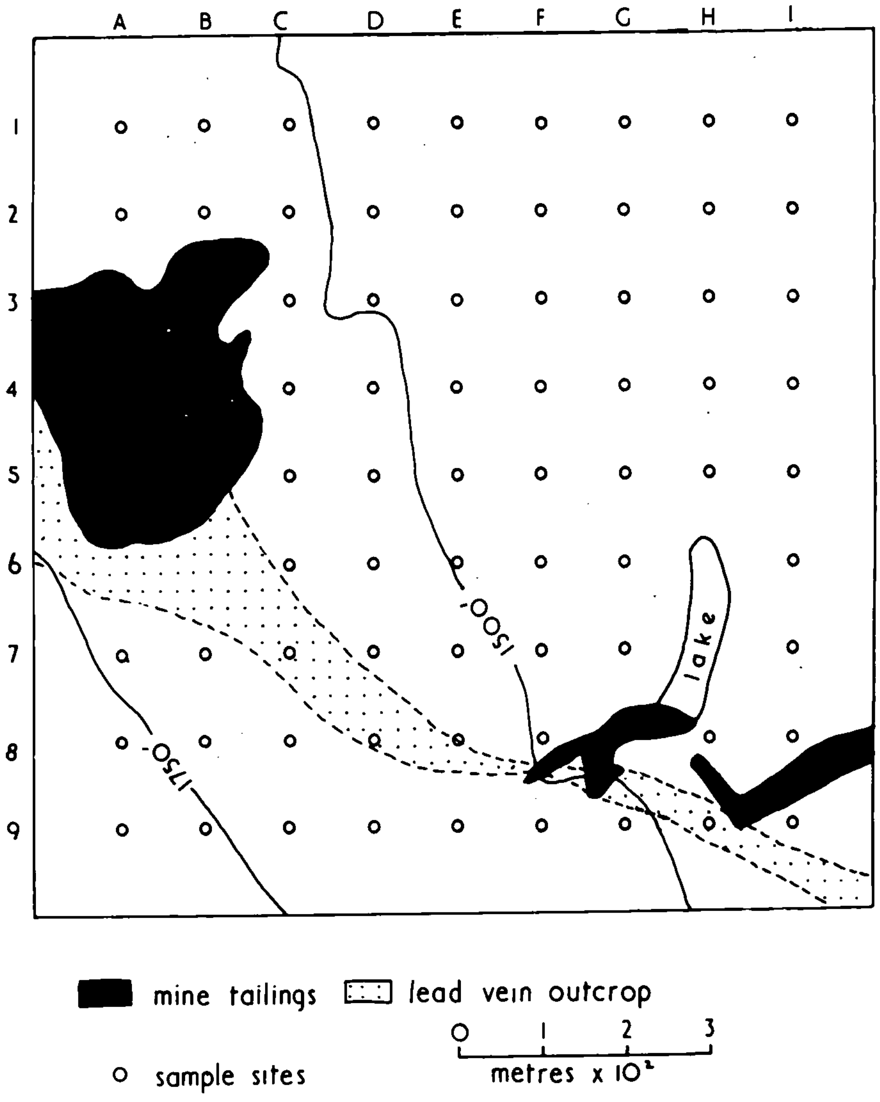


FIG. 49

# BRECKENSIKE RESULTS

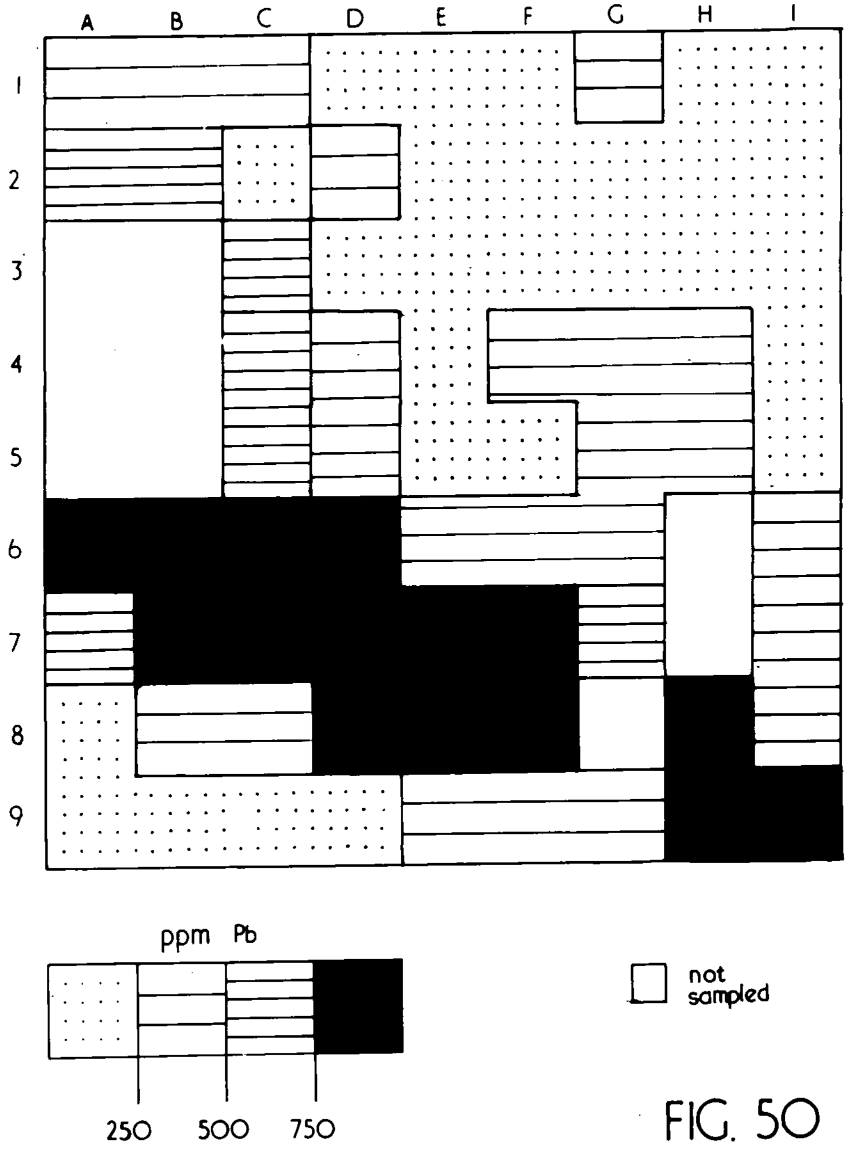


FIG. 50

It is apparent from the analytical results that the movement downslope of lead from the oreshoot outcrop is considerable. Increased lead values from downslope movement can be detected for a distance of approximately two hundred metres. Although the detailed results of a geochemical prospecting survey which has been carried out for the whole of the Pennines are not available for consultation, McMURDO (private communication) is of the opinion that the results of the Breckensike survey probably even underestimate the downslope movement of non-ferrous metal ions. A representative transect in the direction of maximum slope is given in Table 35.

TABLE 35. LEAD TRANSECT

| Site | ppm Pb |
|---|---|
| A9 | 237 |
| B8 | 324 |
| C7 | 1231 |
| D6 | 981 |
| E5 | 242 |
| F4 | 308 |
| G3 | 206 |

A major question of interest of the lead analysis results is the phase of movement of the metal. Do the values reflect the movement of discrete particles of galena (Pb5) and cerussite ($PbCO_3$) or is the lead moved in the ionic form, either as Pb ions in soil moisture or as lead ions adsorbed on soil colloids?

A partial answer to this query is given by the results of a survey carried out in Swinhope Burn at Campmeeting Allotment (fig. 51). At a height of some 1730' is located an outcrop of Seat Earth (DUNHAM, private communication),

