THE UNIVERSITY OF HULL

Soil Development, Environmental History and the Dating of Terraced Valley Fill Deposits in the North York Moors, with specific reference to Dovedale Griff and Jugger Howe Beck

being a Thesis submitted for the Degree of

Ph. D.

in the Unversity of Hull

by

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University College Swansea

September 1989

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ABSTRACT

Summary of Thesis submitted for Ph.D. degree
by N.R.Peters

on

Soil Development, Environmental History
and the Dating of Terraced Valley Fill Deposits
in the North York Moors, with specific reference to
Dovedale Griff and Jugger Howe Beck

Detailed investigation of the valley fill deposits of Dovedale Griff and Jugger Howe Beck, together with a sedimentological and palaeomagnetic investigation of the sediments of Lake Gormire, provide the basis for an integrated analysis of the temporal and palaeoenvironmental aspects of Holocene valley floor landform development in the North York Moors.

A Holocene alluvial chronology is developed for Dovedale Griff and Jugger Howe Beck based on surface soil stratigraphy, radiocarbon dating, morphology and sediment stratigraphy. Surface soils developed into the deposits of the Dovedale Griff terrace fragments are divided statistically into three groups of soils using a combination of Principal Components Analysis and Cluster Analysis. The first principal component is shown to be a compound index of soil properties that represent some of the main morphological and chemical properties of brown podzolic soils and the grouped soils are shown to represent a chronosequence of brown podzolic soils. Each cluster of soils represents one soil stratigraphic unit.

The age-calibrated surface soil stratigraphic units from Dovedale Griff are used in a Discriminant Analysis procedure to estimate the ages of undated valley floor surfaces in Jugger Howe Beck. An additional soil stratigraphic unit is identified from Jugger Howe Beck. This fourth unit is shown to have a freely drained phase and a gleyed phase.

In Dovedale Griff the alluvial surfaces are dated to about 7100BP, 900BP and about 300BP. In Jugger Howe Beck the main alluvial surfaces are shown to be about 10000BP, 900BP and about 300BP in age. These phases of valley floor development are correlated with phases of instability and stability as revealed by erosion indicators from the sediments of Lake Gormire. Two main phases of synchronous behaviour between the three sites are identified and their environmental significance discussed. These phases occurred at about 1000 - 900BP and again around about 300BP. A phase of synchronous behaviour between Jugger Howe Beck and Gormire are identified at about 10000BP. Phases of site specific behaviour are also identified at 7100BP in Dovedale and 2500BP in Lake Gormire.

The Holocene environmental changes in the North York Moors are placed in the context of valley floor development in upland Britain. Chronologies of valley floor development for upland regions may not reveal a common temporal pattern of response.

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AMENDMENTS

1. Use of the term C^{14} throughout this thesis should be read as ^{14}C.

2. On page 218b Blackham et al.'s (1981) pollen diagram from Lake Gormire is presented, with pollen spectra identified in this thesis from the lake sediments superimposed on the diagram.

3. Soil data from pits in Dovedale and Jugger Howe Beck are presented in Appendix 5.

4. Soil profile descriptions of the Dovedale and Jugger Howe Beck soil pits are given in Appendix 6.

5. Additional References to those appearing in the Bibliography are given on pages 338 - 341.

Chapter 1

Introduction

1.1 Background

Rivers are sensitive components of the physical landscape and as such may respond rapidly to changes in the background environmental conditions of climate, vegetation and sediment supply (Knighton, 1989). Such changes, especially when they occur on a basin-wide scale, may alter the flow regime and/or sediment load of the stream so creating a disequilbrium in the channel. Upland valleys constitute high energy sediment sinks and generally possess streams with large stream powers (Ferguson, 1981). In such catchments where reworking, removal and replacement of the valley floor sediments are common processes, stream response to external disturbance and channel disequilbrium is likely to be reflected in changes in the elevation of the valley floor sediment surface as aggradation and incision of the stream alternates in response to changes in stream flow and sediment load.

River terraces, tributary valley cut and fill sequences, alluvial fans and debris cones form dominant features of the floors of many upland valleys in Britain. These features provide a record of landscape response to temporal changes in the balance between fluvial transport capacity and sediment supply. Recent research is beginning to demonstrate that across the uplands of Scotland, northwest England and Wales the occurrence of extensive suites of these landforms reflects complex histories of valley floor development as streams and slopes adjust to changes in background environmental conditions over the Holocene time scale (see for example, Crampton, 1969; Harvey et al., 1981; Innes, 1983; Macklin and Lewin, 1986; Robertson-Rintoul, 1986a; Harvey and Renwick, 1987; Brazier et al., 1988; Brazier and Ballantyne, 1989). These changes include climatic change, man-induced changes in hydrology and sediment yield associated with land use changes, and may also arise as a result of individual extreme events rather than general climatic change.

1.2 Evidence of Holocene valley fill development in upland Britain

Recent research in upland Scotland is beginning to demonstrate the existence of extensive assemblages of Holocene valley floor landforms in the central highlands of Scotland and in the western Grampians. In Glen Feshie SW Cairngorms five terrace levels have been identified (Robertson-Rintoul, 1986a). The oldest and highest surface is comprised of the dissected deposits of a Late Devensian palaeosandur deposited about 13000bp. The second terrace is limited in aerial extent and is represented by alluvial fan units and small terrace remnants. This surface is suggested to date to the deglacial phase which followed the Loch Lomond glaciation and is therefore Late Glacial/very early Holocene in age. Aggradation of the gravels making up deposits of the third terrace has been dated using radiocarbon dates to about 3500bp. Alluvial fan accumulation at tributary junctions has also been identified and correlated with this terrace surface. The fourth terrace surface is dated to about 1000bp. The very recent terrace surface is a part of the floodplain complex and was dated using historical map data to about 80bp. Work carried in the upper Spey catchment has shown that recent terraces such as the Glen Feshie 80bp surface may be widely recognised in the central highlands of Scotland (McEwan, 1985).

Examination of the Holocene landforms in several tributaries of the River Feshie using a combination of radiocarbon dating, sediment stratigraphy and soil stratigraphy has shown that the tributary valleys possess fluvial stratigraphic units which correlate with units already identified in the main Feshie valley (Robertson-Rintoul et al., in prep). This work has demonstrated that a basin-wide valley floor response to changes in background environmental conditions took place in the Glen Feshie basin at about 3500bp and again at about 900-1000bp. Work carried out in the neighbouring basin of the upper Tromie suggests that the landform sequences described from Glen Feshie may be common to several valleys in the central Highlands of Scotland.

Late Holocene debris flow activity related to slope instability has also been identified in the central Highlands (Brazier and Ballantyne, 1989). In upper Glen Feshie C^{14} dates from a complex sequence of debris flows indicate a phase of debris flow activity at about 2000bp. This phase was

followed by a period of stability at the site until about 300bp when there ensued another period of vigorous debris flow activity. Recent debris flow activity is likely to be a common feature of the Scottish Highlands. Innes (1983) investigated debris flows in several areas of the Scottish Highlands, including the Cairngorms, and found that debris flow activity has been widespread over the past 250 years.

Recent work is also beginning to reveal evidence of Holocene valley floor landforms in the western Grampian Highlands. In Glen Etive a complex debris flow site has been examined by Brazier et al. (1988) and has been shown to reveal evidence of debris flow accumulation dating from the post Loch Lomond period and more recent fluvial activity dated to about 550bp.

Valleys in the uplands of northwest England have been the subject of extensive research concerned with Holocene landform development. In the middle Langdale Beck, Howgill Fells, Harvey et al. (1981) have investigated the deposits of a large alluvial cone. The cone is a part of a complex of cones which are now stabilised and which appear to be products of a phase of regional gully erosion that produced the extensive fossil gullies that occur in many parts of the Howgills. The debris cones rest on terrace deposits which represent the youngest phase of terracing in the middle and upper Langdale valley. Developed into upper terrace sediments is a soil which has been buried by the overlying debris flow deposits. The base of the buried soil has been dated to 2580 +/- 55 bp and the upper layers of the soil yielded a date of 940 +/- 95 bp. The date from the upper soil layers gives a maximum age for deposition of the overlying debris flow deposits.

In nearby Carlingill in the Howgill Fells the highest valley floor terrace is an alluvial terrace at 6-8m above the present river level (Harvey et al. 1984). At the base of the fluvial gravels is soliflucted till. Although there is no dating control available for this terrace, assessment of the soil profile developed into the upper sediments of the terrace indicate that the mature soil profile must have been developing since the middle and more probably early Holocene. This terrace predated the major phase of gully and debris flow activity which in the Middle Langdale site is dated to about

940bp. Set well below the level of this high surface are two low terraces which vary from about 2-4m above present river level. Estimates of the ages of these terraces are made by relating them to the Middle Langdale site. It is suggested that the low terraces probably date from approximately 2500-1000 years bp.

Investigation of river terraces and alluvial fans in the Bowland Fells some 50km to the south of the Howgill Fells enabled Harvey and Renwick (1987) to compare phases of Holocene landform development in two upland regions of northwest England. Two valleys were investigated in the Bowland Fells, the Hodder main valley and the upstream tributary valley of the Langden.

The Langden and Hodder valley floors are characterised by a number of tributary valley alluvial fans and cones as well as river terraces. The highest terrace trims the solifluction surfaces and is probably late Pleistocene in age and comparable with that found in Carlingill in the Howgill Fells. The availability of some dating control has allowed identification of several phases of Holocene fluvial activity. A phase of gravel aggradation and incision has been identified around 5400bp, fan and terrace development around 2000bp and a further phase of fan and terrace development at about 900bp.

Although there is some variation in the timing of phases of landform development between the Howgill Fells and Bowland Fells, there are also some phases of regional synchroneity. Most of the valleys studied appear to possess a late Pleistocene/very early Holocene solifluction surface. Evidence of a phase of landform response at about 900bp is also common to both the Howgills and the Bowland fells. A phase of valley floor aggradation may also be common to both upland areas about 2000bp. In the Bowland Fells however, there appears to have been a phase of valley floor gravel accumulation at about 5000bp for which no evidence has yet been found in the Howgills.

Terrace sequences and alluvial fans have been described from south-east Wales (Crampton, 1969) and from upland valleys in mid-Wales (Macklin and Lewin, 1986). Low level terraces in south-east Wales are suggested to be the result aggradation and braiding associated with increased sediment supply, the latter a consequence of deforestation by Iron-age man. In the Rheidol valley, mid-Wales Macklin and Lewin distinguished and interpreted five terrace levels on the basis of sedimentological criteria.

In the Rheidol valley the upper gravels of the oldest and highest terrace were interpreted as the deposits of a Late Glacial braided stream (Macklin and Lewin, 1986). The second terrace is the least extensive of the sedimentary units in the Rheidol sequence and was probably deposited by a Late Glacial/very early Holocene braided stream. The very extensive third terrace is suggested to represent a period of late Holocene sedimentation which may have been initiated about 2775bp. The fourth and youngest terrace probably has a maximum age of about 625 years bp. The most recent sedimentary units making up the Rheidol sequence are the floodplain complex. Aggradation and incision of the floodplain sediments has been occurring in historic times with similar examples of historical valley alluviation in mid-Wales having also been described from the Afon Ystwyth (Lewin et al. 1983).

The valley floor landform sequences in the mid-Wales and central Highlands valleys show some similarity in pattern of development. Both possess valleys with a high terrace surface related to the late Devensian deglaciation and both possess a very fragmentary surface of lateglacial/very early Holocene age. The central Highlands and Welsh valleys also possess two phases of late Holocene aggradation and an historical phase of sediment accumulation and incision.

A regional picture of Holocene landform development therefore appears to be emerging for upland Britain with most valleys possessing a Late Glacial/very early Holocene terrace and two to three phases of low level terrace development. Compound alluvial fan development at main tributary valley/main valley junctions and debris flow activity in headwater valleys also appears to be a common landform response to destabilisation of sediment stores.

1.3 Holocene environmental change and valley processes in the North York Moors

It is notable that, apart from brief reference to Mesolithic valley alluviation at the mouth of Dovedale Griff in the North York Moors (Richards, 1981), very little is known about either the extent or pattern of Holocene fluvial activity in the upland valleys of the North York Moors in north-eastern England.

Palynological and pedological studies in the North York Moors have identified phases of vegetation clearance and landscape instability on the moorland tops and steep hillslopes. A number of studies have identified mineral sediment inwash layers in peat bogs (Simmons and Cundill, 1974; Simmons et al., 1975) developed on the moors of the central watershed. At Ewe Crack Slack, a soligenous mire, Simmons et al. (1975) identified a number of distinct inorganic inwash layers which were interpreted as the result of phases of intensified catchment erosion. Palynological evidence enabled the earliest inwash layer to be identified as Mesolithic in age, with this inwash layer being attributed to burning on adjacent slopes by Mesolithic hunters thereby creating temporary woodland clearances. Subsequent inwash layers were attributed to the more permanent effects of Neolithic and Bronze Age agriculture. At West House Moss in the northern North York Moors mineral inwash layers have also been identified which have been C^{14} dated to 6650bp (Jones et al., 1979). Further inwash layers in the mires were identified as occurring in the middle Bronze Age, a time when there was considerable anthropogenic impact on the vegetation of the surrounding catchment. Curtis (1975) identified "k-cycles" of alternating pedogenesis and slope erosion on Levisham Moor, on the northern edge of the Tabular Hills. The k-cycles comprise a complex sequence of truncated podzols in the upslope region of Levisham Moor and buried organic layers and thick accumulations of sand with thin layers of eroded Ao horizons in the downslope regions. These are indicative of phases of soil instability on the hillslopes of Levisham Moor. Although no dating control was available to place these phases of pedogenesis and surface stripping within the Holocene time scale, there is both pollen and extensive

archaeological evidence of severe woodland clearance, iron smelting and agriculture on the Moor occurring during Iron Age and Medieval times. It is therefore likely that the k-cycles were formed primarily during the last 2000 years.

There is thus considerable evidence from the moorland tops and slopes of the North York Moors to indicate episodic phases of Holocene landscape instability and vegetation change. To date however, very little work has been carried out to investigate the valley floor responses to the hydrological and sediment supply changes which must have accompanied the changes in background environmental conditions implied by these phases of accelerated slope instability. The lack of detailed study of Holocene valley floor alluviation in the North York Moors therefore provided the impetus for the present study, which has the following major aims:-

1. To identify and place in a chronological order the Holocene landform sequences in two valleys in the North York Moors, one in the south-east of the North York Moors and one at the eastern edge of the central Moors region;

2. To assess the extent to which correlations may be established for phases of valley floor landform development in these two valleys and the degree to which landform responses may be site specific;

3. To examine the evidence for Holocene environmental change as it may be reflected from pollen spectra examined in this study from a bog within one of the valley catchments and to examine the evidence for erosion indicators in lake sediments as they may reflect phases of catchment instability;

4. To relate the evidence of discontinuous valley floor landform development with the evidence of environmental change from the continuous record provided by lake sediments and to assess the evidence against the background of known palynological and archeological change in the North York Moors;

5. To assess the phases of Holocene landform development established for the two valleys and their background environmental causes, in relation to identified phases of Holocene landform development in other upland areas in Britain.

The three sites in the North York Moors selected for study in this thesis are two valley locations and one lake; these sites are described in Chapter 2. The valley sites are Dovedale Griff in the southeast of the North York Moors and Jugger Howe Beck at the eastern edge of the central Moors region. Both of these valleys contain valley fill deposits with the sediments of the fills stored in terraces fragments and alluvial fans. These sequences of landforms are described in Chapter 2. The lake site is Lake Gormire on the western edge of the North York Moors region.

1.4 Methods of analysis of valley fill landforms

Reconstruction of the history of terrace and alluvial fan sequences must be based on the careful subdivision and correlation of the deposits making up the valley fill (Butzer, 1980). Terrace morphology provides one of the keys to developing a history of valley fill evolution. Morphology of terrace sequences, and in particular the relative height and continuity of fragments in a downstream direction, has traditionally been used to correlate individual terrace fragments and reconstruct prior floodplain surfaces.

A terrace fragment may be regarded as a plane surface, at least for a short distance downstream, and the slope of the plane as projected onto a height range diagram, will approximate to the maximum channel slope, known as the valley slope, preserved by the terrace fragment (Culling, 1957; Richards, 1982). A height range diagram represents a projection plane on which the heights of the terrace fragments are plotted. Distance is plotted on the x axis and height is plotted on the y axis. Such a diagram enables continuity of terrace fragments to be traced downstream (Kirby, 1969). Thus for example Haible (1980) used height range techniques to show that in its upstream reaches Walker Creek in California possesses two terrace levels but in its downstream reaches has only a floodplain. Harvey et al. (1984) used a height range diagram to show the

contrast in river behaviour and terrace development between two reaches of valley in Carlingill, Howgill Fells. In the upstream reach the present channel is stable and locked in bedrock, although prior to its stabilisation about 1900AD the river was an unstable migrating channel, adding sedimentary units to the valley floor sequence. In the downstream reaches the channel is unstable and has an extensive sequence of low level surfaces. In Scotland height range techniques have been used extensively to trace continuity of Late Devensian and Loch Lomond age outwash terraces in highland valleys (eg. Young, 1976; Sissons, 1979).

Terrace profiles that are not parallel indicate slope adjustment to changing environmental controls in the river catchment (Leopold, Wolman and Miller, 1964; Haible, 1980). Changes in valley slope that are preserved by terrace long profiles may be identified on height range diagrams. Height range diagrams have been used, for example, to identify downstream convergence of terraces in suites of outwash terraces in the Scottish Highlands. The gradient changes of the prior valley floor sediment surfaces evident in the height range diagrams is attributed to rapid changes in hydrology and sediment supply of proglacial streams (Sissons, 1981). Similarly, height range techniques were used by Thompson and Jones (1986) to examine changes through time in the long profile of the proglacial Kota and Svinafellsa streams in Iceland. Projection of levelling data from the terraces onto height range diagrams showed that the Kota River exhibited a reduction in gradient between the higher and lower terraces, this being attributed to changes in the balance between hydrology and sediment supply through time. The Svinafellsa height range diagram exhibited more complex changes, as suggested by several converging and crossing terraces.

Data from height range diagrams therefore have an important role to play in developing a history of valley fill deposits, for the technique allows identification of different terrace levels both at a cross section and in a downstream direction, and also allows changes in the gradient of the prior floodplain to be identified. In Chapter 2 detailed levelling survey data are used to construct a height range diagram for the Dovedale Griff terrace fragments in order to determine the relative heights of each fragment above present river level, and also to examine the changing slope of the

prior floodplain surfaces. Although detailed levelling data were obtained for Juggerhowe Beck a height range diagram was not constructed for the alluvial surfaces in this valley for several reasons. First, and as discussed in Chapter 2, much of the upper part of the Jugger Howe Beck study reach consists of an extensive tributary junction alluvial fan with a smaller inset fan below the main fan surface. The gradients of these fans could not be compared with the alluvial surfaces in the main Jugger Howe Beck valley. Second, the upper alluvial surface of Jugger Howe Beck is very degraded which made levelling of the surface very difficult. Finally, the low terrace which constitutes the major part of the valley floor below the alluvial fan, is made of a series of bars and channels, the alignments of which are variable in a downstream direction. As discussed in Chapter 2, such alignment changes will complicate interpretation of the slopes as they are projected onto a height range diagram. For these reasons, detailed levelling data were therefore used to construct a series of cross profiles for Jugger Howe Beck. These cannot show continuity of surfaces downstream but they are able to give relative heights of each surface above present river level. Cross-sectional data for Jugger Howe Beck are presented in Chapter 2.

However, as the gradients of former floodplains change through time, terraces may converge downstream so that relative heights of a prior surface may therefore vary downstream. Further, changing gradients may mean that, as in the case of the Svinafellsa in Iceland referred to above, terraces may cross. Crossing of terraces was demonstrated also by Haible (1980) for Walker Creek. In the downstream reaches of this Creek the modern stream has aggraded and buried the two terraces which are present upstream. Thus, as a consequence of the complex relationship between phases of incision and aggradation both spatially and temporally within a river system, and the changing slopes of prior floodplains, interpretation of a terrace sequence cannot be based on morphological data alone. Rather, correlation of terrace fragments and separation of different levels must be based on both a morphometric and stratigraphic framework (Born and Ritter, 1970; Richards, 1982). Hence in the study of the Rheidol terrace sequence in mid-Wales Macklin and Lewin (1986) used granulometry, lithology, and sedimentary structures to provide a lithostratigraphic framework, which in addition to terrace morphology, was used to correlate discontinuous alluvial units and terrace fragments into surfaces of particular age periods.

Recognising the difficulty of correlating unpaired terrace fragments on the basis of height data alone, Mills and Wagner (1984) introduced indices of time progressive weathering of the surficial deposits of the terrace fragments to separate the higher and lower terrace fragments of the New River in southwest Virginia. In Alaska Ritter and Ten Brink (1986) used depth of oxidation to provide relative ages of the four outwash aggradations related to late Wisconsin glacial advances. Height range data and data from relative weathering studies were used in conjunction to establish the time sequence of valley floor development in Carlingill in the Howgill fells. Here Harvey et al. (1984) used the terrace fragments identified from the height range diagram to carry out lichenometric surveys which were then used to distinguish the terrace fragments on the basis of relative age data. The high terrace fragments were distinguished in terms of age on the basis of the degree of pedogenesis of the surficial terrace sediments.

These studies demonstrate that sedimentological data and evidence of relative weathering of terrace sediments may provide important sources of stratigraphic data to both validate and supplement morphological relationships. The relative dating methods used by these workers measure the degree of post-depositional alteration of surficial deposits. When calibrated with some absolute dating control relative weathering data may be used to predict the ages of undated surfaces. For example, Thompson and Jones (1986) used age-calibrated lichenometric data to date individual terrace fragments. The dated terrace surfaces were then used to calculate mean rates of net erosion between each dated surface. Age calibrated soil-stratigraphic data from the surface soils developed into the upper gravels of the Glen Feshie terraces were used to discriminate terrace levels of different age (Robertson-Rintoul, 1986a). This latter study emphasised the difficulty of attempting to separate into surfaces of one age the discontinuous, often unpaired, low level terrace fragments typical of Holocene valley floor development in upland valleys in Britain. In upland valleys terrace surfaces may differ significantly in age, although there may be little relative height difference between levels. In this situation quantitative soil-stratigraphic data may provide an extremely valuable tool for correlating terrace fragments and arranging them in a time sequence.

Separation of alluvial deposits within the Holocene time scale on the basis of surface soil profile development has been extensively carried out in the Wind River Mountains (Mahaney, 1974), and the Colorado Front Range (Mahaney, 1978; Mahaney et al., 1981) and is reviewed in more detail in Chapter 3. Mahaney (1978) argues that the state of the soil system varies with the age of the deposit and as such provides an important means of assessing the relative age of a deposit as well as assisting in deposit differentiation. Soil morphology, particle size, clay mineralogy and soil chemistry may all be useful in differentiating deposits of different relative age and allow the development of surface soil-stratigraphic units.

The soil-stratigraphic unit is defined as a soil with physical features and stratigraphic relations that permit its consistent recognition and mapping as a stratigraphic unit (American Commission on Stratigraphic Nomenclature, 1961). The correlation and relative dating of deposits using degree of soil development on the alluvial surfaces forms the basis of soil-stratigraphic studies (Finkl, 1980). Birkeland (1974) and Finkl (1980) outline some of the primary properties of soil-stratigraphic units. In order to qualify as a soil-stratigraphic unit a soil must meet certain criteria which include:

1. Morphological and chemical features that are pedogenic in origin;
2. A consistent relationship to associated stratigraphic units in the local succession;
3. A wide geographical distribution;
4. Possess clearly defined features which permit its recognition as a marker horizon.

Any individual soil-stratigraphic unit may show a range of development and a range of soil features caused by changes in the soil forming environment (Rose et al., 1985).

As used by Mahaney and his co-workers in the Rocky Mountains and Robertson-Rintoul in the central Highlands of Scotland, the surface soils developed on glacial and river terrace deposits take on a stratigraphic significance, as they represent periods when there was a fairly stable land surface with little or no deposition or erosion. Further, the soil units consist of soil profiles which

exhibit a similar degree of soil development as demonstrated by morphological and chemical soil properties, which are mappable in the field and exhibit consistent relationships to associated stratigraphic units.

Such soil units should be distinguished as stratigraphic units independent of lithostratigraphic, chronostratigraphic, biostratigraphic or morphostratigraphic units (Catt, 1988). Once calibrated with some absolute dating control soil stratigraphic data may be used to predict the ages of undated landforms in other areas of similar environment where the land surfaces cannot be dated by conventional absolute dating techniques (Mellor, 1985). This is particularly valuable in studies of alluvial deposits, since preservation of datable material in coarse grained material is limited.

The valley fill sediments of Dovedale Griff and Juggerhowe Beck contain only a few sites where material is suitable for C^{14} dating so that correlation and dating of deposits cannot be based on radiometric dates. Further the lack of differentiation between the stratigraphy of the terrace fragments making up the fill in Dovedale Griff precluded the use of sedimentological criteria such as those used by Macklin and Lewin (1986) in the Rheidol valley to correlate and separate terrace levels. In Chapters 3 and 4, therefore, the main Dovedale Griff and Jugger Howe valley floor landforms are correlated and grouped into surfaces of different relative age using soil profile data from the surface soils developed into the terrace fragments.

Differentiation of soil profiles on a relative age basis requires the measurement of soil properties that are time dependent. The parameters used for the soil-stratigraphic analysis of the Dovedale Griff and Jugger Howe Beck soils were selected to take into account the dominant soil-forming processes likely to be operative in the valley floor soils. The soils developed on the upper terrace and some of the lower terrace surfaces are shown to be brown podzolic soils. The soil-forming processes likely to be operative in such brown podzolic soils are therefore discussed with reference to the available literature and the soil parameters selected for inclusion in the soil-stratigraphic analysis were based on this discussion. Using multivariate statistical methods the

soil profile data from Dovedale Griff are quantitatively differentiated into surface soil-stratigraphic units, and the constituent soil profiles shown to be brown podzolic soils in differing stages of soil profile development. As Holocene chronosequences of brown podzolic soils have received little attention in the literature some of the salient morphological and chemical properties of the chronosequence are described (Chapter 3).

Chapter 4 is concerned to develop some absolute dating control which will enable the soil-stratigraphic units developed in Dovedale Griff to be placed tentatively on a Holocene time scale. The chapter begins with a discussion of the available C^{14} dating control which will used to estimate the approximate ages of the soil stratigraphic units. The stratigraphy of the C^{14} sites is described and the significance of the C^{14} dates is discussed in the context of the soil sequence.

Only three sites with C^{14} dating control are available, so any conclusions made regarding the ages of the soil stratigraphic units must be regarded as tentative. Further, very little C^{14} dating control is available from Dovedale Griff, with two of the three sites being obtained from the study reach in Jugger Howe Beck. For this reason the C^{14} dates are supported by some additional dating control from soil pollen extracted from two soil profiles in Dovedale Griff and by a C^{14} date from an infilled bog in Bridestones Griff, a tributary to Dovedale Griff.

Following a discussion of the dating control for the soil groups Chapter 4 develops a statistical procedure for allocating new, ungrouped soil sites to one or other of the previously recognised soil stratigraphic units. Discriminant analysis is used to allocate new sites to an established relative age soil group with the smallest probability of error. The age calibrated soil stratigraphic units are then used to interpret the alluvial surfaces in Jugger Howe Beck and an additional soil stratigraphic unit is recognised and described from this valley.

In Chapter 5 the stratigraphic data from Chapters 3 and 4 are integrated to establish phases of landform development within the history of valley fill evolution in Dovedale Griff and Jugger Howe Beck.

The existing studies of Holocene landform development in upland Britain have all demonstrated the need to relate an examination of Holocene landform development to studies of the vegetation history and catchment stability that can be provided by palynological analysis and the study of lake sediments. This is required if the sedimentary history of the valley fill deposits is to be interpreted within the context of environmental change.

The postglacial vegetation history of the North York Moors has been well documented. Within the vicinity of the two valleys under consideration in this thesis, Atherden (1976) has correlated palynolgical evidence from several bog sites within a 10km radius to provide a regional picture of vegetation changes. These regional data enable a palynological examination of a bog core taken from within the Dovedale Griff catchment to be correlated with the C^{14} calibrated regional vegetation history. In Chapter 6 an integrated approach is adopted towards the analysis of the pollen spectra and other biological evidence as well as lithological evidence in the reconstruction of the bog history. This approach was taken in order to develop a more complete picture of the vegetation history of the catchment as well as landuse changes and changes in the stability of the slopes surrounding the bog.

Although river terraces and alluvial fans represent sediment sinks they can only give a discontinuous record of the history of a catchment. Further the landforms may be of a temporary nature which may therefore complicate reconstruction of the alluvial chronology. As Macklin and Lewin (1986) point out, the sequence of landforms that they have discussed from the Rheidol valley in mid-Wales is probably incomplete with phases of aggradation possibly having been removed by subsequent erosion. This is particularly likely in upland valleys where streams migrate relatively rapidly across the valley floors reworking valley fill sediments (Ferguson, 1981).

More permanent sediment sinks for the products of catchment erosion are those formed by the accumulation of lake sediments (Oldfield, 1977). Thus lake basins, as sediment sinks, contain a record of processes which have taken place within the lake catchment (Edwards and Rowntree, 1980). Cores taken through lake sediments may therefore provide information on, and permit

some degree of correlation between, palaeoenvironmental conditions and sediment yields in the lake catchment (Berglund, 1979). The integration of pollen stratigraphy from the lake together with an analysis of the sedimentological and chemical properties of the sediments from the lake cores is particularly useful because it helps to provide an estimation of the history of landscape stability as it responds to climatic and vegetation change. The value of the lake cores in this context is much enhanced by a chronology of sedimentation that the palaeomagnetic record of the sediments can provide (Mackereth, 1971; Thompson and Turner, 1979).

In an attempt to expand the regional picture of Holocene alluviation and landscape stability in the North York Moors as well as to facilitate interpretation of the background environmental causes of phases of Holocene landform development, a lake core was taken and analysed from Lake Gormire in the western edge of the Tabular Hills region (Chapter 7). The chronology of sedimentation for the lake core is established using palaeomagnetic techniques. The results of physical and chemical analyses from the core sediments are presented and using these data a number of indices provide indicators of periods of stability and low erosion in the catchment and periods of instability and high erosion. Trends in these erosion indicators are discussed in the context of the Holocene time scale.

These three sites, Dovedale Griff, Juggerhowe Beck and Lake Gormire provide data from three separate areas of the North York Moors which taken together enable some initial assessment to be made of the periods of Holocene landscape instability and stability within the North York Moors region (Chapter 8). In this chapter an assessment is made of valley floor landform development within the context of environmental change as identified through the analyses conducted on the bog and lake sediments as well as from published regional data. Similarities and differences between the valley floor development of the two valleys are discussed and set against the regional pattern of Holocene landform development as it is emerging for upland Britain at present.

This thesis seeks to provide a methodology for correlating and dating valley floor landforms in one upland region in England. It also provides an integrated analysis of the environmental and chronological context of discontinuous valley floor landform development in two small valleys in the North York Moors during the Holocene against the background of environmental change established from the continuous lacustrine sedimentary record provided by Lake Gormire.

Chapter 2

The Regional Setting and Description of Study Areas

2.1 The North York Moors Region

The North York Moors form a distinct physiographic region within northeast Yorkshire. The Moors comprise Jurassic rocks which rise in a broad anticline above the Vales of York and Pickering to the west and south, and the Cleveland Plain to the north, with the North Sea coast forming the region's eastern boundary.

2.1.1 Regional Physiography

The North York Moors can be divided into four physiographic areas, as shown in Figure 2.1. The largest such area is the high Moors which form the central watershed of the region. The highest point in the North York Moors, at 450m, is found on Urra Moor towards the western edge of this central watershed, which gradually decreases in altitude eastwards towards the coast. The valley of the eastward flowing River Esk, divides the moors of the central watershed from the second physiographic area. This area is the Cleveland or northern Moors, which are considerably lower than the central watershed, only rising to 326m on Guisborough Moor. Like the central watershed the Cleveland Moors descend to lower altitudes towards the east.

The third physiographic area comprise the Tabular Hills which form the southern edge of the North York Moors, and which are separated from the moors of the central watershed by a north facing scarp of variable height. The scarp is best developed in the Levisham and Lockton areas and at the edge of Grime Moor in the Dovedale catchment, where it ranges between 270m - 240m O.D. The Tabular Hills name is derived from the extensive plateau like surface of the southwards sloping dip slope.

THE NORTH YORK MOORS REGION: TOPOGRAPHY, DRAINAGE AND PHYSIOGRAPHIC AREAS



TEESSIDE

CLEVELAND PLAIN

NORTH SEA

WHITBY

R. Esk

R. Esk

ROBIN HOOD'S BAY

J_X

D_X

Dalby Beck

SCARBOROUGH

R. Derwent

VALE OF YORK

G_X

THIRSK

PICKERING

VALE OF PICKERING

380m +

244 - 380m

122 - 244m

KEY

NORTHERN MOORS

CENTRAL MOORS

TABULAR HILLS

HAMBLETON HILLS

D_X DOVEDALE

J_X JUGGER HOWE BECK

G_X LAKE GORMIRE

0 5Km

Figure 2.1

The Hambleton Hills, which form the upland area at the southwestern margin of the North York Moors comprise the fourth physiographic area. The Hambleton Hills are separated from the Tabular Hills by the incised valley of the River Rye, the headwaters of which almost completely separate the Hambleton Hills from the central watershed of the North York Moors.

In the present study, the Tabular Hills are distinguished from the moors of the central watershed and the Cleveland Moors. These latter two areas are referred to collectively as the central Moors in this study. This distinction is made primarily on the basis of the differing geology of the Tabular Hills from the rest of the North York Moors, and the Tabular Hills' characteristic plateau like topography. The Hambleton Hills, because of their similar geology and topography, are considered as an extension of the Tabular Hills in this study.

2.1.2 Regional Geology

The solid geology of the North York Moors region, shown in Figure 2.2, exerts an important control on the physiographic distinctions in the region. Geology divides the region into the Tabular Hills area, underlain by the Corallian series of Upper Jurassic age, and the central Moors, which are dominated by the Estuarine Series of Middle Jurassic age. These two areas are separated by the north facing Corallian scarp of the Tabular Hills which has formed as a result of more rapid erosion of the Oxford Clay at the base of the Corallian (Kent, 1980).

The Corallian consists of a succession of grits and thinner limestone beds, while the Estuarine series include a wide variety of sedimentary rock types, including sandstones, grits, limestones, and shales. Underlying the Corallian, the Oxford Clay is exposed in the floors of many of the more deeply incised valleys on the Tabular Hills. In the floors of valleys which have incised through the Estuarine series in the central Moors are exposures of Liassic rocks, mainly comprising mudstones.

GENERALISED SOLID GEOLOGY OF THE NORTH YORK MOORS REGION

TEESSIDE

CLEVELAND PLAIN

NORTH SEA

WHITBY

R. Esk

ROBIN HOOD'S BAY

J_X

D_X

Dolby Beck

R. Derwent

SCARBOROUGH

PICKERING

VALE OF YORK

G_X

THIRSK

VALE OF PICKERING

Location of North York Moors Study Region

N

0 5Km

JURASSIC

UPPER
- KIMMERIDGE CLAYS
- CORALLIAN SERIES (STANDSTONE & LIMESTONE)
- OXFORD CLAY & KELLAWAYS ROCK (SANDSTONE)

LOWER MIDDLE
- ESTUARINE SERIES (MAINLY SHALES WITH SANDSTONE BANDS
- LIAS (MAINLY MUDSTONE)

TRIASSIC
- KEUPER MARL (MUDSTONES & SILTSTONES)
- BUNTER SANDSTONE

D_X DOVEDALE
J_X JUGGER HOWE BECK
G_X LAKE GORMIRE

Figure 2.2

During the Alpine orogeny these Jurassic sediments underwent only gentle folding. The anticlinal axis runs east west along the alignment of the central watershed, and to the south of this axis, the strata dip to the south at an angle not exceeding 3°; to the north of the anticlinal axis, the strata have a similar degree of dip to the north. Tertiary marine planation resulted in the various Jurassic strata being exposed at the surface. Subsequent erosion caused the recession of the less resistant clays, and the formation of the Corallian escarpment is a notable consequence of this process.

2.1.3 Climate

Precipitation varies across the North York Moors primarily as a consequence of altitude changes. Mean annual rainfall is generally not less than approximately 700mm on the lowest ground in the south and west of the region, but rises to up to 1020mm on the high ground on the central watershed. Average (1916-1950) monthly precipitation data from sites across the region are presented in Table 2.1

Table 2.1 **North York Moors Precipitation Records (mm)**

1. Wykeham (SE 950860) 145m

Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Year
58	57	50	60	56	44	62	68	60	53	93	76	737

2. Sylpho Moor (Broxa Forest) (SE 957946) 203m

Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Year
85	57	50	52	57	57	82	85	70	74	87	80	836

3. Mount St. John, Felixkirk (SE 474848) 152m

Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Year
71	52	44	47	51	54	75	77	61	67	71	64	734

The Wykeham recording station is located 10km southeast of Dovedale on the dipslope of the Tabular Hills, and the Sylpho Moor station is 7km south of Jugger Howe Beck at the top of the Corallian escarpment. The Felixkirk station is only 3.5km northwest of Lake Gormire, below the Hambleton Hills escarpment. These data show there to be very little variation in precipitation

recorded on an east-west transect across the the North York Moors region, and a comparison of the Wykeham and Felixkirk stations with Sylpho demonstrates that altitude is the main control on precipitation amounts. The data from Felixkirk should be highly representative of the precipitation regime at Lake Gormire, while that from Wykeham should provide an approximation of the monthly precipitation pattern in the Dovedale and Jugger Howe Beck catchments. The data shows there to be little variation in precipitation between Lake Gormire and the Dovedale and Jugger Howe Beck study sites.

The number of days that snow lies varies from 45 days on the uplands to 30 days at lower altitudes, although there is wide variation from year to year. Average annual evapotranspiration varies from 430 - 480mm, depending an altitude.

Accumulated air temperatures range between 1550 day/ °C. at an altitude of 76m, to 800 day/ °C. at 304m (Bendelow and Carroll 1976). The accumulated temperatures represent the integrated excess or deficiency of temperature with reference to a fixed base temperature. The base temperature adopted is 6°C., which is the temperature at which grass growth commences (Birse and Dry 1970). Monthly average daily temperatures recorded at Scarborough (altitude 36m) range from 4.1°C. in January to 16.0°C. in July. The annual average temperature is 9.8°C. At higher altitudes inland temperatures will be lower than these during the winter because the warming effects of the North Sea will be less significant.

2.1.4 Vegetation

The central Moors are dominated by Calluna heather moorland which is extensively managed for grouse rearing. Where heather moorland is not present, poor Nardus-Agrostis-Molinia grassland provides rough grazing for sheep. In most of the deep valleys incised into the central watershed the valley floors are under pasture, with limited arable use. The Tabular Hills are used for a wide range of agriculture, including cereals, root crops, some pasture, and rough grazing for sheep. The southeast corner of the North York Moors is dominated by coniferous plantations. The

establishment of coniferous plantations was begun by the Forestry Commission in 1921 in the North York Moors region. Afforestation has been concentrated in the southeast of the region, primarily on the northern half of the Tabular Hills to the south and east of Dovedale, and on the Kellaways Rock outcrop in the central Moors between Dovedale and Jugger Howe Beck.

2.2 Dovedale Grlff

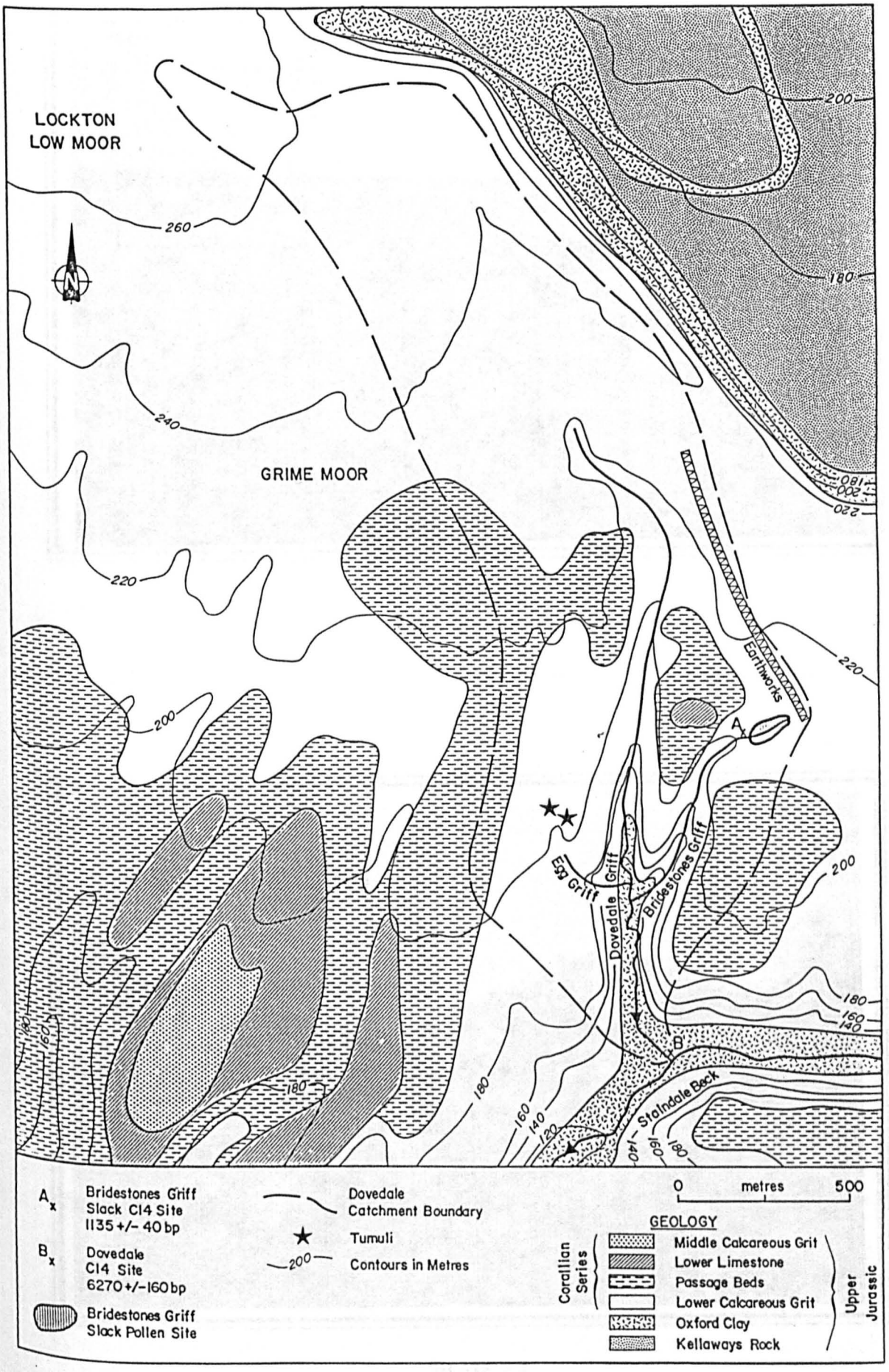
2.2.1 Location

Dovedale Griff (Grif Reference SE 871908) is located towards the eastern end of the Tabular Hills, 16km west of Scarborough and 10km northeast of Pickering (see Figure 2.1). Dovedale Griff stream flows south into Staindale Beck, which is the major contributary of Dalby Beck. The south flowing Dalby Beck eventually debouches, 13km south of Dovedale Griff, into the River Derwent in the Vale of Pickering.

2.2.2 Topography

The north-south trending valley of Dovedale Griff has a similarly aligned and rather narrow, linear catchment, which is 3km long along its major north-south axis, with a maximum width of approximately 1.0km. The catchment, shown in Figure 2.3 has an area of approximately 2.25km^2. A 1km long section of the catchment's eastern boundary is marked by a Forestry Commission plantation. The northerly continuation of the catchment's eastern boundary is formed by the top of the Corallian escarpment, which in this area rises 76m above the scarp-foot valley of Crosscliffe Beck to the north. The western catchment boundary is less distinct, and is formed by a gently sloping, northwest-southeast aligned low ridge which forms part of Grime Moor.

Above the valley floor, the catchment gently slopes up to the north. The highest point in the catchment, on Lockton Low Moor, is at approximately 265m. Plate 2.1 was taken towards the NW,



DOVEDALE: CATCHMENT AREA, TOPOGRAPHY AND DRAINAGE

Figure 2.3



PLATE 2.1



PLATE 2.2

with Lockton Low Moor forming the central skyline. The photograph was taken at the break of slope above the eastern valley side of Bridestones Griff. At its lowest level, at the southern end of the catchment, this surface is at an altitude of approximately 195m. The confluence of Dovedale Griff with Staindale Beck is at approximately 130m.

Dovedale Griff is a deeply incised second order headwater stream. The greater part of the valley floor is at an altitude of 135m - 145m, which indicates in the region of 50m - 60m of incision below the surrounding catchment plateau top. In this reach, partly shown in Plate 2.2, the valley floor varies between 40m - 55m in width. This reach extends 400m northwards from the bedrock constriction which marks the junction of Dovedale valley with the valley of Staindale. The bedrock constriction is located 120m upstream of the confluence of Dovedale Griff and Staindale Beck.

Bridestones Griff, a deep gully incised through Dovedale's eastern valley side slope, joins Dovedale 350m north of the junction of Dovedale and Staindale, and 50m south of the Egg Griff confluence. Egg Griff is a short steep and rocky gully, upstream of which Dovedale's valley floor rapidly decreases in width to 30m. The valley floor continues to decrease in width over a further 250m, until ultimately the valley floor is completely occupied by the stream bed and the lower valley side slopes are replaced by rock walls which vary from 10 - 20m in height. This incised section of the valley gradually decreases in depth until at a point 750m further upstream it rises to the level of the surrounding catchment surface, at an altitude of approximately 215m.

2.2.3 Geology

The incised nature of Dovedale Griff has resulted in several different lithologies being exposed in the gently south dipping Jurassic rocks. The bedrock underlying the valley floor is the Oxford Clay, which in this area becomes more shaley as its junction with the overlying Lower Calcareous Grit is approached. The Oxford Clay outcrop extends up the lower 7.5m of the valley side slopes. In Dovedale Griff the Oxford Clay grades out at the downstream end of the rockwalled reach, and

in Bridestones Griff it dips below the surface approximately 150m from the confluence with Dovedale Griff. Oxford Clay also forms the valley floor bedrock in Staindale (see Figure 2.3).

Above the Oxford Clay, the valley side slopes of both Dovedale and Bridestones Griffs are underlain by the Lower Calcareous Grit, which is the oldest member of the Corallian series. The Lower Calcareous Grit is a coarse sandstone, which despite its name forms a predominantly acidic outcrop in the North York Moors.