## CAMPMEETING ALLOTMENT SURVEY.

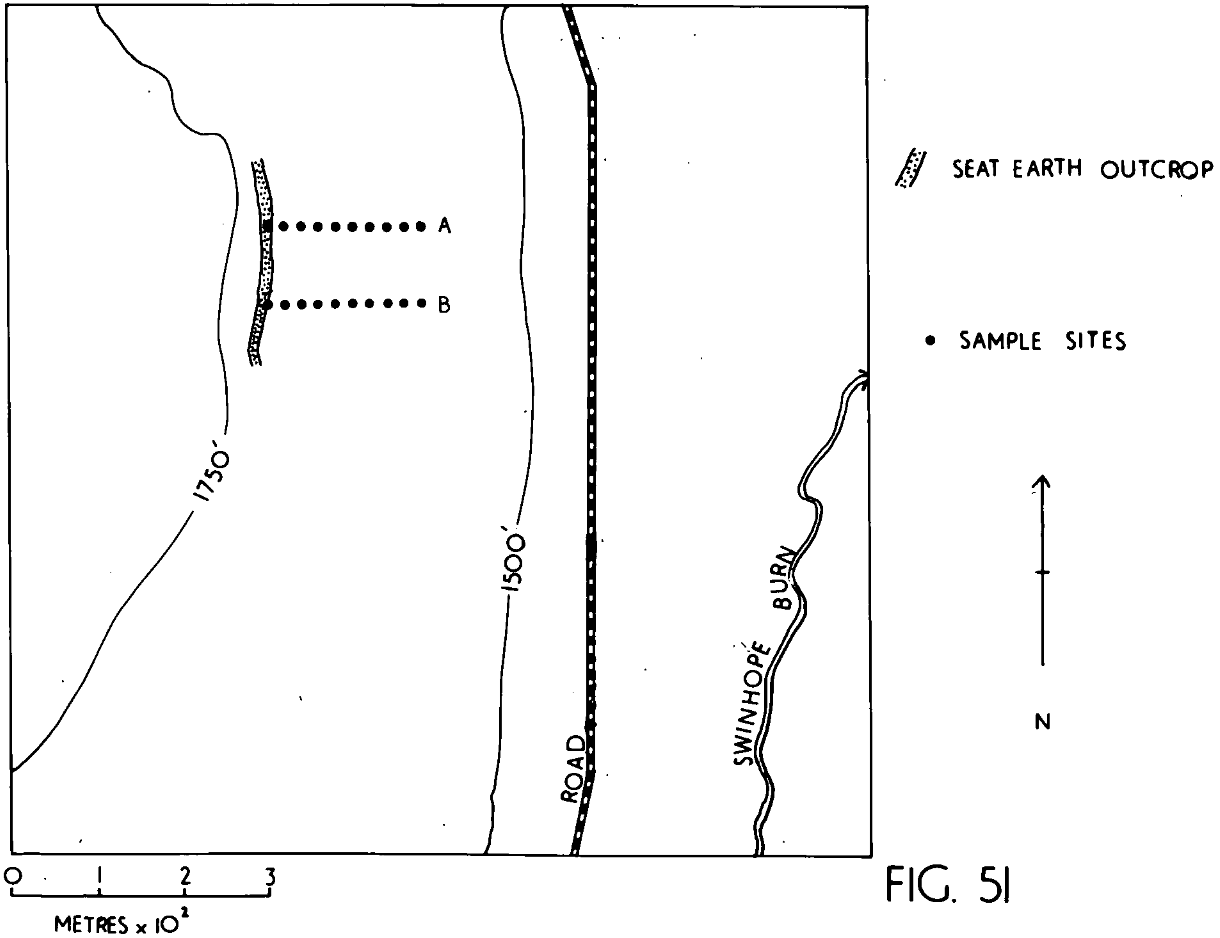


FIG. 51

half way up a slope of 11$^{o}$. The outcrop of seat earth occurs in an area of slope deposits of loam texture and acid brown earth soils.

Clay mineralogical analyses of superficial deposits of Upper Weardale show that the clay fraction of the majority of superficial deposits is consistently dominated by the 10A peak of illite clay minerals, with variable amounts of chlorite and finely divided quartz. Seat earths represent a minor but important divergence from this homogeneous pattern on account of the high kaolinite content of their clay fraction. Thus kaolinite here represents a significant index of contamination from a Seat Earth deposit.

In the Campmeeting Allotment survey, samples were taken along two transects downslope of the Seat Earth outcrop.(fig. 51); the transects were 100 metres apart and samples were taken at distances of 20 metres along each transect from the surface mineral horizon. Estimates of clay mineral proportions* were made in each sample according to the classic principles of SCHULTZ (1965) and the percentage of kaolinite in each was interpreted as indicating contamination by Seat Earth material. The results of the analyses are presented in Tables 36 and 37 and in figure 52.