On the western slopes of Dovedale Griff, the Lower Calcareous Grit extends well up onto the surrounding plateau top. On the eastern slopes of both Dovedale and Bridestones Griff however, the Lower Calcareous Grit is succeeded just below the break of slope at the top of the valley sides by the sandstone of the overlying Passage Beds. Developed in the Passage Beds are the tors and cliff faces of the Bridestones, which Palmer (1956) attributed to more rapid weathering of the underlying Lower Calcareous Grit. The position of the Passage Beds at the top of the valley slopes in the Dovedale catchment was a necessary pre-condition for tor development. In such a position, the highly silicified Upper Passage Beds formed a caprock which reduced the rate of vertical degradation of the plateau top. Slope retreat proceded at a faster rate in the Lower Calcareous Grit, consequently exposing the Passage Beds at the slope top. Once exposed in this manner, the slightly less resistant Lower Passage Beds weathered faster than the Upper Passage Beds, eventually forming the undercut pedestal tor forms of the Low Bridestones (see Plate 2.3). The High Bridestones, shown in the right foreground in Plate 2.1, are, by contrast only exposed as rock faces at present. Palmer (1956) considered this contrast to be a result of the shorter period of slope retreat that has occurred above the less mature rock walled reach of Dovedale Griff and Bridestones Griff. As Palmer (1956) considered the degree of slope retreat to be directly related to the maturity of the valley floor development, he associated the relatively wide lower Dovedale valley with the well developed tors of the Low Bridestones, and the poorly developed, rock walled valley of upper Dovedale with the cliff faces of the High Bridestones.



PLATE 2.3

The Passage Beds comprise much of the plateau top to the east of Dovedale Griff, but the Lower Calcareous Grit underlies most of the Bridestones Griff catchment and much of the plateau top to the west of Dovedale Griff. The northern half of the catchment is also underlain by the Lower Calcareous Grit. Immediately east of the High Bridestones there is a very small outlier of the Lower Limestone, surrounded by the Passage Beds (see Figure 2.3).

2.2.4 Valley Side Slopes

The valley side slopes above both Dovedale and Bridestones Griff are mantled in a thick stony head deposit, derived from the Lower Calcareous Grit. The head is in places over 1.5m thick. The Soil Survey (Bendelow and Carroll 1975) notes the extremely stony soils that develop on this Lower Calcareous Grit head. Thick head deposits have been noted from several locations on the Tabular Hills (Bendelow and Carroll 1975), which are considered to indicate that the area was not glaciated during the Devensian. Where the surface vegetation has been destroyed along footpaths, the sandy soils on the plateau tops and valley sides are rapidly eroded. Where the erosion is especially severe, for example at narrow sections of footpath, gullying has cut down through to the underlying head deposits. Where this occurs, the stoney head material is itself readily eroded and moved down the slope (see Plate 2.1).

At the base of the eastern valley slope of Dovedale are a series of active scars. The stream flows at the base of four presently active scars downstream of Egg Griff. One of these scars can be seen partially on the right of Plate 2.2. 50m upstream of the Egg Griff confluence another scar is presently building up a talus slope of shale from the Oxford Clay and Head. The stream is no longer flowing at the base of this scar. There are several relict and highly degraded scars on both sides of the valley which are adjacent to terrace fragments, and which are now completely vegetated.

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In the rockwalled sections of both Dovedale and Bridestones Griff, the exposed Lower Calcareous Grit appears susceptible to erosion along the sub-horizontal bedding planes which give rise to rock falls of cobble size platey clasts into the gully floors.

2.2.5 Valley Fill Landforms and Stratigraphy in Dovedale Griff

The Present Channel

The present Dovedale Griff is a narrow meandering channel with an overall valley slope, the maximum possible channel slope (Richards, 1982) of 0.028. The stream is bordered in places by narrow floodplain elements and lateral bars comprised of relatively fine gravel and pebbles. Where it flows at the base of the active scars referred to above, the stream has become locked into the exposed Oxford Clay shale bedrock. These bedrock outcrops at the base of the valley side scars form a series of local base-levels for the present day channel (Figure 2.4). As a consequence of the pinning of the channel to the eastern side wall of the valley, and under the present day sediment yield : stream flow ratio, the present day channel has developed a channel pattern that under the channel pattern classification system of Ferguson (1981) would be termed as a confined meandering pattern. Such channels are characterised by meanders which have become ensconced in the valley sides, or high terrace bluffs, with meander bends that are frequently distorted in shape. A characteristic feature of confined meandering streams is that they usually hug one or other of the valley walls for substantial distances. Confined meandering streams may also migrate downvalley. In the case of Dovedale, downstream migration of meander bends has resulted in the abandonment of valley scars, thus forming the several relict scars referred to above. Confined meandering has been described by Lewin and Brindle (1977) and Milne (1983) from other upland valleys in Britain.

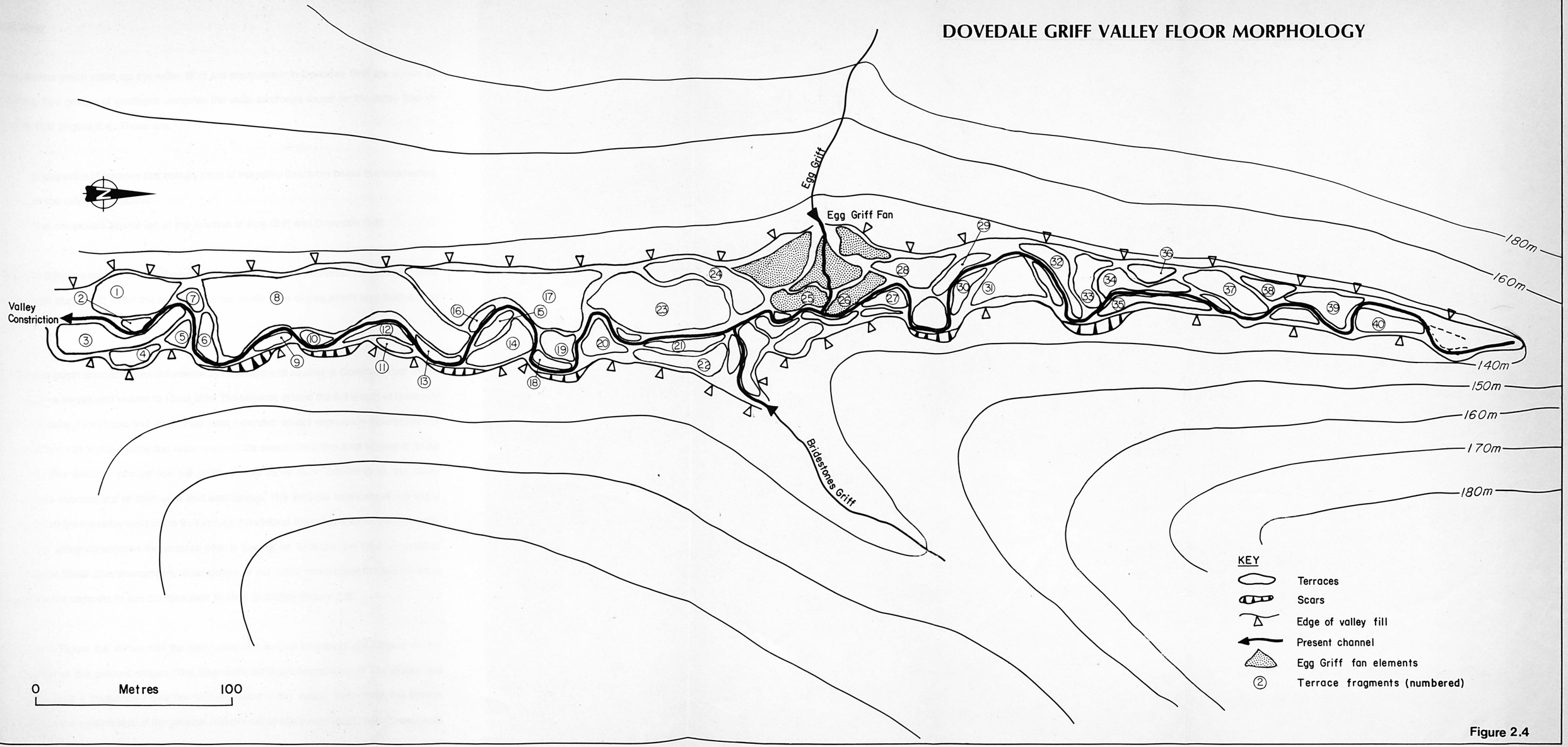

DOVEDALE GRIFF VALLEY FLOOR MORPHOLOGY
N
Egg Griff
Egg Griff Fan
Valley Constriction
Bridestones Griff
180m
160m
140m
150m
160m
170m
180m
0
Metres
100
KEY
Terraces
Scars
Edge of valley fill
Present channel
Egg Griff fan elements
② Terrace fragments (numbered)

Figure 2.4

Morphology

The landforms which make up the valley fill of the study reach in Dovedale Griff are shown in Figure 2.4. Two groups of landforms comprise the main landforms found on the valley floor in Dovedale Griff (Figure 2.4). These are:

1. A sequence of terraces that occupy most of the valley floor from below the headwaters to the valley constriction;
2. The compound alluvial fan at the junction of Egg Griff and Dovedale Griff.

The Egg Griff fan is a steeply sloping cone comprised of several fan elements. The outer fan units have a mean slope of 6° whilst the several inset fan levels have slopes which vary from 4.5° to 2.2°.

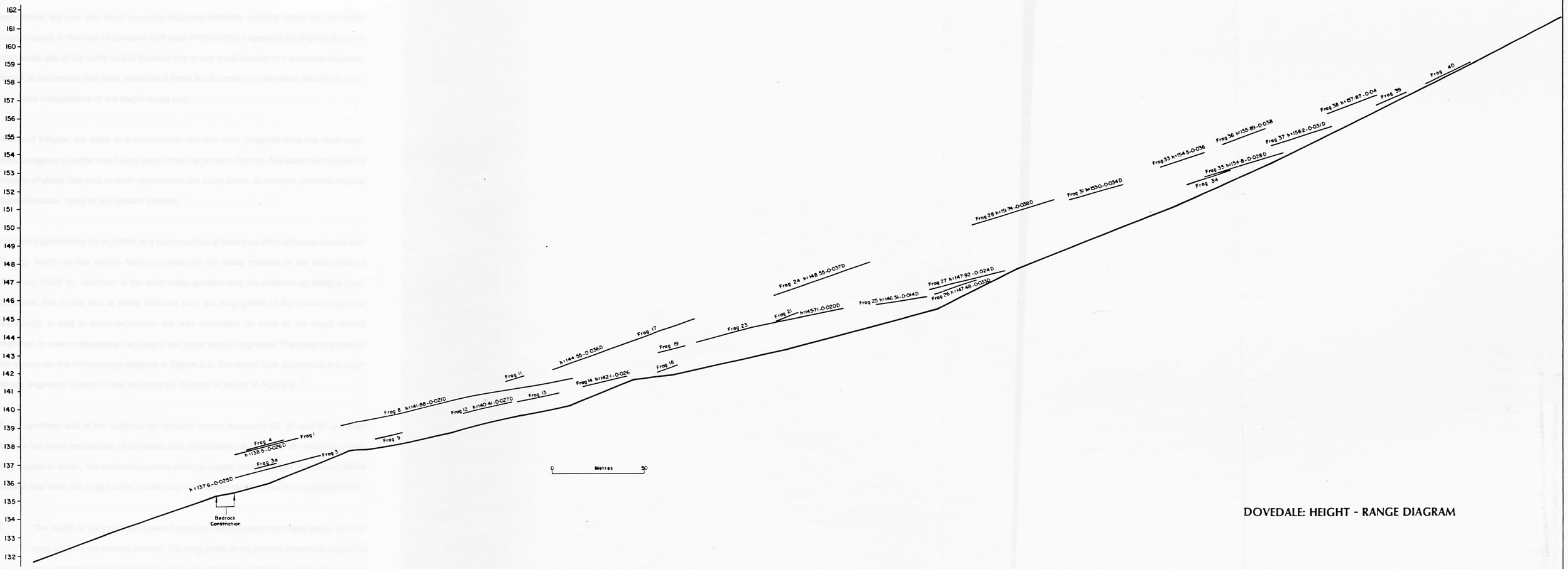
The terraces begin downstream of the narrow incised rock wall section of Dovedale Griff where the valley floor begins and widens to about 20m. The terraces extend the full length of Dovedale Griff to the valley constriction and attain their most extensive spatial expression downstream of Egg Griff (Plate 2.2). In this middle and lower reach of the stream the valley floor widens to about 40 - 55m. The terraces occupy the full width of the valley floor extending to the valley floor/hillslope intersections of both west and east slopes. The terraces terminate at the valley constriction where the valley walls of the Griff reduce the width of the valley floor to approximately 15m. At the valley constriction the present river is flowing on bedrock, the bedrock outcrop continuing for about 20m downstream. Downstream of the valley constriction the stream flows through terrace deposits to join the east-west flowing Staindale (Figure 2.3).

Reference to Figure 2.4 shows that the most extensive terrace fragments are located on the western side of the present stream. The fragments on the western side of the stream are extensive in both a downstream direction and in a cross valley sense. Conversely, the terrace fragments on the eastern side of the present channel are spatially restricted both downstream

and in cross valley direction. This spatial distribution of the terrace fragments in the main section of the valley floor is the result of the progressive migration of the stream towards the east side of the valley, incising through the deposits of the alluvial fill in the process.

Data from the detailed levelling survey of the Dovedale Griff terrace fragments was used to construct a height-range diagram of the Dovedale terrace fragments. This was undertaken to determine the relative heights of each fragment above present river level and to examine any changes in the valley slope or maximum slope of the stream over the time period represented by the terrace surfaces. A height-range plot represents a projection plane on which the heights of the terrace fragments are plotted. Distance is plotted on the x axis and height is plotted on the y axis. The height-range diagram shown in Figure 2.5 was constructed following the procedure outlined by Kirby (1969), ensuring that the vertical plane onto which the height points were projected was parallel with the long axis of the terrace fragments. Most of the terrace fragments in Dovedale Griff follow elongated alignments parallel to the valley axis of Dovedale Griff which is almost exactly north-south. This was therefore used as the projection plane for the height points of the terraces.

Several of the terrace fragments that were located closest to the present river level were not included on the height-range diagram. These included the small terrace fragments bordering the present channel in the vicinity of the scars shown on Figure 2.4. As can be seen from Figure 2.4 the alignment of these terrace fragments more closely matches that of the present meandering stream. As lines of levels for these few terrace fragments could not be aligned along the north-south baseline for the height-range diagram they were not plotted onto the height-range diagram. Unless the line of levels for the terraces is parallel to the projection line, the projected height points will give a series of points on the height-range diagram for which the best fit line will be steeper than that measured in the field (Kirby, 1969). For small differences in direction the projection error will not make a large difference to a best fit slope. However, Kirby has shown that for a deviation of 30° the projected slope would be increased by one seventh of the original slope measured in the field. Such errors not only make calculation of relative height above present river



DOVEDALE: HEIGHT - RANGE DIAGRAM

FIGURE 2.5

level difficult, but may also result in terrace fragments artificially crossing others on the height-range diagram. In the case of Dovedale Griff most of the terrace fragments are aligned along the north-south axis of the valley so this involved only a very small number of the terrace fragments closest to the present river level. Absence of these small number of fragments should not effect the overall interpretation of the height-range plot.

Measured heights, 5m apart in a downstream direction were projected onto the north-south projection plane together with height points from the present channel. The latter were plotted at intervals of about 20m and as such approximate the valley slope, or steepest possible channel slope (Richards, 1982) of the present channel.

A terrace fragment may be regarded as a plane surface, at least for a short distance downstream (Culling, 1957). As the terrace fragment preserves the valley gradient of the prior channel (Richards, 1982) an estimate of the prior valley gradient may be obtained by fitting a linear regression line to the line of levels obtained from the long profile of the terrace fragment. Accordingly a best fit linear regression line was calculated for each of the larger terrace fragments in order to determine the slope of the larger terrace fragments. The linear regressions are shown on the height-range diagram in Figure 2.5. The valley floor location of the larger terrace fragments plotted on the height-range diagram is shown in Figure 2.4.

At the upstream end of the height-range diagram terrace fragments 35, 37 and 38 converge towards the steep headwaters of Dovedale Griff. Downstream of fragment 35, where the valley floor begins to widen, the terrace fragments attain a greater vertical height distribution above present river level. The height of the terrace fragments above present river shows several trends:

1. The height of the individual terrace fragments above present river level varies with the long profile of the present channel. The long profile of the present channel is controlled by a series of local baselevels which are outcrops of bedrock at the base of the valleyside scars. Downstream of each local baselevel the long profile of the stream

steepens so that the relative height of the terrace fragments above present river level locally increases. As a result of this the height of a terrace fragment may vary by as much as 0.5m from its upstream to its downstream end.

2. A series of relatively high terrace fragments dominate the upstream and middle portions of the height-range diagram. These fragments, including fragment numbers 36, 33, 31, 28, 24, 17 and 11, are steeply sloping with valley slopes that vary locally from 0.034 to 0.038. These terrace fragments vary in height above present river level from 2m for fragment 36 at the upstream end of the diagram to 3.25m above present river level for fragment 24. Fragments 17 and 11, which represent the downstream fragments of this high terrace group are about 2-2.25m above present river level.

3. Set below the level of this group of higher terrace fragments are a series of lower level fragments. The gradients of the lower terrace fragments are locally variable, but overall exhibit a marked reduction in gradient from the valley slopes of the higher terrace fragments. The lower level terrace fragments have valley slope gradients which vary from about 0.02 to 0.028. The lower terrace fragments vary in height above river level from about 1.6m to 0.75m.

4. As a consequence of the reduction in terrace gradient between the high terrace fragments and the lower level fragments, the high terrace fragments 17 and 11 converge towards the lower level fragment 8. There is thus a contrast in the terrace sequence observed between a given cross section upstream of terrace fragment 17 and downstream of fragment 11. Upstream of terrace fragment 17 there are sometimes three terrace levels present. However, downstream of fragment 11 there are consistently only two terrace levels present.

5. As a consequence of the spatial distribution of the terrace fragments on the valley floor (Figure 2.4) the terrace fragments are usually unpaired, although the terrace fragments 1 and 4 and 3a and 3 at the downstream end of the diagram are paired.

Bank exposures coupled with excavations through the terrace deposits made during the course of soil pit digging revealed that the deposits making up the terrace fragments are massively-

bedded, imbricated gravels with no obvious differences between the higher and lower terrace fragments. The gravels are matrix supported with the matrix deposits being comprising of fine sand. Gravel accounts for between 30-80% of the terrace deposits, thereby placing them in the sG (sandy gravel) textural class in the textural classification of Folk (1974). Clast sizes measured from the gravels excavated from soil pits varied in size with a range of D50 from 26mm - 58mm and D84 between 40mm - 125mm. In the stream cut sections the sediments showed some lateral variation in the relative proportions of sand and gravel. There is no evidence of fining upwards cycles in the sediments with the sandy gravel facies extending to the surface of the terrace deposits at all levels above the present river.

2.2.6 Vegetation

The vegetation in the wider reach of the valley floor in Dovedale is dominated by coarse Agrostis - Festuca grassland (see Plate 2.2). Wetter areas also support various members of the Umbelliferae and Liliaceae family, and along the stream banks and floodplain Carex sp., water mint (Mentha aquatica) and marsh-marigold (Caltha palustris) are found. The floodplains also support a few shrubs, most notably the dog rose (Rosa canina). On some of the higher alluvial surfaces there occur isolated birch (Betula pubescens) and hawthorn (Crataegus monogyna) individuals, occasionally growing above a mixed ground flora of grass Agrostis sp., bracken (Pteridium sp.), bilberry (Vaccinium myrtillus) and heather (Calluna vulgaris). In the much narrower upper reach of the Dovedale valley, and in Bridestones Griff (see Plate 2.1), the floodplains are vegetated predominantly with sedges (Carex sp.) Further upstream where there is no floodplain, the sheltered lower slopes just above the rock walls in both Dovedale and Bridestones Griff support relatively dense stands of birch (Betula pubescens) with some alder (Alnus glutinosa).

Downstream of Egg Griff, the western slope of Dovedale supports an area of oak woodland, with a ground flora dominated by Vaccinium myrtillus and Holcus mollis (Creeping Soft-grass). Upstream of Egg Griff, which itself supports a small copse of oak (Quercus sp.) and sycamore

(Acer psuedoplatanus), the valley slopes are covered by Pteridium sp., Vaccinium myrtillus and Calluna vulgaris (see Plate 2.2).

The southern end of the eastern valley slope above Dovedale supports a mixed woodland of firs, conifers, oak and ash (Fraxinus excelsior). This rapidly gives way to a Vaccinium - Calluna flora, with a few scattered birch and rowan (Sorbus aucuparia). This vegetation assemblage is co-dominant with extensive areas of Pteridium sp. on the plateau top to the east and north of Dovedale and Bridestones Griff (see Plate 2.3).

The plateau top to the west of Dovedale has been reclaimed for agriculture, and at present supports pastureland in which there is a complete absence of trees and shrubs.

2.3 Jugger Howe Beck

2.3.1 Location

The study reach in the valley of Jugger Howe Beck (Grid Reference NZ 923002) is located towards the eastern margin of the central Moors, 6km southwest from the village of Robin Hood's Bay and 16km northwest of Scarborough (see Figure 2.1). Jugger Howe Beck is a major south flowing tributary to the upper reaches of the River Derwent. The confluence of Jugger Howe Beck with the Derwent is 13km downstream from the study reach. The study reach, shown in Figure 2.6, is 425m long and starts 100m upstream of the confluence of the Hollin Gill with Jugger Howe Beck (see Plate 2.4). The downstream limit of the reach is marked by a boundary fence which crosses the valley floor. The grid reference of the upstream limit is NZ 922003 and the downstream limit is NZ 925000. The downstream extension of the study reach out of shot to the left in Plate 2.4 is shown in Plate 2.5.

Hollin Gill is the only tributary entering Jugger Howe Beck in the study reach (see Figure 2.6), and is a steeply incised second-order headwater stream 1.3km in length which enters the western

JUGGER HOWE BECK: STUDY REACH, CATCHMENT AREA, GEOLOGY, TOPOGRAPHY AND DRAINAGE

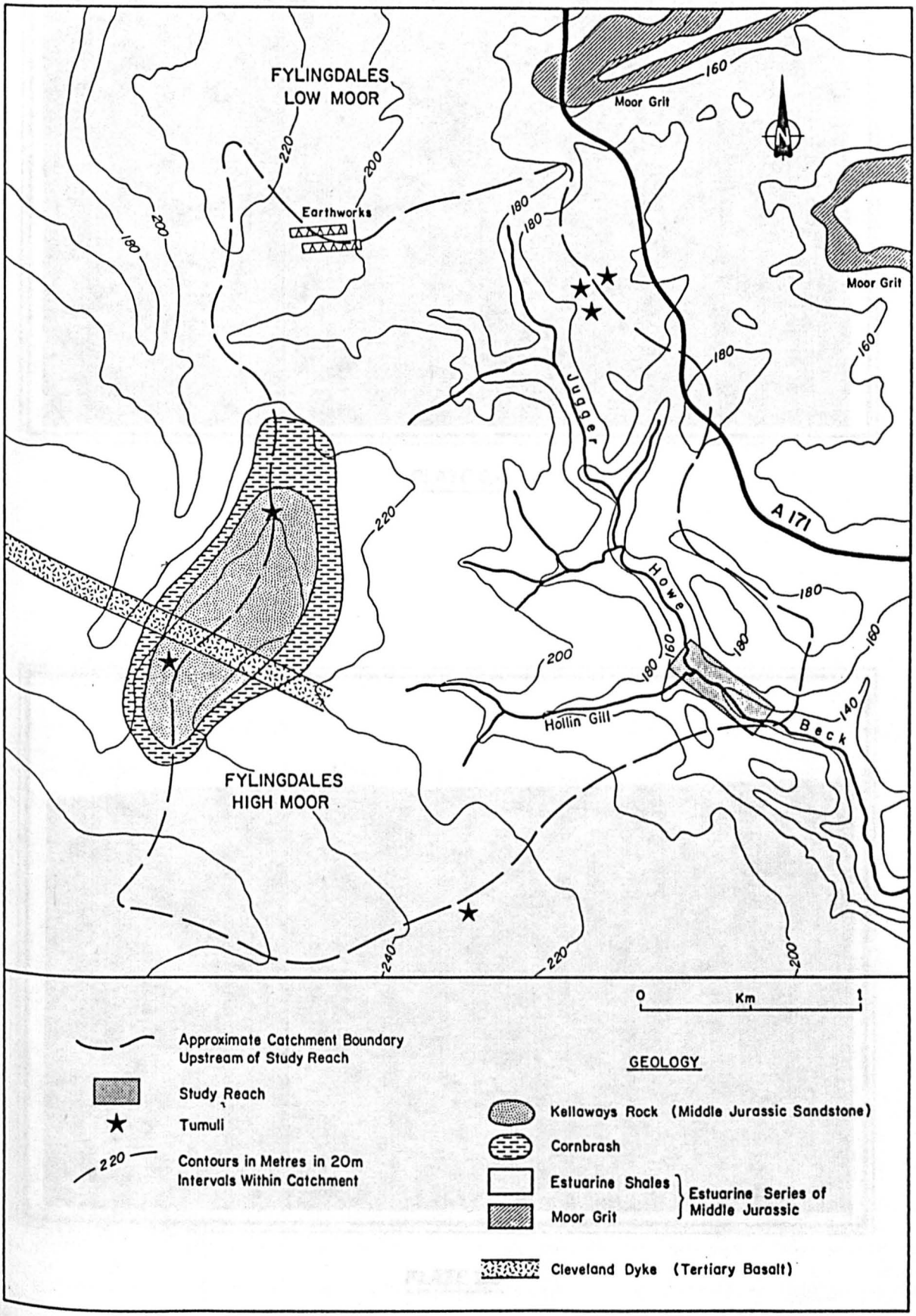


Figure 2.6



PLATE 2.4



PLATE 2.5

side of Jugger Howe Beck valley. The confluence is shown in the right of Plate 2.4. At the study reach, Jugger Howe Beck is a third order stream which flows south in a deeply incised valley. The valley floor varies in width between 50 - 85m, and lies at an altitude of 138 - 145m. The valley floor is therefore incised approximately 25m - 40m below the break of slope at the top of the valley sides, which are at an altitude of 180m.

The catchment above the study reach has an area of approximately 6.25km^2, with the greater proportion of the catchment extending westward onto Fylingdales High Moor. The catchment's eastern boundary is marked by the ridge which separates the valley from the A171. The northern catchment boundary is less distinct due to an extensive area of boggy ground with ill-defined natural drainage lines (see Figure 2.6). Above the steep valley sides of Jugger Howe Beck and Hollin Gill, the catchment is comprised of moderately sloping terrain with broad interfluves between a number of very small, gullied first-order headwater tributaries, upstream of the study reach.

2.3.2 Geology

The solid geology in the Jugger Howe Beck study reach is considerably simpler than that found in Dovedale. The shales of the Estuarine Series extend over the whole area, with relatively thin (2 - 3m) flaggy sandstones outcropping, often at the breaks of slope above valley sides. Sandstone is found in such topographic situations on the western side of Jugger Howe Beck and in Hollin Gill, but also occasionally lower down the valley side slopes. This is shown in Plate 2.6. On the western margin of the catchment is a small outlier of upper Jurassic Kellaways Rock, fringed by a narrow Cornbrash outcrop. The outlier is bisected by a Tertiary basalt dyke, forming the southeastern extremity of the Cleveland Dyke.



PLATE 2.6



PLATE 2.7

2.3.3 Valley Side Slopes

The valley side slopes show considerable evidence of landslip activity. Throughout the study reach there are many old, stabilised slips which are now vegetated, as shown in Plate 2.7. At present there is only one slip, at the downstream end of the reach, which is sufficiently recent to have remained unvegetated. The slips' primary mechanism of formation appears to be the overlying sandstone strata slipping down over the shales which outcrop further down the slopes. This is displayed occurring at present in Plate 2.8. In addition, slips also seem to have formed within the shale outcrop, possibly as a result of smaller variations in permeability concentrating percolating water along potential slip planes. This would appear to be the cause for the most recent slip, as there is no overlying sandstone strata involved in this example. In Hollin Gill there are extensive areas of bare shale slopes (see Plate 2.9), often with large sandstone slabs slipping down the slope face.

2.3.4 Valley Fill Landforms and Stratigraphy in Jugger Howe Beck

The Present Channel

The present channel of Jugger Howe Beck has incised to the base of the thin valley fill along most of the study reach, and in some places is flowing on bedrock (see Plate 2.6) or huge slabs of sandstone that had fallen from the valley sides. This process of progressive stream incision through fill deposits is suggested to be characteristic of the Holocene where progressive stream incision may eventually result in the locking of upland channels into bedrock (Ferguson, 1981; Harvey et al., 1984). The stream is bordered intermittently by low floodplain elements (see Plates 2.4 and 2.5) about 0.5m above present river level and small lateral bars made up of fine gravel and pebbles. The valley slope of the reach is 0.019.

In the upstream portion of the study reach, (upstream of the Hollin Gill confluence) Jugger Howe Beck displays a confined meandering pattern under Ferguson's (1981) classification scheme



PLATE 2.8



PLATE 2.9

with the meanders pushed over to the western side of the valley by large, vegetated debris flow deposits on the eastern side of the valley. Immediately downstream of the two confined meanders (Figure 2.7) the stream is pinned to the eastern valley side wall. Downstream of the confluence with Hollin Gill the stream is confined by bedrock for about 15m whilst along the remainder of the study reach the stream assumes a relatively straight course flowing on either outcrops of bedrock, huge slabs of bedrock which have fallen from the valley sides, or on boulders and large cobbles. The stream has a stepped profile for much of its course in the study reach. Under Ferguson's (1981) classification the present channel would fall into his category of inactive channels with such channels characteristically possessing a stepped profile and rectangular cross-sections, these being wider at pool sections.

Hollin Gill would also be classed as an inactive channel with the stream flowing over bedrock in its upper reach. This is stepped with small falls separated by relatively deep bouldery pools (see Plate 2.9) Downstream of the apex of the fan the stream flows on large boulders and cobbles again with a stepped profile. Hollin Gill follows a west- east course until it reaches the toe of the fan elements where it turns sharply to follow a north-south course for about 40m. The stream then turns sharply to follow a west-east course to its confluence with Jugger Howe Beck, shown in Plate 2.6.

The landforms which make up the valley fill of the study reach in Jugger Howe Beck are shown in Figure 2.7. Three groups of landforms make up the main landforms found on the valley floor in Jugger Howe Beck. These are:

1. The landform elements of the Hollin Gill fan in the upper section of the study reach and a small terrace at the toe of the Hollin Gill fan;
2. A degraded bench which hugs the valley side along the western wall of the study reach, both upstream and downstream of the Hollin Gill fan;
3. A low terrace downstream of the Hollin Gill confluence.

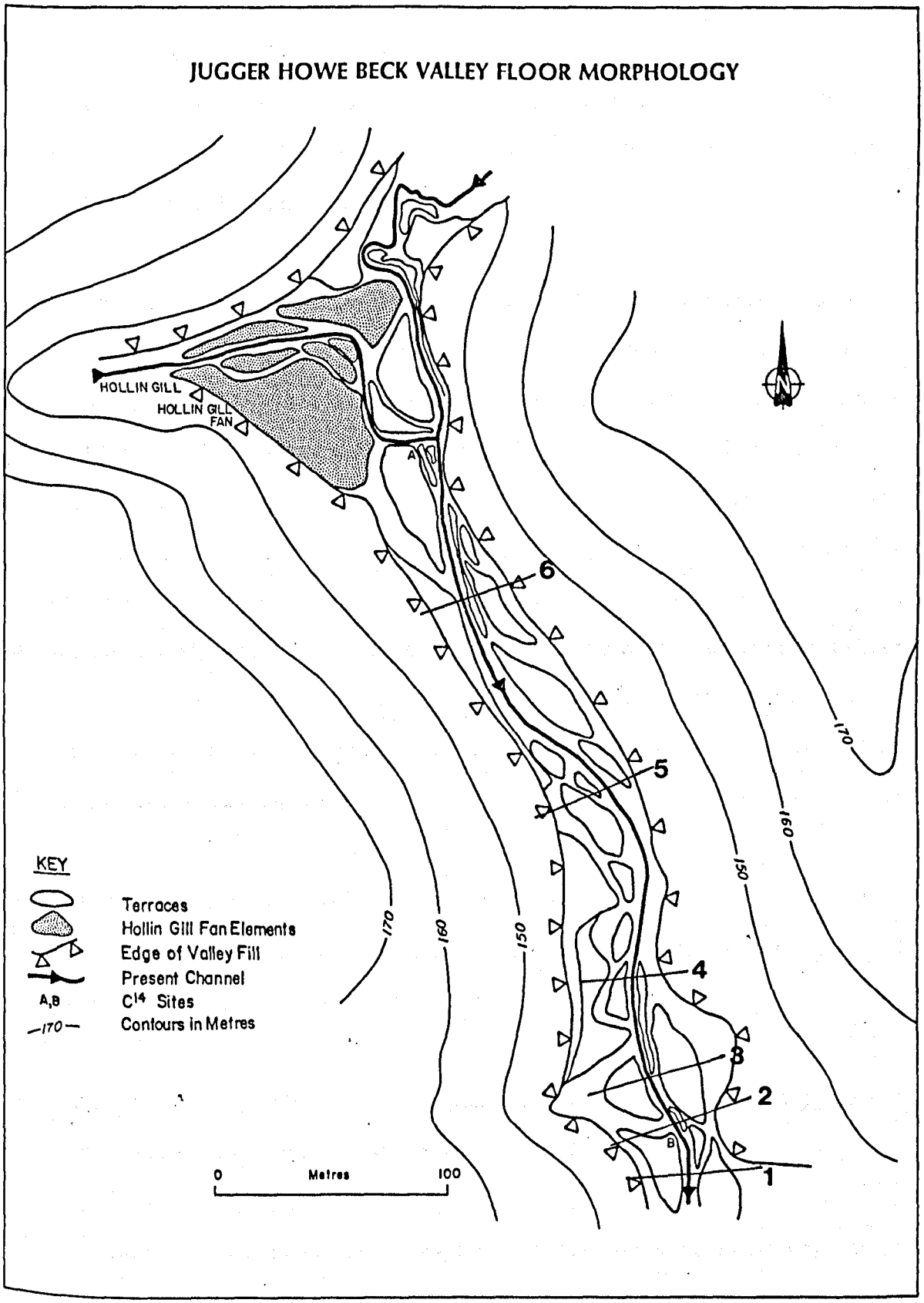

JUGGER HOWE BECK VALLEY FLOOR MORPHOLOGY
HOLLIN GILL
HOLLIN GILL FAN
N
6
5
4
3
2
1
A
B
170
160
150
170
160
150
KEY
Terraces
Hollin Gill Fan Elements
Edge of Valley Fill
Present Channel
A,B C14 Sites
170 Contours in Metres
0 Metres 100

Figure 2.7

The Hollin Gill fan is a compound feature with the main fan unit being located on the southern side of the west to east flowing section of Hollin Gill. The main fan unit has a mean gradient of 4°. The toe of the main fan unit fan abuts a small terrace fragment with an infilled palaeochannel separating the toe of the fan from the gravelly terrace deposits. Inset below the surface of the main fan unit is a lower fan with palaeochannel alignments visible on its surface. Elements of the lower inset fan are found on both the northern and southern sides of the present Hollin Gill channel. The lower fan has a mean gradient of 2.2°.

Exposures through the trimmed margin at the north side of the fan and the erosional bluff at the eastern edge of the fan indicate that the fan is made up of at least two main facies types. These are matrix rich (silt and clay) deposits supporting angular clasts and blocks of bedrock and clast supported fluvial cobbles and gravels. The lower fan unit is comprised of imbricated cobbles set in a sandy matrix.

The degraded bench, visible on the right of Plate 2.5 beneath the drystone wall, that is found along the western edge of the valley floor rarely exceeds a cross valley distance of more than about 15m and is usually only 2-3m in width. This upper bench is located at the western valley side/valley floor junction. The eastern margin of the bench is degraded and is seldom more than 0.5m higher than the adjacent low terrace.

The low terrace downstream of the Jugger Howe constriction occupies most of the valley floor (see Plates 2.4 and 2.5). The low terrace is comprised of a series of well defined bar and channel complexes which have an overall valley slope of 0.023.

As discussed in Chapter 1, a height-range diagram was not constructed for the Jugger Howe Beck study reach for several reasons. These reasons included:

1. Much of the upper part of the study reach consists of the extensive tributary junction with a smaller inset fan below the main fan surface; the gradients and relative heights

above present level could not be compared with those of the alluvial surfaces downstream of the bedrock constriction;

2. The upper bench is very degraded making accurate heighting difficult;

3. There is considerable variation in direction of the maximum down valley slope of some of the bar and channel complexes which make up the low terrace so for the reasons outlined by Kirby (1969) and discussed above, some of the gradients of these bars would be artificially steepened.

For these reasons the detailed levelling data obtained during the survey of Jugger Howe Beck were used to construct a series of cross profiles for the reach of Jugger Howe downstream of the bedrock constriction. These cross-sections are shown on Figures 2.8A and 2.8B, with the location of the cross-sections being shown on Figure 2.7. During the course of the excavation of the soil pits used in the surface soil stratigraphy for Jugger Howe Beck, it became clear that, unlike the valley fill sediments in Dovedale Griff, there is variation in the sedimentary units which make up the landforms of the valley fill. For this reason the stratigraphy of the valley floor surfaces is also shown on Figure 2.8A and 2.8B. Dashed lines indicate the approximate boundaries of the sedimentary units.

Several morphological and sedimentological trends can be recognised in the cross-sectional diagrams given in Figures 2.8A and 2.8B.

Morphology

The morphological units making up the valley floor landforms in the study reach downstream of the bedrock constriction include the upper bench and the low terrace bar and channel complexes. The cross-sectional plots show that there is only a very small relative height difference between the upper bench and the abutting low terrace, with the degraded margins of the upper bench frequently grading onto the low terrace. Cross-sections 4 and 6 show a scarp height of about 0.5m for the upper bench whilst cross-sections 1, 2 and 3 show very little height

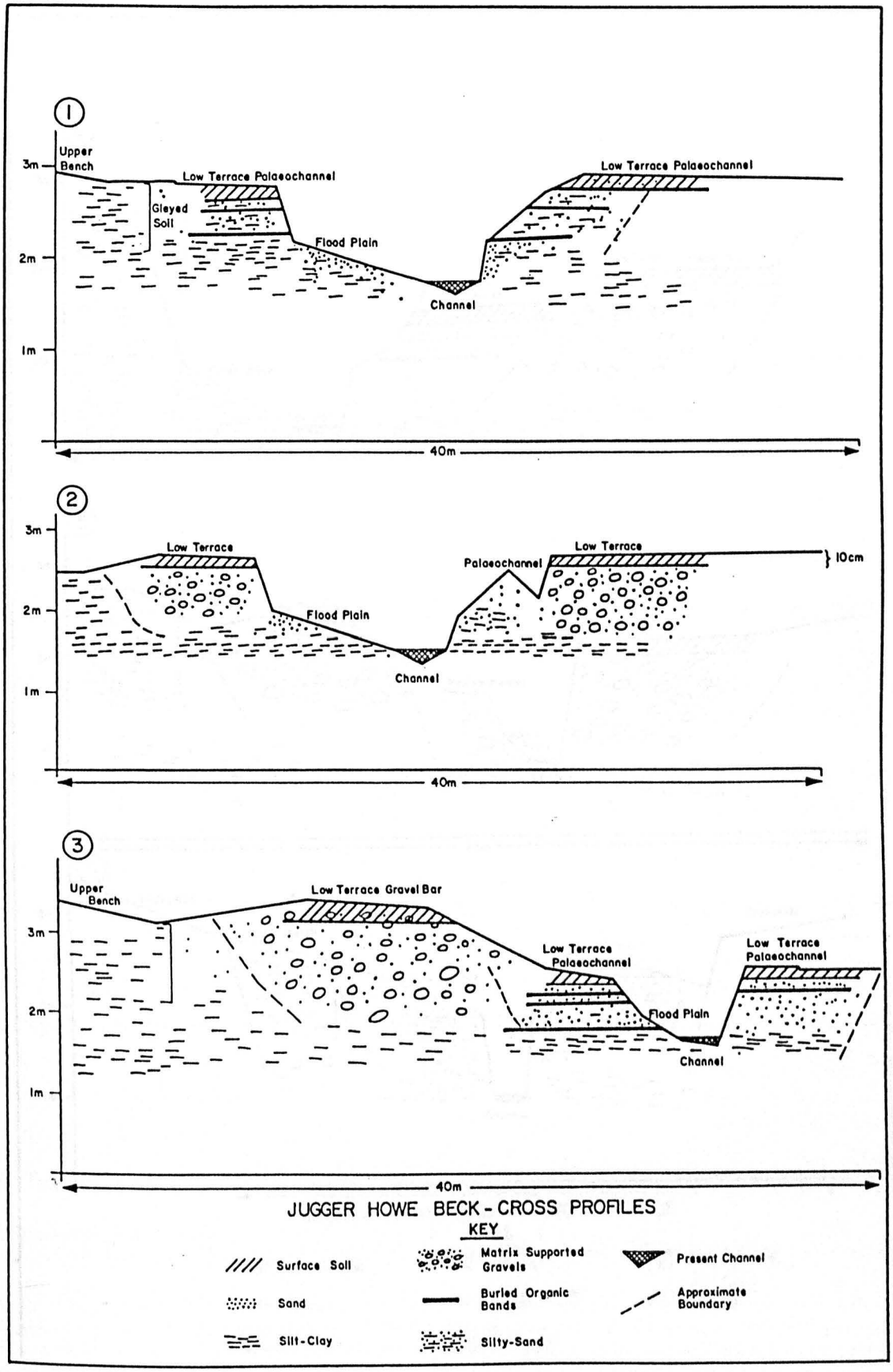

1
Upper Bench
3m
Low Terrace Palaeochannel
Gleyed Soil
Flood Plain
2m
Channel
Low Terrace Palaeochannel
1m
40m
2
3m
Low Terrace
Palaeochannel
Low Terrace
10cm
Flood Plain
2m
Channel
1m
40m
3
Upper Bench
Low Terrace Gravel Bar
3m
Low Terrace Palaeochannel
Low Terrace Palaeochannel
2m
Flood Plain
Channel
1m
40m
JUGGER HOWE BECK - CROSS PROFILES
KEY
Surface Soil
Matrix Supported Gravels
Present Channel
Sand
Buried Organic Bands
Approximate Boundary
Silt-Clay
Silty-Sand

Figure 2.8A

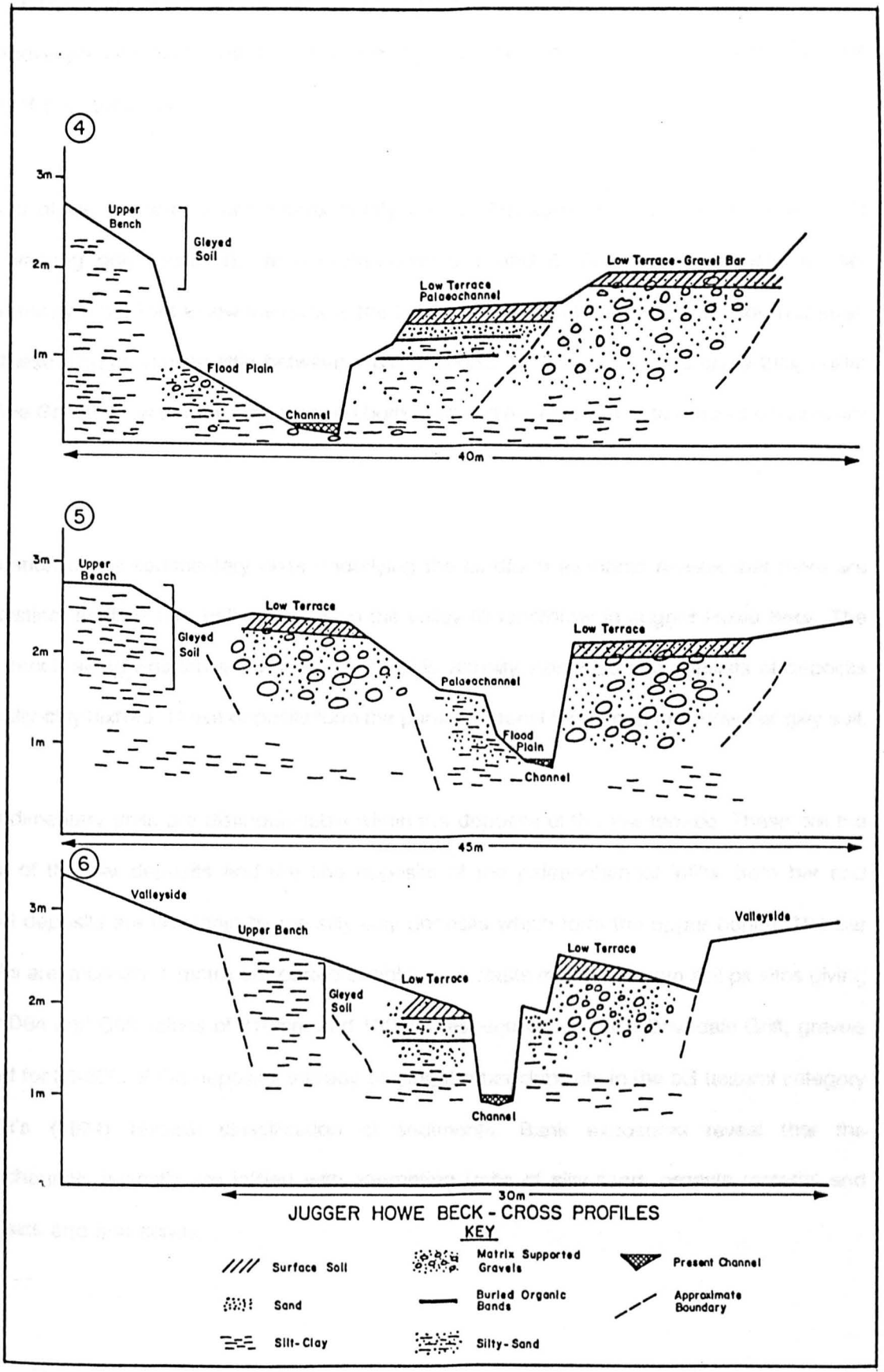

4
3m
2m
1m
Upper Bench
Gleyed Soil
Flood Plain
Channel
Low Terrace Palaeochannel
Low Terrace - Gravel Bar
40m
5
3m
2m
1m
Upper Beach
Gleyed Soil
Low Terrace
Palaeochannel
Flood Plain
Channel
Low Terrace
45m
6
3m
2m
1m
Valleyside
Upper Bench
Gleyed Soil
Low Terrace
Channel
Low Terrace
Valleyside
30m
JUGGER HOWE BECK - CROSS PROFILES
KEY
Surface Soil
Sand
Silt-Clay
Matrix Supported Gravels
Buried Organic Bands
Silty-Sand
Present Channel
Approximate Boundary

Figure 2.8B

difference between the low terrace and the upper bench. The upper bench is approximately 2m-2.5m above present river level, this representing the maximum depth of the valley fill in this section of the study reach.