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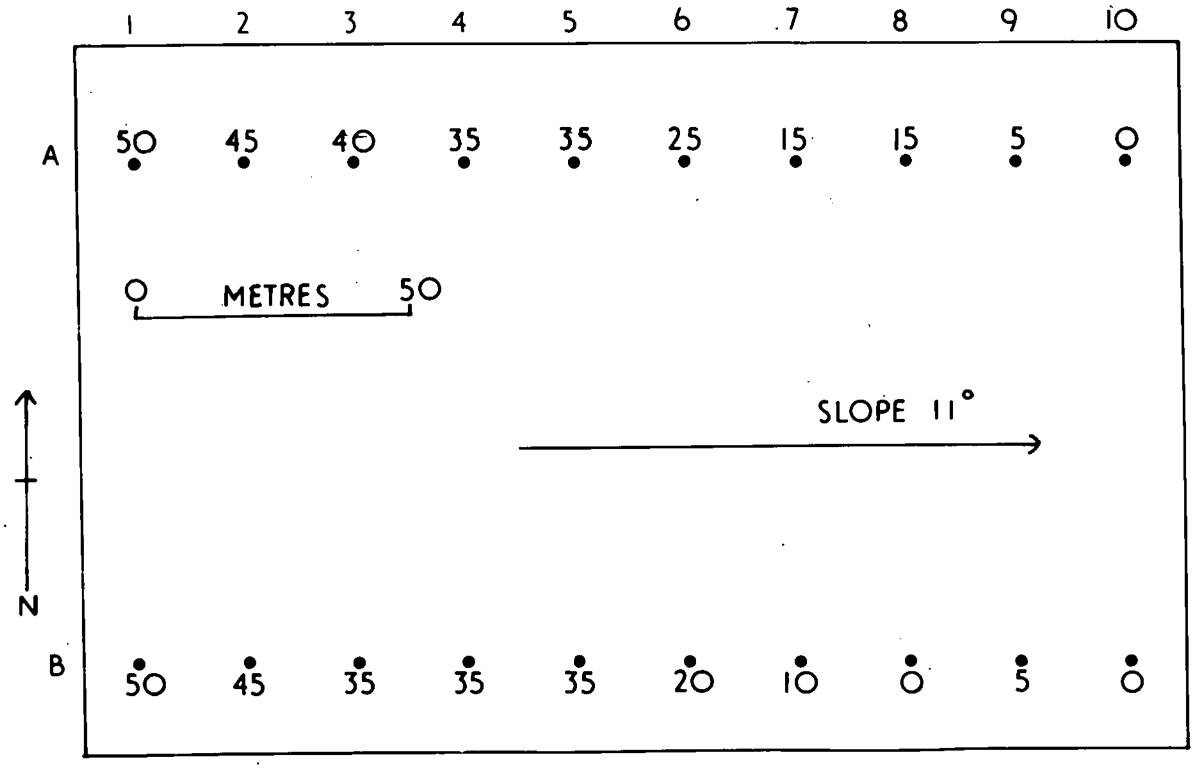
* Clay mineral analyses kindly performed by Mrs. M. Kaye, Department of Geology, Durham University.

# KAOLINITE ANALYSIS.

FIG. 52



CAMPMEETING ALLOTMENT FIGURES IN PERCENTAGES

TABLE 36. CLAY MINERAL COMPOSITION OF SWINHOPE BURN SEAT EARTH OUTCROP

| Mineral | Percent |
|---|---|
| Kaolinite | 50 |
| Montmorillonite | 0 |
| Illite | 25 |
| Chlorite | 5 |
| Mixed Layer Illite-Chlorite | 5 |
| Quartz | 15 |

TABLE 37. KAOLINITE TRANSECTS, SWINHOPE BURN

| Transect A | | Transect B | |
|---|---|---|---|
| Sample | %Kaolinite | Sample | %Kaolinite |
| A1 | 50 | B1 | 50 |
| A2 | 45 | B2 | 45 |
| A3 | 40 | B3 | 35 |
| A4 | 35 | B4 | 35 |
| A5 | 35 | B5 | 35 |
| A6 | 25 | B6 | 20 |
| A7 | 15 | B7 | 10 |
| A8 | 15 | B8 | 0 |
| A9 | 5 | B9 | 5 |
| A10 | 0 | B10 | 0 |

The main care in interpreting these results should be exercised in relation to SCHULTZ's (op cit) statement that if a mineral is present in an amount greater than 15% of the sample, the precision of its determination is

± 10%. However, from the diffractometer traces it is evident that kaolinite can be distinguished downslope for a distance of 160 metres in transect A and 120/160 metres in transect B. Such distances are slightly less than those determined in the Breckensike survey. In this cae, however, they point to a definite downslope movement of colloidal material, a feature which emphasises the importance of slope in accounting for the pedogenic processes operating in Upper Weardale.