The bars of the low terrace are approximately 1.75m-1.5m above present river level, with this height varying only locally between cross-sections 1 and 6. The palaeochannels are set approximately 0.5-0.75m below the level of the bars and are about 1m above present river level, again these heights varying little between cross-sections. The cross-sections show that, unlike Dovedale Griff, the low terrace fragments on both west and east banks of the present channel are paired.

Examination of the sedimentary units underlying the landform elements reveals that there are three distinct sedimentary units making up the valley fill landforms in Jugger Howe Beck. The upper bench along the western edge of the valley fill is virtually stoneless and consists of deposits with a silty-clay texture. These deposits form the parent material for a deep groundwater gley soil.

Two sedimentary units are distinguishable within the deposits of the low terrace. These are the gravels of the bar deposits and the fine deposits of the palaeochannel infills. Both bar and channel deposits are underlain by the silty-clay deposits which form the upper bench. The bar deposits are imbricated, matrix supported cobbles with clasts measured from soil pit sites giving typical D84 and D50 values of 210mm and 130mm respectively. As with Dovedale Griff, gravels account for 30-80% of the deposits, thereby placing the bar deposits in the sG textural category of Folk's (1974) textural classification of sediments. Bank exposures reveal that the palaeochannels typically are infilled with alternating units of silty-sand, organic material and sandy silts and fine sands.

2.3.5 Vegetation

Apart from the fan surface at the Hollin Gill confluence, the vegetation (see Plates 2.4 and 2.5) in the study reach valley floor is dominated by bracken (Pteridium sp.) and heather (Calluna vulgaris), with some mat-grass (Nardus stricta). In occasional very wet areas, formed in some palaeochannels and along spring lines at the base of old slips, various species of sedge (Carex sp.) including cotton grass (Eriophorum sp.) occur with some cross-leaved heath (Erica tetralix). The only trees are a few birch (Betula pubescens), growing in one small area on the higher surface towards the downstream end of the study reach. The Hollin Gill fan surface is dominated by bracken (Pteridium sp.) with Calluna (Calluna vulgaris) occupying low scarp edges (see Plate 2.6)

The western valley side slopes in Jugger Howe Beck are vegetated by a mixed heather (Calluna vulgaris) and bracken (Pteridium sp.) community. By contrast the eastern slopes are almost entirely covered by bracken, with the exception of the bluff above the Hollin Gill confluence where heather (Calluna vulgaris) occurs (see Plate 2.6). Above the valley floor, the catchment vegetation is dominated by heather (Calluna vulgaris) to the west of Jugger Howe Beck and bracken (Pteridium sp.) to the east.

2.4 Topographic Survey of Valley Floor Landforms

The valley floor landforms in Dovedale and the Jugger Howe Beck study reach were surveyed using the methods recommended by Pugh (1975). In both valleys, surveying was conducted on a grid which had a spacing interval of 5m longitudinal by 2.5m transverse to the valley line. A combined Kern DKM2-A 1" theodolite with infra-red electronic distance meter (EDM) was used for the surveys.

In Jugger Howe Beck, the survey was not tied into Ordnance Survey datum and was used to provide data on the distribution of the valley floor landforms and their relative heights above stream level only.

In Dovedale the survey was related to Ordnance Survey datum by using the 130m contour line which crosses the Dovedale Griff - Staindale Beck confluence. The survey grid referred to above was constructed upstream of the bedrock constriction marking the junction with Staindale. The survey was extended to include stratigraphic details of the section at the site of the C_{14} dated wood (Richards 1981) near the Staindale confluence. The survey data from Dovedale was used to construct the height-range diagram shown in Figure 2.5.

2.5 Lake Gormire

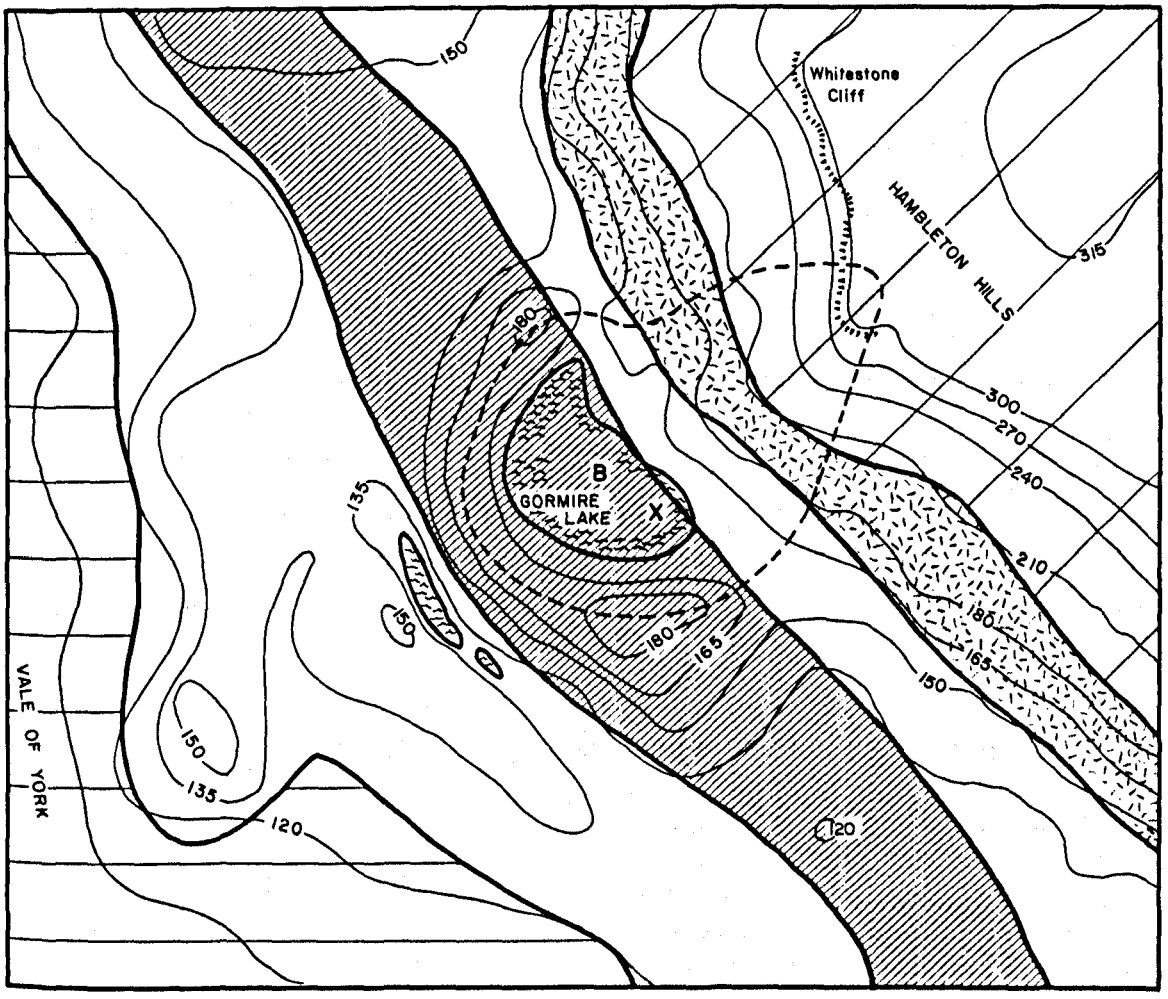
2.5.1 Location

Lake Gormire (SE 503832) is located 7.5km east of Thirsk at the junction of the Vale of York and the North York Moors uplands (see Figure 2.1). It is situated below the high scarp which marks the western edge of the North York Moors uplands (see Plate 2.10). The scarp is formed in the Hambleton Hills, a southwesterly extension of the Corallian Tabular Hills. The lake, lying at an altitude of 160m is 140m below the scarp crest (see Figure 2.9).

2.5.2 Catchment Geomorphology

Lake Gormire is thought to occupy an ice-marginal meltwater channel, carved during the Late Devensian when the Vale of York ice abutted against the Hambleton escarpment (Kendall and Wroot, 1924). Downstream damming of the meltwater channel to form the lake is considered to have taken place when retreat of the ice at the end of the Late Devensian triggered landslips from the scarp face. Beckett (1975) provided a C14 date of 13,045 +/- 270 bp for the disappearance of ice from Holderness in East Yorkshire, and Jones (1976) dated ice retreat from Seamer Carrs

LOCATION AND GEOLOGY OF THE LAKE GORMIRE AREA



—120— Contour heights in metres

– – – Approximate boundary of lake catchment

B Site of Blackam *et al.*'s (1981) main core

X Site of core for this study

0 metres 350

GEOLOGY KEY

- Middle Calcareous Grit and Lower Limestone (Corallian Series)
- Oxford Clay
- Estuarine Shales
- Moor Grit

  } Estuarine Series (Middle Jurassic)

- Liassic Mudstone

Figure 2.9



PLATE 2.10

in the eastern Vale of Pickering to 13,042 +/- 140 bp. These dates suggest that the Vale of York adjacent to Gormire was free of ice sometime around 13,000 bp, which suggest that Lake Gormire formed soon after that date.

The lake has a small catchment (see Figure 2.9) of approximately 0.3km^2 delimited to the east by the scarp of the Hambleton Hills and to the west by the low ridge of Gormire Rigg. It is likely that the northern catchment boundary has been formed by a landslipped mass from the scarp of Whitestone Cliff, similar to the southern landslip which is thought to have resulted in the formation of the lake. Although the Hambleton scarp forms the eastern boundary to the lake's catchment (see Plate 2.11) the scarp face does not directly abut the eastern edge of the lake itself. The scarp is 350m - 400m to the east of the lake, with the terrain in between comprised of a talus slope of rock fall material at the base of the scarp, which grades into a gently sloping area that extends to the lake edge. This latter area is best developed to the northeast of the lake, where it is almost 200m wide. At the location of the rockfall which dammed the southern end of the ice-marginal channel, the land similarly slopes gently towards the lake.

The western margin of the lake is marked by the narrow ridge of Gormire Rigg, which attains its greatest height of 180m at the north and south ends of the ridge (see Plate 2.10). The steep slopes of the Rigg descend directly to the western edge of the lake, with only a narrow 3m - 4m wide fringing low bank between the Rigg slopes and the lake edge.

There are no surface water inflows into Lake Gormire, and the only visible outflow occurs through a rock fissure near the centre of the eastern lake margin. The entrance to the outflow is choked with rocks and dense vegetation, and consequently it is very slow flowing. Blackham et al. (1981) found that the lake sediment-water interface lies at a depth of approximately 6.0m.

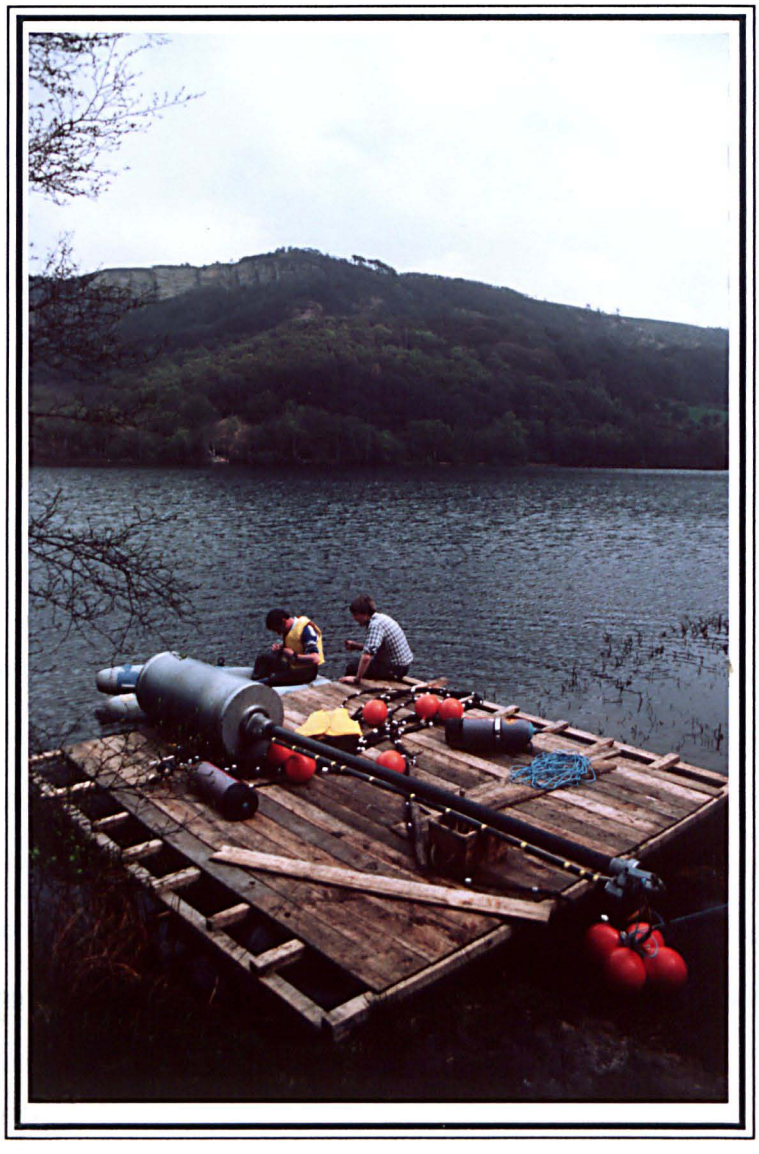


PLATE 2.11

2.5.3 Solid Geology

The lake catchment is underlain by a varied succession of Jurassic age rocks (see Figure 2.9), which increase in age from Upper Jurassic at the scarp crest to Middle Jurassic beneath the lake itself. The shear rock wall of Whitestone Cliff on the Hambleton scarp is comprised of the Corallian Middle Calcareous Grit and Lower Limestone outcrops. The situation of these massive sandstone and limestone strata above the underlying Oxford Clay and Estuarine Series shales lower down the scarp results in undercutting and periodic rockfalls from the top of the scarp. A thin outcrop of Middle Jurassic Moor Grit of the Estuarine Series outcrops below the lake and extends west to form Gormire Rigg.

2.5.4 Soils and Vegetation

The catchment soils are dominated by the gently and steeply sloping phases of the Firby series, and the Long Load series (Bendelow and Carroll 1979). The Firby series soils are typical brown earths which have a coarse loamy texture. The steeply sloping phase occupies the scarp foot slopes, and the gently sloping phase is found on the slopes of Gormire Rigg and on the southern landslip plug. The Long Load series are pelo-stagnogleys, which have developed on the Estuarine shale outcrop which comprises the lower, flatter area of the catchment between the lake and the Hambleton scarp.

The southern area of the catchment supports a pasture-arable rotation, with some root cropping on the lighter Firby series. The flatter area between the lake and the Hambleton scarp is not cultivated, and is vegetated by willow (Salix sp.) and alder (Alnus glutinosa) scrub in the less well-drained areas. Adjacent to the northern corner of the lake is a small area of Phragmites swamp. On the lower slopes of the Hambleton scar, the steep phase of the Firby series supports the deciduous woodland of Garbutt Wood (see Plate 2.11). Gormire Rigg similarly supports a deciduous woodland with oak (Quercus sp.) and alder being the dominant species. At the top of the scarp, increasing exposure and decreasing soil thickness results in the vegetation being

dominated by hawthorn (Crataegus monogyna) scrub with a grass, bilberry (Vaccinium myrtillus) and rose bay willow herb (Epilobium angustifolium) undergrowth.

Chapter 3

Brown Podzolic Soils and the Surface Soil Stratigraphy of Dovedale Griff.

3.1 Introduction

Recent studies of Late Glacial and Holocene river terraces, alluvial fan sequences and valley fills in both lowland and upland areas have demonstrated the need to use a range of morphological, sedimentological, stratigraphic and soil stratigraphic data both to establish the sequence of landforms present on valley floors, and to estimate the age ranges of the landforms (see for example, Harvey et al., 1984; Macklin, 1985; Macklin and Lewin, 1986; Robertson-Rintoul, 1986). The adoption of such a wide range of techniques for the study of valley fills has occurred with the growing realisation that the aggradation and incision of the fill within a single basin is likely to be both spatially and temporally complex. As noted by Brakenridge et al. (1988) an areal, valley-wide stratigraphy may develop within a basin in response to regional environmental changes. Conversely, local site stratigraphies which form an integral part of the valley fill may develop when a within-system geomorphic threshold, such as an upstream meander cutoff, is crossed. The interpretation of the environmental signficance of stratigraphic units within an alluvial fill is made even more problematic when consideration is given to the significance of random, extreme events which may affect a single slope within a catchment at any time (Richards et al., 1987).

Reconstruction of the history of valley fill deposits must therefore be based on the careful subdivision and correlation of the deposits making up the fill, with correlations over short distances being essential to a detailed reconstruction of landscape development (Butzer, 1980). Any attempt to relate the correlated deposits to periods of known environmental change requires absolute dating evidence. However, in some valley fills material suitable for absolute dating may be scarce. This is particularly the case in coarse alluvial deposits such as those found in many fills and glacial deposits in upland valleys (Walker and Lowe, 1980), but has also been noted as a

problem in fine grained deposits in lowland valleys (Macklin, 1985). It is the scarcity of absolute dating material in valley fill deposits that has helped to contribute to the development of a range of relative dating techniques. These techniques, if used with care and with adequate age calibration from at least some sites, may be used to correlate deposits, bracket the age ranges of the landforms making up the valley fill and enable alluvial landforms to be related, however tentatively, to periods of known environmental instability and change.

Soils have long been regarded as important stratigraphic markers for the subdivision of Quaternary sediments, whether the soils are at the surface or are buried (Birkeland, 1974). The growing interest in the development and environmental significance of both glacial deposits and terraced valley fills which span the Late Glacial and Holocene time scale has lead to a number of investigations showing an increasing awareness of the ability of surface soil profiles to differentiate between stratigraphic units of different age (for example Mahaney, 1974, 1978; McDowell, 1983; Harvey et al., 1984; Robertson-Rintoul, 1986a). In these studies the relative degree of soil profile development of soils which form a chronosequence provides the basis for deriving soil-stratigraphic units which are then used as a tool for temporal control of deposits where radiometric or other methods of age determination are not available (Rockwell et al., 1985).

Discussion of the Dovedale Griff terrace sequence in Chapter 2 showed that the terrace fragments are developed in massive gravelly deposits set in a sandy matrix with little between fragment variation in terrace sediments. Height separation between the terrace fragments is small, often less than 1m, whilst the height of a terrace fragment above present river level may vary relative to the local baselevel controls imposed by the bedrock reaches of the present channel. Correlation of terrace fragments making up the valley fill deposits in Dovedale on the basis of sedimentology and relative height is therefore problematic. These difficulties in Dovedale are compounded by variation in the slope of the terrace fragments which has resulted in a differing number of terrace levels being present in the upstream and downstream reaches of the valley. In Jugger Howe Beck, although there are distinctive sedimentary units within the fill

deposits, the deposits lack sufficient material for radiometric dating to place the landforms on an absolute time scale and to correlate the landforms between successive cross-sections. In these situations quantitative soil-stratigraphic data may provide a means of correlating the fill deposits and arranging them in a relative age sequence. Some absolute dating control would also allow the landforms to be placed tentatively on an absolute time scale.

In order to interpret the development of the alluvial landforms that make up the valley fills in Dovedale Griff and Juggerhowe Beck,the phases of landform development associated with the evolution of the valley fills needs to be identified. The principal objectives of this and the subsequent chapter are therefore to establish the stratigraphic relationships between the surfaces making up the valley floor landforms and to place their development tentatively on an absolute time scale. The terrace fragments in Dovedale and the landform elements making up the fill deposits in Jugger Howe Beck are therefore grouped into surfaces of different relative age using quantitative surface soil-stratigraphic techniques.

In the present chapter, attention is directed mainly to the terrace deposits in Dovedale Griff and to the surface soil profiles developed into the terrace deposits. The soil profiles are grouped into surface soil-stratigraphic units using a combination of quantitative soil data and multivariate statistical analyses. Principal Components Analysis is used to abstract the main variance trends from the Dovedale Griff soil data set whilst the principal component scores for each soil profile are grouped to form the surface soil-stratigraphic units using a hierarchical clustering routine. The main characteristics of the surface soil-stratigraphic units are discussed. In the subsequent chapter attention is directed to providing some absolute dating control for the soil-stratigraphic units developed in Dovedale Griff as well as to the surface soil profiles developed into the landform elements which make up the valley fill in Jugger Howe Beck.

3.2 Soil Chronosequences, Soil Stratigraphy and Alluvial Landforms: Previous Studies

Mahaney (1974) states that soil development varies with the age of the deposit and thus provides a useful means of distinguishing land surfaces of different age. Soil-forming processes differentiate parent material, either rock or alluvial materials, from the surface downwards into horizons. As Jenny's (1941) well known function demonstrates:

$$S = f(T): Cl, O, R, P$$

(where S = soil, T = time, Cl = climate, O = organisms, R = relief and P = parent material) the same kind of horizons may form under similar genetic conditions whilst degree of soil formation will vary with the length of time the soil-forming processes have been operating. The identification of the variation of soil properties through time is carried out as a soil chronosequence study. If vegetation, topography, climate and parent material are held constant and if the age range of the soils is known, soil properties can be examined for systematic changes with soil age.

Soil chronosequence studies are frequently carried out on river terraces, alluvial fans, debris flows and glacial and glaciofluvial landforms such as moraine ridge sequences. These alluvial landforms provide ideal surfaces on which to carry out soil chronosequence studies as they are landforms which develop episodically and therefore are likely to carry soil profiles which are present in varying stages of development, both in their morphological and chemical properties.

Soil chronosequence studies have generated a considerable volume of literature for soil sequences which span only a few hundred years (see for example, Mellor, 1985) to several million years (see for example, Birkeland, 1978) and have been carried out over a very wide range of environments and climatic zones. Discussions of the concepts and problems of soil chronosequence studies of soils have been extensively reviewed (Stevens and Walker, 1970; Yaalon, 1975) and some authors have constructed chronofunctions using several statistical models applied to a very wide range of published chronosequence data (Bockheim 1980). In soil stratigraphic studies conducted in the Late Glacial and Holocene time scale soil properties that show significant changes in this time span are utilised to derive the soil stratigraphic units. These

include morphological properties of the soil profile, particle size characteristics and chemical characteristics. Considering these factors the brief review of soil chrononosequence literature that is presented below has concentrated on a selection of studies which demonstrate changes in some of these soil properties over the Late Glacial and Holocene time scales.

A number of studies have considered soil morphological properties as a part of their soil chronosequences. For example, Mahaney (1974) and Mahaney et al.(1981) have developed soil chronosequences and soil-stratigraphic units in coarse grained Neoglacial deposits in the Colarado Front Range and Cascade Ranges of North America. They found that the soil properties of use for differentiating the deposits included total solum depth, horizon development and colour of both the surface organic horizon and the B horizons of the soils. Working on soil chronosequences on Neoglacial moraine ridges in Jostedalsbreen and Jøtunheimen in southern Norway, Mellor (1985) demonstrated significant increases in thickness of horizons in podzolic soils over a 250 year period. Increases in thickness of the surface organic horizon, the bleached Ea horizon and the visual B horizon were all noted.