The importance of slope has a final relevance to the soils of Upper Weardale in relation to the incidence of erosion phenomena, both past and present. The effects of both past and contemporary erosion and solifluction activity are much in evidence in Upper Weardale, partly as a result of periglacial and "normal" erosion processes in response to slope and partly as a result of human activity in the form of mining and land-use practices. The net result of mining activity has been to create disturbed areas of unconsolidated debris which have since been eroded by slumping, gullying and sheet washing. Land-use practices which induce instability are principally heather burning, which destroys the protective vegetative cover, and overstocking which can lead to the degradation of grass heath and even of grassland-areas, (plate 22). In all cases water-erosion appears to be the main erosive agent on the unstable surfaces.

The influence of erosion cycles on the pedology of upland areas has received scant attention in Britain, despite the authoritative statements of BUTLER (1959) in a more general context. He envisages the modification of slopes by erosion to lead to a distinction between

'Sloughing Zones' of truncated soils and 'Accreting Zones' of buried soils, with relatively undisturbed profiles only occurring in "Persistent Zones' beyond the limits of either erosion or deposition. The difficulty of applying this general model to Upper Weardale is due to the relatively recent and catastrophic events which have affected the area during and since the Pleistocene period. AVERY (private communication) believes that BUTLER's concepts can only apply to Britain by regarding interglacial and post-glacial periods as stable phases, and glacial readvances and man's interference in the recent phase of accelerated erosion as unstable phases. In detail even this analysis has obvious limitations.

In Upper Weardale two major difficulties have arisen in the attempt to assess the palaeopedology of the area. Firstly it has not been possible to identify buried soils, sensu stricto, in Upper Weardale, despite depositional evidence for past and contemporary erosional phenomena, and, secondly, even when depositional sequences have been identified, it has proved almost impossible to give absolute datings for the sequence of events.

Despite intensive field investigation in profile pits, natural and man-made exposures, and along the courses of 'cleughs' and sikes', no buried and fossil soils have been identified in the area. The fact that ASHLEY (private communication) in Northumberland and HORNUNG (private communication) in the Cross Fell area report a similar lack of buried soils suggests that this conclusion may be relevant to the North Pennines as a whole. As such it presents an interesting contrast to the recent findings of LEE et al. (1964) in the Galtee

Mountains of Eire and of CURTIS (1965) in the North York Moors. In both these areas buried and comparatively fossilised profiles are described below colluvial layers and the prevailing soil-landscape relationships interpreted in terms of the periodicity of stable and unstable phases.

Within the study area there is ample profile evidence to suggest widespread colluviation at different periods in the recent landscape history of the area. Stratification within the parent material has already been mentioned (Chapter 3) and appears to be related to solifluction phases in Glacial and late-Glacial times. The superposition of bands of slope deposit of different textures leads to the development of a layering which is often highlighted by present hydrologic conditions.

The layering of the colluvial material can give striking horizonation to exposures. Plate 53 shows the sharp distinction between a stony, loam slope deposit at the head of Rookhope Burn and the overlying relatively stone-free surface colluvium. Plate 54 shows the very distinctive layering of a site with four major phases in its history. Firstly the deposition of sand and silt laminae by water, secondly the deposition of fine peat particles eroded from nearby peat-haggs, thirdly the build-up of a loam slope deposit on top of the peat, and finally the development of the contemporary brown earth profile.

The problem of absolute dating in the sequence of erosion phenomena is very much connected with the lack of definable buried soils. Although profile layering would indicate as many as three past erosion phases in

Plate 53. Colluvial layering at the head of Rookhope Burn.

Plate 54. Buried peat washings in Puddingthorn Pastures.

addition to the present one, the lack of recognisable buried humus horizons suggests that the erosional history has been continuous rather than periodic. Whether the major colluvial features are recent, i.e. during the last one hundred years as indicated by CURTIS (1965) for the North York Moors, or are older and connected with prehistoric and historic exploitation (ATKINSON and ROBERTS 1967) is uncertain. No artefact and refuse material has been found which might help in giving some absolute datings. Certainly around datable mine workings colluviation can usually be ascribed to an eighteenth or nineteenth century period, but away from such obvious disturbance sites the relationships of the contemporary erosion period to past periods is difficult to determine.