A small number of soil chronosequence studies have used as their data base only morphological properties of the soil profile with these studies developing soil profile morphology indices. Harden (1982) examined a chronosequence of well drained soils developed on the Merced River fluvial terraces which include the Holocene but range in age to over 3 million years.She demonstrated that the soils in her chronosequence showed variation in their physical properties with age of the soil by developing a quantitative index of soil profile development based on pedological properties identifiable and measurable in the field. The soil properties used in the index include clay film development around soil peds, texture, rubification, soil structure, dry consistence, moist consistence, colour value and pH.

Harden's index is a sophisticated index of field properties which has built on earlier indices such as that developed by Bilzi and Ciolkosz (1977) whose soil profile development index is a field morphology rating scale based on two indices, Relative Horizon Distinctiveness and Relative

Profile Development. These give a measure of degree of soil profile development by providing a comparison between respective soil horizons and the parent material or C horizon. This index was applied to a chronosequence of four late Holocene soils developed on alluvial landforms in the Ridge and Valley region of central Pennsylvania. The soils were dated at about 205, 320, 470 and 1955 years bp (Bilzi and Ciolkosz, 1977b) and showed that although it was possible to differentiate the oldest soil from the young soils, it was not possible to use the index to differentiate successfully the three youthful soils.

Meixner and Singer (1981) also devised a field morphology rating system to evaluate a chronosequence of soils developed on the terraces of Dry Creek, a tributary to the Merced river. Soil ages showed a greater range than those studied by Bilzi and Ciolkosz, varying from recent to approximately 250 000 years bp. This study demonstrated that differences in both A and B horizons of the soils could be distinguished using the field index.

Many soil chronosequence studies examine systematic changes in chemical and particle size properties of the soils with time. As well as providing data for differentiating deposits in a landform sequence examination of the chemical and particle size properties of the soils may also provide insight into the nature and intensity of pedogenic processes. These data are important because using this information it should be possible to demonstrate the genetic relationships between the soils in the chronosequence and also ensure that the features examined are indeed pedogenic in origin.

Working in the Late Glacial and Holocene time scale in the Arapaho and Henderson cirques in the Colarado Front Range, Mahaney (1974) used particle size analyses to show that podzolic soils tend to develop more loamy textures with greater age. However, variation in texture from sandy, to loamy sand to sandy loam is very gradual with the sandy loam textures being more evident in the older (mid-Holocene) soils.

Walker (1962) utilised data relating to the clay content of the surface soils developed on four river terraces in New South Wales. These terraces were independently dated to about 29,000bp, 3,700bp, 390bp and a modern age for the youngest terrace. Walker was able to demonstrate an increase in soil depth and number of horizons from the soils developed on the youngest to the oldest terrace surface, as well as an increase in the clay content of the B horizons of the soils although this latter trend was more noticeable between the 3700bp soil and the 29000bp soil.

Certain soil properties appear to be "more rapidly adjusting" which do attain a steady state within 10^3 years (Yaalon, 1971). Such properties include organic carbon in the surface horizons of the soils and pH. Ellis and Richards (1985) show a plot of the rapidly adjusting soil variable, % organic carbon in the surface horizon against time. They demonstrated a rapid increase in organic accumulation during the first 500 years of soil development. Subsequently, the rate of increase of organic carbon slowed, suggesting an approach towards steady state. Similarly in the Colarado Front Range (Mahaney, 1974) organic matter content of the surface horizon showed a rapid increase during the initial 2000 years of soil development, but subsequently slowed in its rate of increase.

Soil pH decreases as basic cations are leached from the soil.The length of time over which this process operates to produce acid surface organic horizons seems to vary, but with podzolic soils is likely to occur reasonably quickly. For example, in southern Norway, Mellor (1985) showed an approach to steady state in A horizon pH within about 230 years. In the Colorado Front Range pH reached a steady state in about 1000 years (Mahaney, 1974), but in the Cascade Range (Mahaney et al.1981) decline in pH to steady state took place over about 3000 years.

Working with podzolic soils some of which are Holocene soils, Franzmeier and Whiteside (1963) demonstrated an increase in intensity of translocation of sesquioxides to the B horizons of the soils with increasing length of time available for the operation of the soil forming processes. They also describe several changes in soil morphology of the podzols with increasing soil age. These

changes included more pronounced horizon differentiation with soil age, as well as increasing total solum depth.

Data have been published by Ellis and Richards (1985) relating to a dated chronosequence of podzolic soils developed on alluvial surfaces in Ulvadalen, Norway. The soils were dated to about 20 years old, 55 years, 500 years and 9000 years bp. A series of chronofunctions have been produced which demonstrate the rate of increase of soil properties with soil age. For example, indices of Ea : B horizon extractable iron and aluminium displayed steady decreases with increasing soil age. These trends indicate the progressive translocation of these soil components from the Ea horizon to the illuvial B horizon with increasing pedogenesis and therefore podzolisation of the soils.

Both in the studies made on the podzolic soils in North America by Mahaney (1974) and Mahaney et al.(1981), and a study of podzolic soils carried out in the central highlands of Scotland(Robertson-Rintoul, 1986) increasing amounts of iron oxides were shown to be accumulating in the B horizons of the soils relative to the C horizons as soil age increased.

These studies all show an increase in the amount of iron and aluminium in the B horizons of the soils with increasing soil age. Frequently these increases are also shown to be associated with changes in soil morphology, with increases in total solum depth and B horizon thickness and more distinctive horizonation. As sesquioxides appear to continue to increase in podzolic B horizons over at least the Holocene and Late Glacial time scales they represent "slowly adjusting soil properties" (Yaalon, 1971) which show no evidence of reaching a steady state over 10^3 years.

In the North American soil studies made by Mahaney (1974, 1978), and Mahaney et al. (1981) each soil in the chronosequence is described as comprisng a distinctive soil-stratigraphic unit with the deposits into which the soil unit has developed being comprised of glacial deposits from a distinctive glacial limit.

Soil stratigraphic studies in the Late Glacial and Holocene time scale have largely centred upon an examination of surface soil profiles that have been correlated on the basis of degree of soil profile development. To avoid confusion with soil-stratigrapic units used to define interglacial and interstadial episodes of the Pleistocene, soil stratigraphic units derived on the basis of degree of surface soil profile development will be referred to as surface soil stratigraphic units.

Soil stratigraphy deals with the chronological ordering of pedological episodes (Finkl, 1980). As landform evolution is commonly episodic soils may provide data on the lengths of time separating episodes of deposition so that the aim of the soil stratigrapher is to recognise soil-stratigraphic units and rank them chronologically (Finkl, 1980). The soil-stratigraphic unit is defined as a soil with physical features and stratigraphic relations that permit its consistent recognition and mapping as a stratigraphic unit (American Commission on Stratigraphic Nomenclature, 1961). Birkeland (1974) and Finkl (1980) outline some of the primary properties of soil-stratigraphic units. In order to qualify as a soil-stratigraphic unit a soil should meet certain criteria which include:

1. Morphological and chemical features that are pedogenic in origin;
2. A consistent relationship to associated stratigraphic units in the local succession;
3. A wide geographical distribution;
4. Possess clearly defined features which permit its recognition as a marker horizon.

Any individual soil-stratigraphic unit may show a range of development and a range of soil features caused by changes in the soil-forming environment (Rose et al., 1985).

A great deal of work identifying surface soil-stratigraphic units and describing their main features has been carried out on glacial and periglacial deposits in North America. Mahaney (1974, 1978) is a leading exponent of the technique and his work includes the development of surface soil-stratigraphic units over the Late Quaternary time scale. He has used a combination of degree of soil development and radiocarbon dating to develop surface soil-stratigraphic units which can be

used on a regional basis to both relatively and absolutely date Late Quaternary deposits. Mahaney and his co-workers have found a number of soil properties of use for differentiating the deposits of different age. These include total solum depth, horizon development, colour of both the surface organic horizon and the B horizons of the soils, amount of free iron oxides, particle size distribution of soil matrix material and clay-mineral assemblages. In the Wind River Mountains Mahaney (1978) used a range of these soil properties to identify five soil-stratigraphic units which developed following periods of glaciation. These soil stratigraphic units have been dated using a variety of techniques to ages between 100BP and 100,000BP. He suggests that these five major soil-stratigraphic units are common on a regional scale in the Wind River Mountains. Further, the soil profiles making up the soil-stratigraphic units are also said to be representative of similar soil-stratigraphic units in other areas of the Rocky Mountains. Correlative soil-stratigraphic units have been found in adjacent areas, including the Teton Range, the Big Horn Mountains and the Front Range in Colorado (Mahaney, 1974, 1988; Mahaney et al.1981).

A combination of soil chronosequence data and soil stratigraphy has been successfully used in the Ventura Basin, southern California by Rockwell et al. (1985) to estimate the ages of undated alluvial surfaces of fluvial origin. Here seven soil units were identified, these ranging in age from 10-20 years old to about 200000 years in age. The surface soil-stratigraphic units were derived using a range of soil properties including particle size characteristics, soil pH, organic matter content, exchangeable bases, calcium carbonate content and free iron oxides. The age-calibrated surface soil stratigraphic units were used to estimate the ages of undated deposits which had been displaced by tectonism.

Similar techniques were used by Ritter and Ten Brink (1986) in their examination of terraces and fans in Alaska. In their outwash sequence four phases of gravel accumulation have resulted in the development of a series of fans and terraces. Ritter and Ten Brink used lack of evidence of weathering and pedogenesis between the surfaces of the landform units to show lack of relative age difference between phases of gravel accumulation. The terrace gravels were not oxidised

beneath the fan deposits, thus indicating little time for the onset of pedogenesis, and as a corollary, inferred rapid fan accumulation after terrace aggradation. Depth of oxidation of the surface sediments was used to correlate each of the four phases of terrace and fan accumulation.

The use of soil stratigraphy as a methodology for subdividing deposits of different age and correlating terrace surfaces has also been found to be a very useful tool in helping to unravel the Late Glacial and Holocene history of valley floor development in upland Britain, although as noted by Rose et al. (1985), soils have generally played a relatively minor role in the determination and correlation of British Quaternary environments.

Working in the Howgill Fells, northwest England, Harvey et al. (1984) were able to differentiate between deposits of Late Glacial/early Holocene age and more recent late Holocene fluvial surfaces on the basis of degree of surface soil profile development. The older landsurfaces were distinguished by mature podzolic soils whilst the younger deposits were characterised by shallow soils showing evidence of incipient podzolisation only.

The studies discussed above have all used soil stratigraphic units to assign relative and absolute ages to deposits following a qualitative appraisal of the quantitative soil data. A recent study has used multivariate statistical techniques to derive the surface soil stratigraphic units. Using the surface soils developed on the river terrace sequence in Glen Feshie, SW Cairngorms soil stratigraphic units were quantitatively defined using a genetically related sequence of podzolic soils and a combination of Principal Components Analysis and cluster analysis (Robertson-Rintoul, 1986a), In this study the soil properties used to define the soil stratigraphic units included soil pH, organic carbon, and quantities of organically bound iron and inorganic iron in the soil horizons. Various methods of dating control allowed the surface soil-stratigraphic units to be dated to 80bp, 1000bp, 3600bp, 10000bp and 13000bp.

3.3 Field and Laboratory Methods for the Surface Soil Stratigraphy in Dovedale Griff and Jugger Howe Beck.

The field and laboratory methods outlined in this section were applied to the soil sites excavated in both Dovedale Griff and Jugger Howe Beck. The discussion of the sample sites for the Jugger Howe Beck soils is deferred, however, to the following chapter.

3.3.1 Soil Sample Sites

Soil pits in Dovedale Griff were excavated on the main terrace fragments making up the valley fill deposits. Several exploratory pits were excavated on most of the terrace fragments to ensure that sample sites were representative of the degree of soil development on each fragment.

All the soil profile sample sites were located at freely drained locations on the terrace surfaces. Upstream of the confluence of Dovedale Griff and Bridestones Griff and at several sites below the confluence waterlogging of some of the lowest terrace fragments prevented soil pits from being excavated. In all 23 soil profiles were examined. The locations of the soil profile sites are indicated on Figure 3.6.

3.3.2 Methods

The soil profiles were described in the field according to the procedures outlined by Hodgson (1976). The soils were classified as far as possible using the classification scheme of the Soil Survey of England (Avery, 1973) using both field and chemical criteria. However, some of the soils on the lowest terrace fragments were immature soil profiles so it was difficult to apply a classification scheme to these soils satisfactorily. These soils were therefore classified as mineral alluvial soils. In the field, the soil horizons were identified on the basis of visual criteria and were classified as A, A/B, B and C horizons in order to provide a working nomenclature.

The morphological criteria described and/or measured from each profile included total solum depth, depth and thickness of each horizon, macro-structure, root density and nature of roots, stoniness, consistency, moistness, horizon boundary distinctness, and moist soil colour for each soil horizon using Munsell colour charts. Magnetic susceptibility was measured for all organic mineral surface horizons using a Magnetic Susceptibility Meter. Details of the method are given in Appendix 2.

Bulk samples for detailed laboratory analyses were collected on an horizon basis for each soil profile. The samples were analysed for soil reaction (pH), organic carbon, and iron and aluminium content using the procedures outlined by Bascomb (1974). Two extraction methods were used to evaluate iron and aluminium in the profiles. Pyrophosphate and dithionite extractable iron and aluminium were evaluated for all of the profiles sampled. Iron and aluminium content was measured by atomic absorption spectrometry. Extractions for pyrophosphate and dithionite extractable iron were performed on separate samples, with the value for the pyrophosphate extraction being substracted from the dithionite extraction. However because the aluminium values were generally low and sometimes proved unstable for the lower terraces these data were not included in the following statistical analysis. Particle size analysis of the fine (<2mm) fraction was also carried out for all horizons. Organic material in the A horizons was removed prior to particle size analysis by H_2O_2 digestion. Details of the laboratory procedures for all the analyses are given in Appendix 1.

3.3.3 Cumulative Soil Profiles

At all soil sample sites care was taken to ensure that the soil profiles did not exhibit any visual evidence of cumulative soil horizons. River terraces are ideal landforms on which to carry out soil stratigraphic studies as they are landforms which develop episodically. However, they may also be subject to the development of cumulative soil profiles, with such soils having been described from the lower terrace of the Severn (Hayward and Fenwick, 1983). Such profiles receive influxes of parent material at the same time that soil formation is proceeding. In such soils the A horizon

builds up with the accumulating parent material so overthickened A horizons may develop. Alternatively, due to organic material at the site being episodically buried by mineral material, stratification, with alternation of buried A horizons and mineral sand and silt layers may also be evident. The features of such soils are therefore partly sedimentolgical and partly pedogenic. This situation may occur particularly in low level river terraces which experience overbank flooding and sedimentation of fines. Fines deposited as a result of overbank deposition or aeolian influx may also be eluviated into deeper horizons.

Analysis of soil texture may provide evidence of additions to soil profiles which are sedimentological rather than pedogenic in origin. Field and laboratory determination of textural class may indicate aeolian or overbank deposits present in cumulative soil profiles. Plotting of chemical properties and texture as depth functions may also show these additions as abberations from the general trend of the depth curves (Gerrard, 1981). No evidence of these indicators was revealed either from observation in the field or from the laboratory analyses of the profiles examined and sampled in Dovedale.

3.3.4 Parent Materials

As noted by Birkeland (1974) all other factors being equal, the texture of the parent material has a great influence on the course of soil formation. This is because variation in parent material properties may account for important differences in the operation of weathering, leaching and translocation processes. For example, Birkeland (1974) notes that depth of leaching is governed at least in part by texture of the parent material, with depth of leaching being greatest in gravelly materials, less in non-gravelly sand, and least in fine textured material. If leaching is a dominant soil process then this factor could greatly influence total solum depth. Thus any stratigraphic correlation based on soil development should take into account the texture of the parent material.

The massive sediments of the terrace fragments in Dovedale constitute the parent material for the soils developing of their surfaces so it is important to determine if these sediments are providing a parent material that is as uniform as possible given natural variation in river terrace sediments. As discussed in Chapter 2, the terrace sediments from the deposits for most the terrace fragments at all levels above the present river level are a mixture of freely drained sand and gravel deposits with no evidence of variation in composition of the sediments in any of the profiles examined. As a more or less constant gravel content to the surface establishes uniformity of parent material in stream gravels (Birkeland, 1974) the terrace soils may be regarded as forming constant parent materials for the development of the soils as far as the coarser fraction is concerned.

The textural properties of the <2mm fraction are also important to a pedological investigation as the sand, silt and clay are most commonly reported to be affected by pedogenesis in terms of their distribution within the soil profile. These components tend to be released by the action of physical and chemical weathering of the coarser fractions. Also the fine sand and silt fractions represent material which is most easily mobilised and susceptible to movement by translocatory processes. This latter feature may result in an increase of these size fractions with depth in the soil profile. As material of a size smaller than gravel is important in soil formation it is important to determine uniformity in these size fractions (Birkeland, 1974).

Particle size analysis was carried out on <2mm fractions of the C horizons of the soil profiles sampled, this being taken as representing the particle size of the parent material of the soils. Details of the laboratory procedure for the analysis are given in Appendix 1. The percentages of sand, silt and clay were calculated on a gravel-free basis. Textural classes were defined as outlined in Hodgson (1976). These textural classes were used as they are utilised in the triangular diagrams for defining sand, sandy loam, sandy silt loam and sandy loam classes used to describe soil horizons. Particle size distribution histograms were used to express the <2mm data. This method of presentation of the data was used because the general features of the sediment are easily interpreted and it enables rapid comparison of the between profile <2mm sediment size distributions.

A range of particle size histograms typical of the <2mm parent materials of the Dovedale soils are presented in Figure 3.1. A notable feature of all the histograms is the very small amount of clay-sized particles present in the C horizons of the soils, a function of the geological materials of the catchment as discussed in Chapter 2. For all the samples fine sand forms the dominant particle size. For example sample 3 has over 52% fine sand. Sample 10 also has over 50% whilst sample 15 has 64% of its <2mm fraction made up of fine sand.

The <2mm samples from the C horizonsof all pits sampled were subjected to analysis of variance in order to determine if any significant differences were discernable in the <2mm fraction of the parent materials of the Dovedale soils. In order to test the null hypothesis that there is no significant difference between the particle size characteristics of the <2mm fraction for the soils in Dovedale Griff analysis of variance was carried out on the percentage of silt and clay contained in each sample. The samples were allocated to one of three groups based on the division of the soil profiles shown in Figure 3.6, the significance of which is discussed in Section 3.8 below. The analysis of variance table is given in Table 3.1

Table 3.1 **Analysis of Valance**

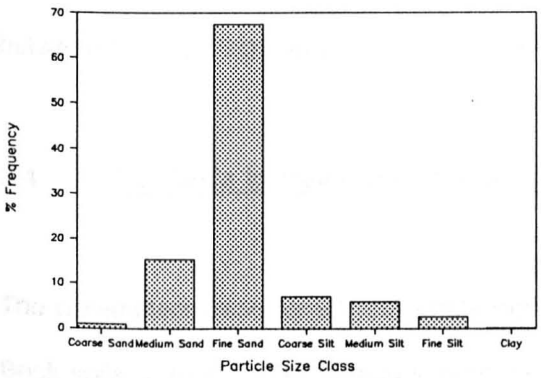
Source	CSS	DF	Mean Sq	F Ratio
Between Gp	195.04	2	97.52	0.847
Within Gp	1957.5	20	115.14	
Total	2152.5	22		

The 1% point for F (2,22) is about 5.72, so the null hypothesis of no significant difference between the groups is accepted giving strong support to the suggestion that the fine fraction in the parent materials of the Dovedale soils show no real difference in textural characteristics.

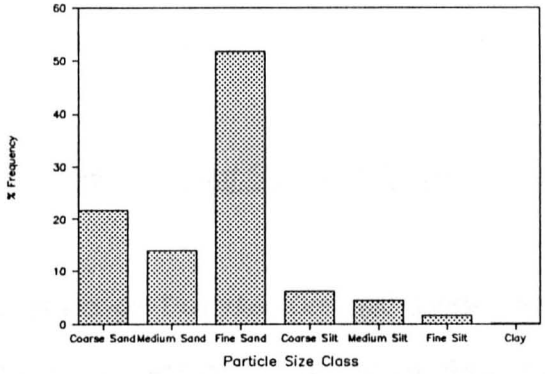
Although mineralogical investigations of the deposits were not carried out the terrace sediments are likely to be mineralogically similar, because the terrace sands and gravels from all levels are derived from the Lower Calcareous Grit which outcrops upstream of the Bridestones Griff/Egg Griff confluence.

Particle Size Histograms for the Parent Materials of the Dovedale Griff soils

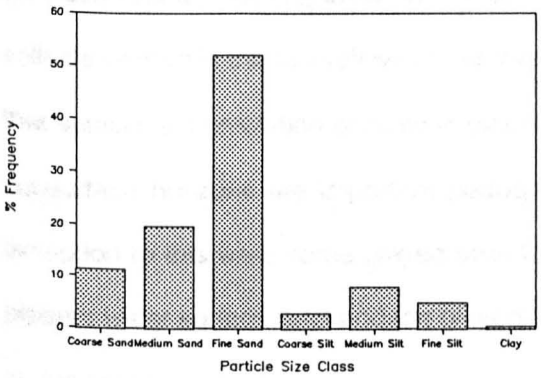
SAMPLE 1 – C horizon



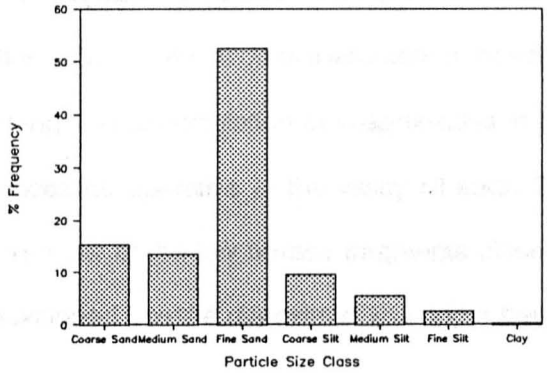
SAMPLE 3 – C horizon



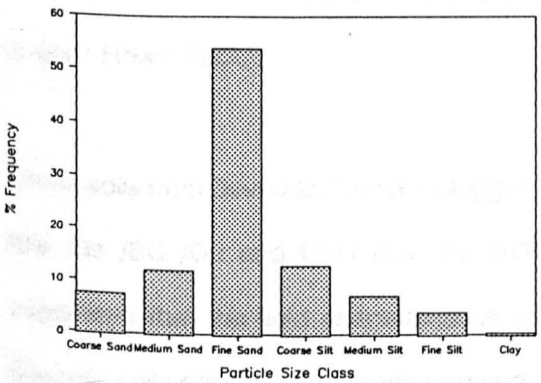
SAMPLE 4 – C horizon



SAMPLE 10 – C horizon



SAMPLE 11 – C horizon



SAMPLE 15 – C horizon

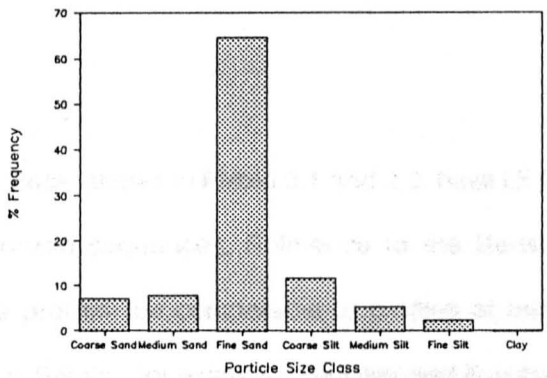


Figure 3.1

As the terrace sediments which form the parent material of the soils developed on the surface sediments of the terrace exhibit a high degree of similarlity, variation in soil profile development between terrace fragments is unlikely to be due to variation in texture of parent material.

3.4 The Soils in Dovedale Griff and Jugger Howe Beck and Soil Classification

The parameters used for the soil-stratigraphic analysis of the Dovedale Griff and Jugger Howe Beck soils were selected to take into account the dominant soil-forming processes likely to be operative in the soils. The soil pit excavations in Dovedale Griff and Jugger Howe Beck showed that the soils developed on the high terrace fragments in Dovedale Griff and those developed on the freely drained fluvial gravels on the main fan unit in Jugger Howe Beck were the most mature soils developed in the two valleys under investigation. Field examination of these soils suggested that surficial accumulation of organic matter, leaching and accumulation of sesquioxides in the subsurface horizons are important pedogenic processes operative in the valley fill soils. The exception to this were some gleyed soils found on a few of the low terrace fragments close to present water surface level and the gleyed soils developed into the deposits of the upper bench in Jugger Howe Beck.

Table 3.2 presents a typical field profile description of the soils developed on the upper terraces in Dovedale Griff and from the soils developed into the fluvial gravels of the main fan unit in Jugger Howe Beck.

These soils from Dovedale Griff and Jugger Howe Beck, shown in Plates 3.1 and 3.2, have LF /Ah /Bw /Bs /BC /Cu and LF/H /Bw /Bs /BC/Cu horizon sequences. Reference to the literature suggested that the field characteristics of these profiles are comparable to profiles of brown podzolic soils described from other upland areas in Britain (for example Mackney and Burnham, 1964; Avery et al., 1977; Ragg et al., 1978; Loveland and Bullock 1976).



PLATE 3.1



PLATE 3.2

Table 3.2 **Typical Field Profile Descriptions**

Upper terrace soil profile description - Dovedale Griff

Slope	0°
Vegetation	Grass, bracken, bilberry, heather
Soil drainage	Free
Parent material	alluvial gravels and sand

LF : 10.5 - 0cm; black 10YR 2.5/1; organic horizon; semi-fibrous; moist.

Ah : 0 - 7.5cm; dark brown 10YR 3/2; mineral-organic sandy loam; crumb structure; abundant medium roots and a few thick woody roots; moist; friable; many bleached grains; few stones; sharp boundary.

Bw : 7.5 - 14cm; dark brown 7.5YR 4/2; loamy sand; weak sub-angular blocky structure; friable; many medium roots; a few thick roots; some stones; gradual boundary.

Bs : 14 - 34cm; strong brown to yellowish brown 7.5YR 5.6 to 10YR 5/6; loamy sand; some medium roots; many sub-angular to sub-rounded medium stones; firm; fine, weak sub-angular blocky structure; merging boundary.

B/C : 34 - 60cm: yellowish brown 10YR 5/6; fine sand; very few fine roots; many sub-angular to sub-rounded stones; moist; friable; single grain structure; merging boundary.

Cu : 60+cm; yellowish brown 10YR 4/4; fine sand; sub-angular to sub- rounded medium stones; friable; massive.

Main fan unit soil profile description Jugger Howe Beck

Slope	4°
Vegetation	heather
Soil Drainage	Free
Parent material	alluvial gravels and sand

LF : 6 - 0cm; very dark brown 10YR2/2; spongey; moist.

H : 0 - 6cm; dark reddish brown 5YR2/2; organic horizon; well humified; moist fibrous roots; many bleached grains; friable; sharp boundary.

Bw : 6 - 19cm; dark brown 7.5YR 3/3; sandy loam; moist; crumb structure; very friable; many fine roots; some large stones; gradual boundary.

Bs : 19 - 59cm; strong brown 7.5YR5/6; sandy loam; crumb structure; very friable; moist; many fine fibrous roots; many large stones; gradual boundary.

B/C : 59-69cm; yellowish brown 10YR5/4; sand loam; no structure; loose; many large stones; merging boundary.

Cu : 69cm+; dark yellowish brown 10YR4/4; sand; no structure; loose; many large stones.

Brown podzolic soils have been mapped by the Soil Survey in various parts of the North York Moors and appear in the Soils in North Yorkshire III (Bendelow and Carroll, 1976) in which they have been designated as the Howard Series. Standard characteristics of Howard Series brown podzolic soils as classified in Soils in North Yorkshire III (Bendelow and Caroll, 1976) are :

Parent Material

Jurassic sandstone.

Standard profile

Horizon sequence : L and F, A, A/E, Bs, C.

Texture

Range sand to loamy sand.

Soil Colour

A horizon 10YR 4/3 to 10YR 3/4; Bs horizon 7.5 YR 4/4 to 7.5YR 5/6; C horizon 10YR 5/8.

Structure

Weak or very weak subangular blocky structure in the B horizon.

Consistence

Very friable.

Howard Series brown podzolic soils have been mapped in Troutsdale and in order to compare the Dovedale Griff upper terrace soils and the Jugger Howe main fan unit soil with the brown podzolics as mapped by the Soil Survey in the North York Moors a soil pit was excavated at SE 942 901 in an area mapped by the Soil Survey as possessing brown podzolic soils. Table 3.3 gives the soil profile description of the Howard Series soil which is also shown in Plate 3.3.

Table 3.3 **Troutsdale Soil Profile Description SE 942 901**

Slope	3°
Vegetation	Grass, bracken, bilberry, heather
Soil drainage	Free
Parent material	sandy head

Ah : 0-20cm; dark brown 10YR 4/3; mineral-organic loamy sand; weak crumb structure; very friable; moist; many fine woody roots; many bleached grains; sharp boundary.

Bw : 20-32cm; dark brown 7.5YR 4/2 to 4/4; loamy sand; fine weak sub-angular blocky structure; very friable; moist; many fine woody roots; clear boundary.

Bs : 32-46cm; yellowish brown 10YR 5/6 to 5/8; sandy loam; massive structure; friable; moist; gradual boundary.

BC : 46-60cms; yellowish brown 10YR 5/8; sand; single grain; friable; merging boundary.

Cu : 60+cms; yellowish brown 10YR 5/4; fine sand; single grain.



PLATE 3.3

This profile has an Ah/ Bw/ Bs/ BC / Cu horizon sequence. Both this profile and the one described from Dovedale Griff possess an acidic vegetation cover of bracken and grass and are developed on Jurassic sandstones. The Jugger Howe Beck soil has an acidic heather vegetation cover and is developed on the Jurassic sandstones. Some differences are discernable betweeen the three profiles with the Howard Series profile at the site sampled not possessing an LF layer, the Ah horizon forming the surface horizon, whilst the Jugger Howe Beck soil possesses an H rather than an Ah horizon. The Bs horizon of the Jugger Howe Beck was also redder than that of the Dovedale Howard Series profile. However in horizon sequence and macromorphological features the three soil profiles are generally comparable. The pH of the Jugger Howe Beck soil was found to be slightly more acid than that for the Dovedale or Howard Series soil. The pH of the surface organic horizon in Jugger Howe was measured as 3.8 whereas as that for the Dovedale soil was 4.1 as was that for the Howard Series soil. The Howard Series soil was also more sandy than either the Jugger Howe Beck soil or the Dovedale soil. These differences may influence the rate of the translocation processes between these different sites in the North York Moors.

The three profiles described above share many of the characteristics of the Howard Series soils as described by the Soil Survey, although they do vary somewhat from the general characteristics of the Howard Series brown podzolics as described by the Soil Survey in that they possess an additional horizon, the Bw horizon. However, this variation in horizon sequence seems to be typical of brown podzolic soils as they are described in the literature. For example, in their paper identifying podzolic soils in upland Britain Avery et al. (1977) give several profile descriptions from brown podzolic soils. These profiles vary in horizon sequence and include Ap/ Bs/ Bcx, H/ Ah/ Ah-Bh/ Bs/ Bcx/ and Ah/ AB/ Bs1/ Bs2/ Bs3 sequences. Loveland and Bullock (1976) describe typical brown podzolic soils and refer to a profile which has a horizon sequence similar to that described from Dovedale, Jugger Howe Beck and the Howard Series soils; this is an Ah/ AB/ Bs/ BC horizon sequence. However, they also describe humic brown podzolic profiles which have an Ah/Bh horizon within the profile.

Brown podzolic soils possess a number of common macromorphological properties. These were observed in the Howard Series profile described in the field and the Dovedale Griff and Jugger Howe Beck profiles. These include:

1. Very dark surface horizons;
2. The presence of bleached grains in the surface horizons;
3. B horizons with high chroma and having a hue of 10YR or redder;
4. Weak fine structure in the B horizon;
5. An acid vegetation cover.

Although the horizon sequence of brown podzolic soils in upland Britain appears to vary, one soil horizon which is suggested to be diagnostic of brown podzolics is the presence of a Bs horizon (Avery et al. 1977; Avery, 1973; Loveland and Bullock, 1976). According to the classification of Avery (1973) in order to qualify as a Bs horizon the horizon should fulfill the following criteria:

1. Value and chroma > 3
2. > 5cm thick
3. Accumulation of amorphous Fe + Al, associated with organic matter
4. Organo-ferruginous coats on mineral grains and/or granular sand or siltsize peds
5. $Fe_p + Al_p$ /% clay > 0.05
6. $Fe_p + Al_p$ >0.3%.

The soil profiles from the upper terrace surfaces in Dovedale Griff, the Jugger Howe Beck fan soil and the Howard Series soil were examined for these properties and the data are presented in Table 3.4 below.

Table 3.4 **Bs horizon data for Dovedale, Jugger Howe Beck and Howard Series soils.**

Dovedale soil	Howard Series soil	Jugger Howe Beck soil
1. 10YR 5/6	1. 10YR 5/7	1. 7.5YR 5/6
2. 20cm	2. 20-25cm	2. 40cm
3. Fe_p 0.45%, Al_p 0.19% O.C. 1.5%	3. Fe_p 0.61%, Al_p 0.07% O.C 0.75%	3. Fe_p 0.41%, Al_p 0.23%, O.C. 0.81%
4. Granular pellets	4. Sesquioxide coats	4. Sesquioxide coats
5. 3.44	5. 0.11	5. 0.13
6. 0.64%	6. 0.68%	6. 0.57%

According to these criteria all three soils possess soil horizons that qualify as Bs horizons. Considering both the morphological and chemical properties of the Dovedale Griff, Jugger Howe Beck and Howard Series soils, they seem to meet most of the morphological and chemical requirements for inclusion in the brown podzolic soil group.

Soils of the brown podzolic group have a brown, friable Bs horizon below an Ah (or Ap, if cultivated) horizon, and no Ea or distinct dark Bh horizon. Brown podzolic soils are extremely extensive in the British uplands. In England and Wales they are typically associated with formerly forested or afforested areas between the lowlands in which brown earths predominate, and the higher moorland areas with stagnopodzols and humo ferric podzols (Avery et al., 1977; Ragg et al., 1977).

These soils have generally been considered as intergrades between brown earths and podzols and have been variously described in the literature as truncated podzols (Robinson et al., 1949), podzolised acid brown soils (Mackney and Burnham, 1964) and ochreous brown soils (Clayden, 1970). The brown podzolic soil is distinguished from typical brown earths developed in similar materials by the presence of a Bs horizon, and from podzols by the absence of a distinct eluvial horizon. Typical profile sequences for brown podzolic soils are LF/ Ah/ AB/ Bs/ C.

Some of the literature concerned with brown podzolic soils has centred discussion around the position of the brown podzolic soil in a genetic sequence extending from the brown earth, through the brown podzolic soil to the podzol. Attention has been devoted to efforts to define boundaries between these different soil types using a variety of chemical and physical soil

properties. For example, Loveland and Bullock (1976) showed that brown podzolic soils and podzols in upland England could be distinguished from brown earths on the basis of Fe_o /Fe_d and Fe_p /Fe_d ratios and higher fluoride activity. Discussing characteristics of brown podzolic soils, podzols and brown forest soils in Scotland, Ragg et al. (1978) suggest that the value 0.36 for ratio of Fe_p to Fe_d in the B horizon differentiates the podzolised brown forest soil from brown forest soils. They suggest that this figure may have to be lower for soils in England and Wales.

Ball (1966) argued that brown podzolic soils should be included within the podzolised soils group. He suggested that the brown podzolic soil was closely linked with podzols by the ease with which podzolisation, that is, illuviation of sesquioxides, takes place under appropriate vegetation conditions. Considering the processes likely to result in the formation of a brown podzolic soil profile, Mackney and Burnham (1964) suggest that the operation of the processes of podzolisation is the most likely explanation for the physical and chemical development of the diagnostic Bs horizon. They suggest that evidence for the processes of podzolisation in brown podzolic soils comes from characteristic trends in down profile variation of silica : sesquioxide molar ratios. High SiO_2/R_2O_3 values in the surface horizons and relatively low values in the B horizons is very similar to the trend found for podzols. They also argue that the B horizons of brown podzolic soils have properties in macro-morphology and micromorphology, as shown in thin section, remarkably similar to those of podzols. Mackney and Burnham thus argue that the two types of soil were likely to be genetically related. Ball and Beaumont (1972) suggest that maxima of extractable iron and aluminium in the subsurface horizons of some brown podzolic soils supports the suggestion that genetic processes in these soils include release of Fe and Al and their transport and accumulation within the profile.

Loveland and Bullock (1976) point out that the Bs horizons of brown podzolic soils normally respond positively to the NaF test for reactive hydroxy-Al, and in this and other respects resemble the corresponding horizons of Andosols having largely amorphous, allophanic clay fractions. Loveland and Bullock (1976) demonstrated that the layer lattice component of the clay fractions of four brown podzolic soils they examined contains significant amounts of amorphous Si, Al and

Fe compounds. The Al and/or Fe is suggested by these authors to have reprecipitated in the interlayer spaces of some layer lattice minerals and has formed, with Si, allophane-like material.

Proto-imogolite allophane is poorly ordered clay material. Proto-imogolite allophane changes from a gel to a crystal-type material with time as the proto-imogolite allophane fibrous stage develops into well crystallised imogolite tubes. In recent research Farmer et al. (1980) ascribed high levels of Al extracted by acetic acid from the Bs horizons of podzols to the presence of imogolite type components and possibly interlayer Al in interstratified layer silicates. Anderson et al. (1982) showed that translocated Al and Fe are present predominately in inorganic forms in the Bs horizons of five podzols they examined in Scotland. The Al was present as imogolite and proto-imogolite allophane. It is argued that the presence in the podzols of allophane- cemented Bs horizons with superficial, often weakly developed Bh horizons could best be accounted for by a two stage process in which the allophane and associated iron oxides in the Bs horizons were deposited as a result of inorganic translocation of sesquioxides associated with a mixed Al_2O_3 - Fe_2O_3 -SiO_2 -H_2O sol, and that the Bh horizon was formed subsequent to this initial stage. This proto-imogolite theory of podzolisation was developed to account for the distribution of allophane, imogolite and organic matter found in freely drained podzols on coarse parent materials in Scotland.

The presence of proto-imogolite allophane is not limited to podzols, sensu-stricto, but has been suggested to be important in the podzolisation mechanism which produces Bs horizons. Thus, Farmer (1982) has shown that proto-imogolite allophane is widely distributed in both podzol and podzolised brown forest soils. This could suggest that both soil types are subject to similar soil-forming processes, and perhaps supports the earlier findings of Loveland and Bullock who suggested that the Bs horizons of the brown podzolic soils they examined contained significant amounts of allophane-like material.

This recent work on podzols has important implications for the choice of chemical criteria used for defining Bs horizons (Anderson et al, 1982; Farmer, 1984). Many classification schemes,

including that advanced by Avery (1973) and used by Avery et al (1977) to identify podzolised soils in upland Britain, place considerable weight on the amounts of organic-complexed Fe and Al measured by pyrophosphate extraction, as indicators of spodic and Bs horizons. However, the recognition of the process of inorganic translocation of sesquioxides suggests that Bs horizons may form without the illuviation of organic complexed Al and Fe.

Whether produced as a result of inorganic translocation of sesquioxides or translocation of organically complexed iron and aluminium, or some combination of both processes, the literature concerned with the development of brown podzolic soils suggests that the Bs horizon which defines this soil type is likely to be produced as a result of the processes of podzolisation. The depth functions in Figure 3.2 constructed using published data (Avery et al., 1977) for brown podzolic soils support the argument that these soils are genetically linked to podzols through the process of translocation of sesquioxides through the profile. Data from several of the Dovedale upper terrace soils, the Jugger Howe Beck and the Howard Series soil are included in the plots.

Most of the profiles shown in Figure 3.2 exhibit increases in depth of Fe_p and Fe_d, with the trends for the Dovedale, Jugger Howe Beck and Howard Series soils coinciding with those for the published data. Maximum amounts of Fe_p occur in the Bs horizons of several of the soils, in the AB horizon of a few of the soils and in the Ah horizon of a few of the soils. For most of the soils maxima of Fe_d occur in the Bs horizons, although a few soils do show maximum values for extractable iron in the Ah horizons. This may be due to either mixing of the upper horizons of the soil due to agricultural disturbance or some variation in soil forming processes. Although the plots show some between profile variations, most of the soil profiles exhibit sub surface maxima of sesquioxides which may be the result of the translocation and subsequent illuviation of iron, a process central to podzolisation. It is interesting to note that all of the soil profiles show substantially greater amounts of Fe_d than Fe_p in the profiles which may be significant given the argument above for the possible importance of inorganic translocation of sesquioxides in the processes of podzolisation.

DEPTH FUNCTION PLOTS OF FeP AND FeD FOR BROWN PODZOLIC SOILS

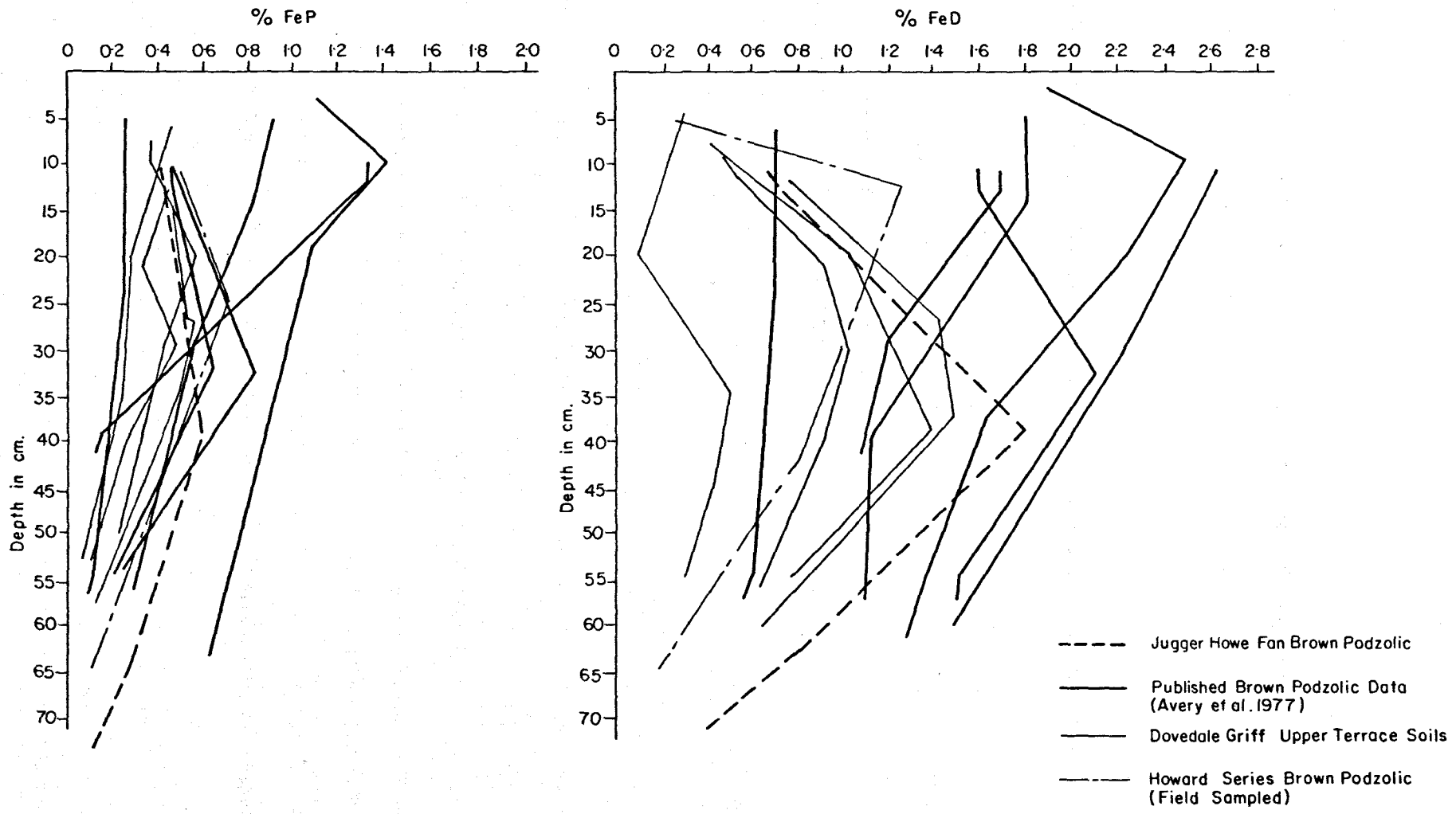


Figure 3.2

3.5 The Soil Parameters used to derive the surface soil stratigraphic units

After consideration of the processes likely to be operative in the formation of the most mature soil profiles in Dovedale Griff and Jugger Howe Beck, nine chemical and morphological variables were selected to derive the surface soil stratigraphic units. These are:

1. pH;
2. The ratio of % Fe_p (pyrophosphate extractable iron) in the B and C horizons of each profile;
3. The ratio of % Fe_d (dithionite extractable iron) in the B and C horizons of each profile;
4. The % Fe_p in the A horizon of each profile;
5. Magnetic susceptibility (Z);
6. Colour Development Equivalent of the B horizon;
7. A horizon darkening;
8. Relative Horizon Distinctiveness;
9. B horizon thickness;

The pH of the surface horizons of podzolic soils shows an increase in acidity with increasing length of time available for the soil-forming processes, although the pH of the surface horizon is likely to reach a steady state relatively quickly and probably within the first few thousand years of soil development (Mahaney,1978; Mahaney et al.1981). For the Dovedale soils pH of each A horizon was turned into a relative index of pH. This was achieved by subtracting the pH value for each A horizon from the the maximum (most alkaline) pH value for the profiles sampled. The reason for representing the pH values in this way is that changes in pH will then show the same sense and direction as the other chemical variables used in the analysis. Thus a lower pH, indicative of an older soil, will then give a higher pH index value than a less acid soil.

Several variables were used to represent the depth function trends of sesquioxides in the soil profiles. Following Ellis and Richards (1985) ratios of B and C horizon Fe_p and Fe_d were used as

indices of iron accumulation in the subsurface horizons of the soil profiles. The ratios assess the relative concentrations of iron in the B horizons of the soils and also allow relative variation between profiles to be compared by eliminating the effect of small scale variability in iron content of the parent materials. In well drained, oxidising soil environments ferrous iron is progressively converted to ferric iron oxides that accumulate in increasingly older and redder soils (Schwertmann and Taylor, 1977), so that several extraction methods are required to represent these changes. The pyrophosphate extractable iron (Fe_p) is generally considered to be iron in an organically bound form (Bascomb, 1968) whilst the dithionite extraction is generally used to extract total free iron, including the more "aged" crystalline iron as well as amorphous iron and organically bound iron (McKeague and Day, 1966; Bascomb, 1968; Anderson et al, 1981). The % Fe_p in the A horizon was used to represent in A horizon soil-forming processes related to the organic complexing of sesquioxises. This variable was therefore included to take into account this possible source of variation in the A horizons of the Dovedale soils.