# DISTRIBUTION OF SOIL SUB-GROUPS

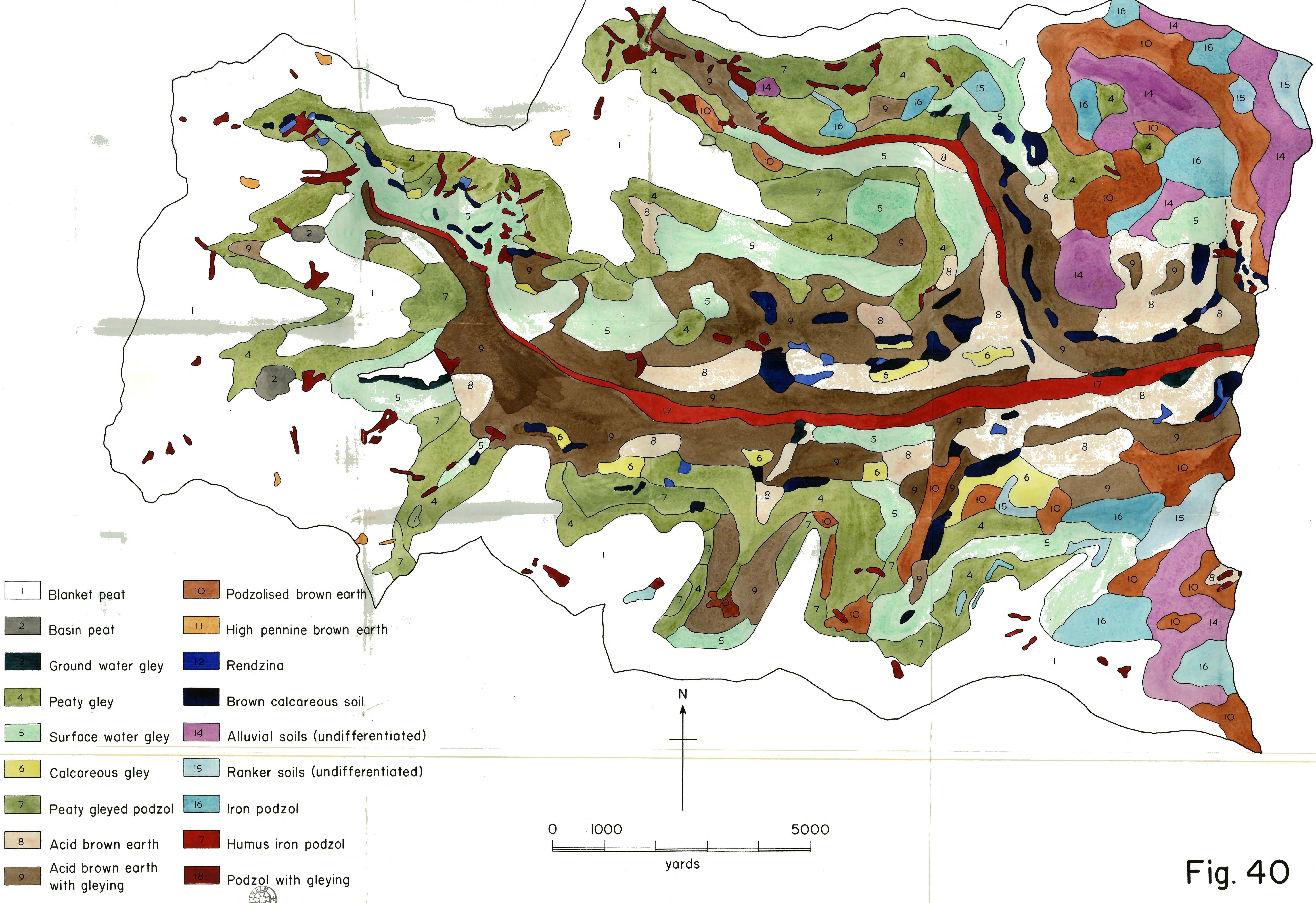


Fig. 40