Iron oxides in the soil are identified using a variety of chemical extraction techniques, some of which are discussed above and used in this study. Recent work, however, has focussed attention on additional techniques by which iron oxides in the soil may be represented. These techniques are based on the mineral magnetic properties of the soil constituents, that is those characteristics of a substance which are an expression of the intrinsic magnetic properties of constituent magnetic components and of their dispersion as particles within the soil.

Work carried out to date suggests that the application of mineral magnetic techniques may be a useful complement to traditional geochemical analyses of soil profiles, particularly as it may be possible to detect changes in magnetic minerals at concentration orders of magnitude below the detection limits of conventional methods (Thompson and Oldfield, 1986). Magnetic mineralogy may therefore provide a means of identifying rapidly relatively small, but possibly significant changes in soil properties. The following discussion of mineral magnetics and its application to the study of soil profiles is taken from Dearing et al. (1985) and Thompson and Oldfield (1986).

The magnetic properties of a soil sample reflect the varied magnetic behaviour of a range of soil minerals. Of importance are the ferromagnetic materials, which primarily include iron in the form of haematite, and the ferrimagnetic and antiferrimagnetic minerals magnetite, maghaemite and goethite. An important property of the ferrimagnetic and antiferrimagnetic minerals is that they are capable of remanence acquisition. In well drained soils formed in temperate environments, soil magnetic properties are most significantly contributed to by the ferrimagnetic iron oxides, magnetite and maghaemite and the antiferrimagnetic iron hydroxide, goethite. Magnetite occurs as both a primary mineral and is widespread as a secondary mineral formed during the operation of the soil-forming processes. Maghaemite is a secondary soil mineral which is widespread in temperate soils, although it tends to be more abundant in tropical soils. Goethite is abundant in well drained soils formed under temperate conditions.

The value of mineral magnetic techniques in the study and characterisation of soil profiles will be particularly enhanced when the mineral magnetic properties of the soils are more firmly related to the soil-forming processes. Some work has already been carried out in this field. For example Maher (1986) has investigated the mineral magnetic properties of both surface and buried soils with a view to relating these properties to the soil forming processes. Variation in mineral magnetic properties between soil types may therefore reflect changing soil processess. One of the main parameters used in mineral magnetic studies for characterising the magnetic properties of the soil is magnetic susceptibility (Z). Dearing et al. (1985) note the marked differences in depth plots of Z values of a well drained soil profile and a gleyed profile, with the Z readings for the gleyed profile giving an order of magnitude less. Marked differences in mineral magnetic properties between well drained soil profiles of different soil types have also been observed. Thompson and Oldfield (1986) have plotted depth function trends for 3 brown earths, and two podzols. The podzols have a small peak in Z very close to the surface which suggests shallow layers of enhancement at or near the soil surface. In the bleached horizon of the podzol Z values reach a minimum and may even be too low to measure. The three brown earth profiles show some variation in absolute values of Z, although in general, Z peaks are achieved in the surface horizons. These peaks extend over a much deeper layer than those for the podzols and appear

to be associated with the physically mixed A horizons where decomposing organic matter and mineral soil are associated.

The measurement of magnetic susceptibility (Z) is simple and rapid to make and can be carried out in the field using a portable electron probe, so magnetic susceptibility is a useful variable to include as a quantitative parameter in a field development index. The susceptibility of natural materials is mainly a consequence of their magnetite content so susceptibility can often be used as a rapid, surrogate measure of magnetite concentration. Because mineral magnetic studies aid in the description of iron distributions through the soil profile this measurement should correlate well with the chemical extractions carried out in the laboratory.

As Harden (1982) points out, a given quantifiable soil morphological property should be designed to represent a given soil process. For podzolic or brown podzolic soils the dominant pedogenic processes appear to include the build up organic material in the surface horizons and the translocation of sesquioxides from the upper to the lower horizons. Certain field characteristics are related to these processes. These include the development of a Bs horizon with red soil colours, a weak sub-angular blocky soil structure in the B horizon and dark surface horizons. Soil parameters to be measured in the field therefore need to be related to these characteristics.

Although the development of a distinctive soil structure is frequently mentioned in studies of brown podzolic soils it is an extremely difficult variable to quantify in the field, particularly for young soils. However two studies carried out on podzolic soils have suggested a number of field variables which could be quantifiable in the field and show variation in the Holocene time span. Considering podzolic soil profiles developed on Neoglacial moraine deposits in southern Norway, Mellor (1985) demonstrated rapid changes in soil profile morphology over the first 250 years of soil development. The podzolic profiles exhibited increases in thickness of the surface organic horizon, the bleached Ae horizon and depth of the visual B horizon. Similar changes are exhibited from the soil profile diagrams presented by Robertson-Rintoul, (1986a) from the

podzolic soil profiles in Glen Feshie, although these profiles span a greater age range than those discussed by Mellor. The Glen Feshie profiles exhibit increases in total solum depth with age of the soil, increases in B horizon depth and pronounced changes in colour of the B horizons relative to those of the C horizons. Similarly the studies of Mahaney (1974) and Mahaney et al. (1981) have reported significant changes in solum depth, horizonation and soil colour. These studies suggest that quantifiable field characteristics likely to be related to changes in degree of soil profile development over the Late Glacial and Holocene time scale include soil colour, horizonation and soil depths.

The three soil colour properties of hue, value and chroma as represented on the Munsell Colour Chart change within the soil profiles relative to the parent material as the soil develops with age and as horizonation of the soil takes place. Variation in value is considered to be due to changes in the percentage of organic matter in the surface horizon of the soils (Dickson and Crocker, 1953; Harden, 1982). As the horizon receives an increasing amount of organic matter build up the value decreases. Variations in chroma are thought to result from changes in percentage of iron oxides in the soils (Dickson and Crocker, 1953; Harden, 1982). Changes in value were used to represent the colour changes in the A horizons of the Dovedale soils. In order to quantify this an index was devised whereby one point was assigned for any unit change in value of A horizon colur from the C horizon colour so that a change from 10YR 5/4 to 10YR 3/2 represents a 2 unit change in value.

Munsell colour values have been shown to vary with both age and depth in the soil profile. Bockheim (1979) used a colour development index, Colour Development Equivalents (CDE's) which were the product of a numerical notation of the hue and chroma. Numerical notations for hue were 2.5YR =6, 5YR = 5, 7.5YR = 4, 10YR = 3 and 2.5Y = 2. Larger values of the notation denote red and brown colour components, which appear to indicate a higher degree of B horizon soil development. As the value of the CDE's decreases, yellow and grey colour components dominate and appear to be more representative of soil parent material colours in freely drained soils and therefore the early stages of soil development. This index was designed as a measure

of oxidation intensity and was shown by Bockheim to be related to soil age. The CDE is calculated by multiplying the numerical notation for hue by the chroma estimated on the Munsell colour chart. CDE's were calculated for the B horizons of the soil profiles using Bockheim's method.

Bilzi and Ciolkosz (1977) introduced the concept of Relative Horizon Distinctness (RHD) which provides a measure of comparison between adjacent horizons. For podzolic soils where B horizons become distinctive this measure should provide a measure of degree of development of the B horizon in relation to the overlying horizons. RHD is measured using a variety of soil properties which include colour, texture,structure, consistence and clay films. As with the Harden (1982) index points are assigned to represent the relative amount of change between adjacent horizons. In the present study colour was used as the index for RHD. One point was assigned for any class change in Munsell Colour chart hue and 1 point for any unit change in value or chroma. For example, a change from 10YR 4/7 to 7.5YR 3/8 would have a value of 2.5 for the class change, a value of 1 for change in value and a value of 1 for the change in chroma, giving a total number of points of 4.5.

The B horizons of the soils are generally the horizons which show development in the long term (Birkeland, 1978). The build up of organic matter in the A horizons is shown in most chronosequence studies to reach a steady state within the first few thousand years of soil development. This is a more "rapidly-adjusting" soil property, reaching a steady state within 10^3 years (Yaalon, 1971; Birkeland, 1978). However, B horizons are those subsurface horizons in which build up sesquioxides and clays over time. These are usually "slowly adjusting" soil properties which show no evidence of reaching a steady state within 10^3 years (Yaalon, 1971; Birkeland, 1978). As these slowly adjusting soil properties develop through time the B horizons of the soil increase in depth, so that B horizon thickness should be indicative of soil age.

3.6 Statistical techniques used in the derivation of the soil-stratigraphic units in Dovedale Griff

In this study a combination of Principal Components Analysis (PCA) and Cluster Analysis is used to derive the soil-stratigraphic units in Dovedale Griff. Ward's (1963) hierarchical grouping algorithm, minimising an error sum of squares objective function, is used for the Cluster Analysis.

Statistical techniques have long been used as an adjunct to soil science and soil classification (Webster, 1977) and, in particular, Principal Components Analysis has been used in a wide variety of pedological investigations (for example, Webster, 1977; Jacobson and Birks, 1980; Sondheim et al. 1981; Richardson and Bigler, 1984; Ovalles and Collins, 1988). Principal components are eigenvectors of the basic variance-covariance matrix of the data set and as such summarise the major relationships between the variables. That is, they reveal patterns of covariance. They may therefore provide significant insight into the structure of the data matrix and it is for this reason that Principal Components Analysis is a particularly useful technique to employ when attempting to evaluate any trends present in a number of morphological and chemical variables representing variation in a series of soil profiles. This is because the variables measured will almost invariably consist of a set of intercorrelated variables representing the soil-forming processes. PCA maximises the variance of the first component from the basic variance-covariance matrix with successive components extracting the maximum amount of residual variance. Each first component may then be used as an index of the variables in the initial data set, so that systematic variation in the original data may be represented on a single scale using the standarised component scores, with components representing orthogonal, uncorrelated variables.

Principal Components Analysis has been used in a number of studies to examine the spatial variation in soil profile development with varying environmental conditions. For example, Webster (1977) used 15 soil properties from 85 sites to quantify the variation in soil profile characteristics with variation in water regime and texture of the soil. The raw data were used as input for a

Principal Components Analysis and two significant components were derived. The loadings on the first two components suggested that the two components represented variation in water regime and texture respectively, and the scores on these components allowed Webster to plot variation in soil profile type. Ovalles and Collins (1988) used 20 soil properties from 151 pedons and a PCA to determine which soil properties most strongly influenced soil variability in NW Florida. These were shown to include total sand, fine sand and clay content of the soils, and organic carbon contents of the soils.

Principal Components Analyis has also been used to examine the temporal changes in degree of soil profile development from data matrices comprised of morphological and chemical properties from soil profiles of differing relative age. Eleven soil variables representing the soil profile characteristics for a chronosequence of podzols on a Canadian prograded beach were reduced into 2 significant components using Principal Components Analysis (Sondheim et al. 1981). The first component was shown to represent intensity of podzolisation, the soil profiles increasing in intensity of podzolisation with increasing soil age. Similarly, Robertson-Rintoul (1986a) used Principal Components Analysis to examine the trends in 10 soil variables for 40 podzolic soil profiles in Glen Feshie. The variables included total solum depth, B horizon thickness, % organic carbon in the surface horizon, pH, and ratios of A to B horizon and B to C horizon dithionite extractable and pyrophosphate extractable iron. The first component accounted for 60% of the variance in the data set and the loadings on the component were shown to represent the processes of podzolisation, an age related process. Mellor (1987) used PCA to isolate two dominant groups of pedogenic processes operative in the soils on neoglacial moraine ridges in southern Norway.The first group of processes were shown to be related to organic matter accumulation and decomposition and the second group to the processes of translocation operative in podzolic soils. Mellor (1987) was able to demonstrate the progressive operation of these dominant processes over time.

Principal components are mutually orthogonal and therefore uncorrelated. An analysis of the pattern in the scores of subsequent components may yield secondary trends superimposed on

the dominant trend in the data set represented by the first component. Both Sondheim et al.(1981) and Robertson-Rintoul (1986a) showed that although the dominant trend in their respective data sets was one of intensity of podzolisation, significant secondary trends were related to spatial variability in environmental factors. In the chronosequence study of Sondheim et al.(1981) the second component showed a secondary, spatial trend in the data for this component indicated systematic variation in the distribution of cations in the soils with increasing distance from the sea. In the Glen Feshie study the second and third components extracted spatial variability in vegetation characteristics and particle size of the parent materials.

The Glen Feshie terrace levels were distinguished, however, using a combination of PCA and Cluster Analysis. The PCA was used to identify the variables associated with the main age trends in the soil profiles developed on the terrace surfaces, and Cluster Analysis was used to group the terrace fragments into terrace levels distinguished by surface soil profiles of similar stage of podzolisation. Each set of soil profiles was regarded as forming a distinctive surface soil-stratigraphic unit, recognisable and tracable over the whole length of the valley floor (Robertson-Rintoul, 1986a).

The combination of PCA and Cluster Analysis has also been used successfully to delineate episodes of deposition using a variety of relative weathering variables. Dowdeswell (1982) and Dowdeswell and Morris (1983) used a number of age dependent parameters to differentiate talus deposits, rock glaciers and moraines. The variables they used included degree of pitting of boulders, weathering rinds, angularity of boulders, lichen size and lichen cover. Using a combination of Principal Components Analysis and Cluster Analysis, these authors were able to show that four age groups of landforms of approximately 10,000bp, 5000-3000bp, 1850-950bp, and 300-100bp age ranges could be distinguished.

The object of a cluster analysis is to sort a sample of cases into groups such that the degree of association is high between members of the same group and low between members of different groups. A cluster analysis may be used to reveal associations and structure in a data set and

may suggest a general model to describe other samples. As the objective of the cluster analysis in soil stratigraphic studies, and other studies using relative weathering variables, is to form clusters of points exhibiting a high degree of similarity in the discriminating variable(s), a minimum variance type of clustering which minimises within group variance and maximises between group differences is necessary. Ward's (1963) hierarchical grouping algorithm, minimising an error sum of squares objective function, is probably the best option for finding tight minimum variance clusters (Wishart, 1978).

Ward (1963) stated that at any stage in a hierarchical grouping analysis, the "loss of information" which results from the grouping of n points into clusters can be measured by the total sum of the squared deviations of every point from the mean of the cluster to which it has been allocated. At each step in the clustering procedure the union of every possible pair of clusters is considered, and the two clusters whose fusion results in the minimum increase in the error sum of squares are combined. At the beginning of the procedure each individual is regarded as a single point cluster. The first fusion combines individuals with the highest similarity, followed by less similar individuals until all the individuals in the data set have been clustered.

Defining cut-off points for grouping procedures is generally acknowledged to be difficult and usually made after a visual appraisal of the dendrogram. Harbor (1986) has commented on the recent trend of using a discriminant analysis to confirm statistically a grouping procedure. He notes that discriminant analysis should not be used on a data set used in a preceding cluster analysis as these data have already been used to generate the groupings being tested. As cluster analysis provides discrete groups, the discriminant analysis should always indicate that the groups are statistically significant, as indeed was the case for the analysis carried out by Dowdeswell and Morris (1982).

Ward (1963) proposed a method for determining the cut-off point in a clustering procedure and this has been used in a number of studies (for example, Ward, 1963; Wishart, 1978; Miles and Norcliffe, 1984;). By this method plotting the similarity level at which to accept a grouping scheme

may be suggested by plotting within-group variance as a proportion of total variance against number of groups at that similarity level. The point at which there is a marked discontinuity in the plot suggests a cut-off for a grouping scheme.

3.7 Quantitative Analysis of the terrace soils in Dovedale Griff

The data from the soil profiles analysed from the Dovedale Griff terrace fragments were subjected to a Principal Components Analysis. The Dovedale Griff data set gave a 23*9 raw data matrix. Where necessary the data were log transformed prior to analysis and the normality of the variables checked. The derived components, or eigenvectors, and the eigenvalues from this analysis are given in Table 3.5. Kaiser's Rule is generally adopted for determining significant principal components from a Principal Components Analysis (eg Sondheim et al., 1981; Dowdeswell, 1982; Robertson-Rintoul, 1986a). An alternative method for determining the number of components to accept from an analysis is that the principal components selected are those that explain at least 100/P of the total variance, where P is the number of variables in the analysis. In the case of the Dovedale data set this would be over 11%. Using either technique the Dovedale data set yielded only one significant principal component. This component alone accounts for 70% of the total variance in the original data set. The second component had an eigenvalue of 0.74 and accounted for an additional 8% of the variance in the data set. Table 3.5 gives eigenvalues and cumulative proportion of the total variance for the first significant component and, for reference, the second component. It also gives the loading matrix of the variables onto the components.

Table 3.5. **Eigenvalues and Loadings matrix for the Principal Components Analysis of Dovedale Griff Soils**

Eigenvalues and cumulative proportion of total variance for two principal components

1.	6.2893	0.6980
2.	0.7440	0.7814

Principal Components Loadings Matrix

1.	% Fe_p B:C	-0.8168	0.2468
2.	% Fe_d B:C	-0.8147	0.3099
3.	% Fe_p A	-0.8689	-0.2583
4.	Z	-0.7100	-0.2275
5.	CDE	-0.8855	0.2273
6.	B hor. thick.	-0.9026	0.0648
7.	RHD (A:B)	-0.9235	0.0355
8.	Adark	-0.8954	0.0081
9.	pH index	-0.7258	-0.5826

Elucidation of the physical meaning of the components is established through an examination of the eigenvector loadings, and, because components are mathematically independent, they should be interpreted individually (Gould 1967). The first component, accounting for 70% of the total variance in the data set, heavily weights the contributions of 7 variables in particular. These are the ratio of B to C horizon dithionite extractable iron, the ratio of B to C pyrophosphate extractable iron, the % of pyrophosphate extractable iron in the A horizon, CDE of the B horizons, B horizon thickness, Relative Horizon Distinctiveness and A horizon colour. The remaining two variables, magnetic susceptibility and pH load less highly onto the first component, with pH also loading onto the second component.

The B to C horizon ratios of pyrophosphate and dithionite extractable iron represent the accumulation of iron in the B horizon relative to the C horizon. The negative loadings of these variables onto the first component together with % Fe_p and the 4 morphological variables suggest that as the amount of iron accumulation in the A and B soil horizons changes so there is a corresponding change in the morphology of the soil profiles. An increase in amount of iron in the B horizon of the soils is likely to be associated with both an increase in B horizon thickness,an increased B horizon redness and increasing horizon distinctiveness.

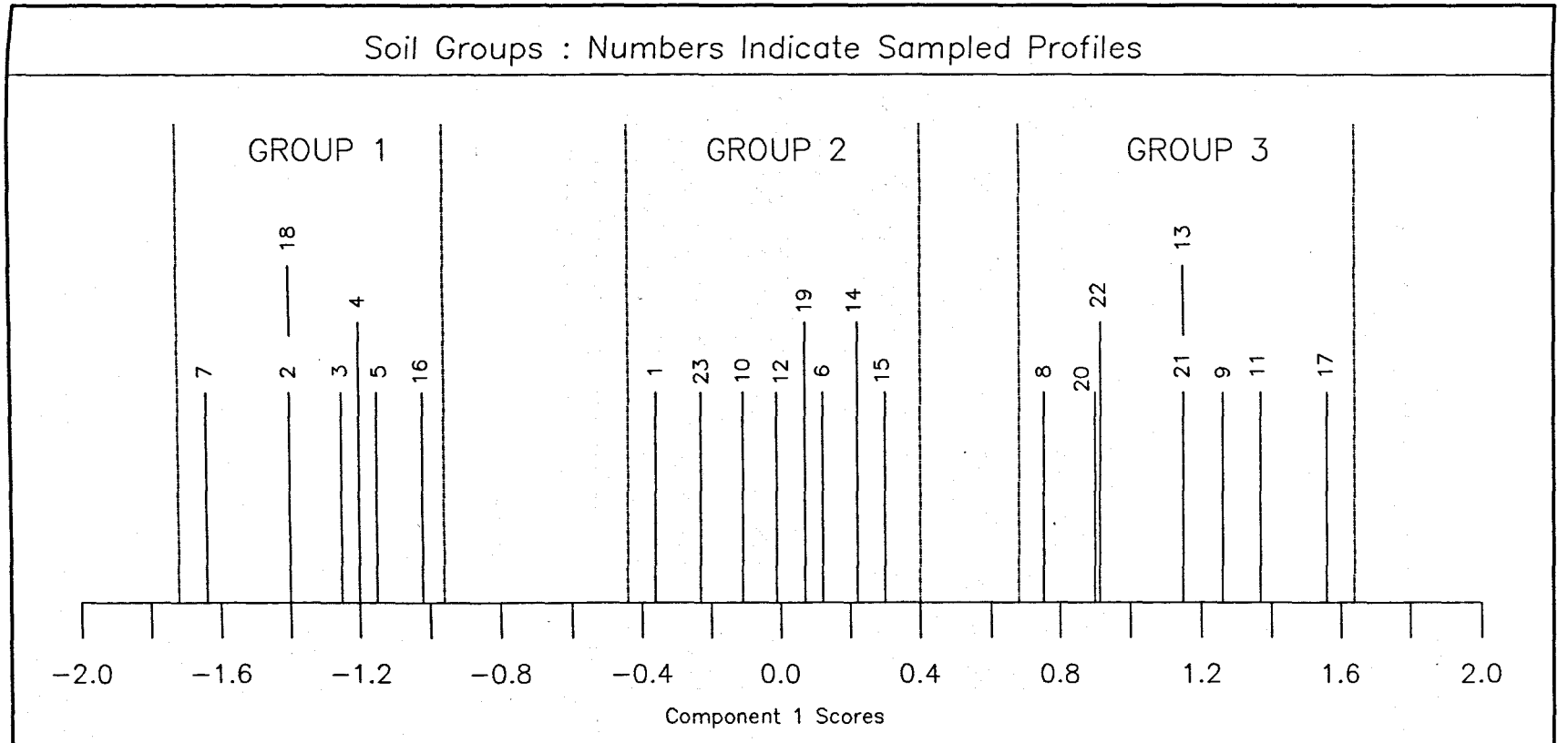
The magnitude and direction of the loadings on the first component suggest that this dimension represents a compound index of some of the main morphological and chemical characteristics of evolving brown podzolic soils. As discussed in Section 3.4 above these characteristics are likely to be associated with the processes of podzolisation. This first component may therefore be interpreted as an index of the podsolisation processes involved in the development of brown podzolic soils. As a number of soil chronosequence studies have shown that positive changes in the variables included in the analysis are a function of soil age (Section 3.2) this first component may be regarded as an index of degree of soil profile development and soil age.

Plotting the standarised component 1 scores on the axis of the first component projects the points into one dimension and enables the trends in the soil profile development component to be graphically represented (Figure 3.3). The standarised scores are ranked on a single numerical scale and show clearly the variation in value of the soil profile development component for the 23 soil profile sites.

The standarised scores range in value from -1.65 to + 1.56. However, it is clear from the plot that these scores are distributed into three discrete clusters along the principal axis, thus suggesting that the soil profiles developed into the terrace fragments in Dovedale Griff may be divided into three groups of soils at differing stages of soil profile development and therefore of soil age.

The scores on the first component were put into a clustering routine in order to divide statistically the data points into more or less homogenous groups. In this study the cluster analysis is being used to support the division of groups already observed in Figure 3.3.

The results of the clustering procedure are shown in the dendrogram in Figure 3.4 and Figure 3.5 shows the plot of number of groups against error sum of squares used to identify the cut off point for the clustering procedure. There is a marked discontinuity from the four to the three cluster cut-off point. Before the discontinuity the error sum of squares increased slowly. Beyond the discontinuity, from four to three clusters, there is a large increase in the error sum of squares.



Dovedale Terrace Soils

PROJECTION OF COMPONENT 1 SCORES ONTO THE FIRST PRINCIPAL AXIS

Figure 3.3

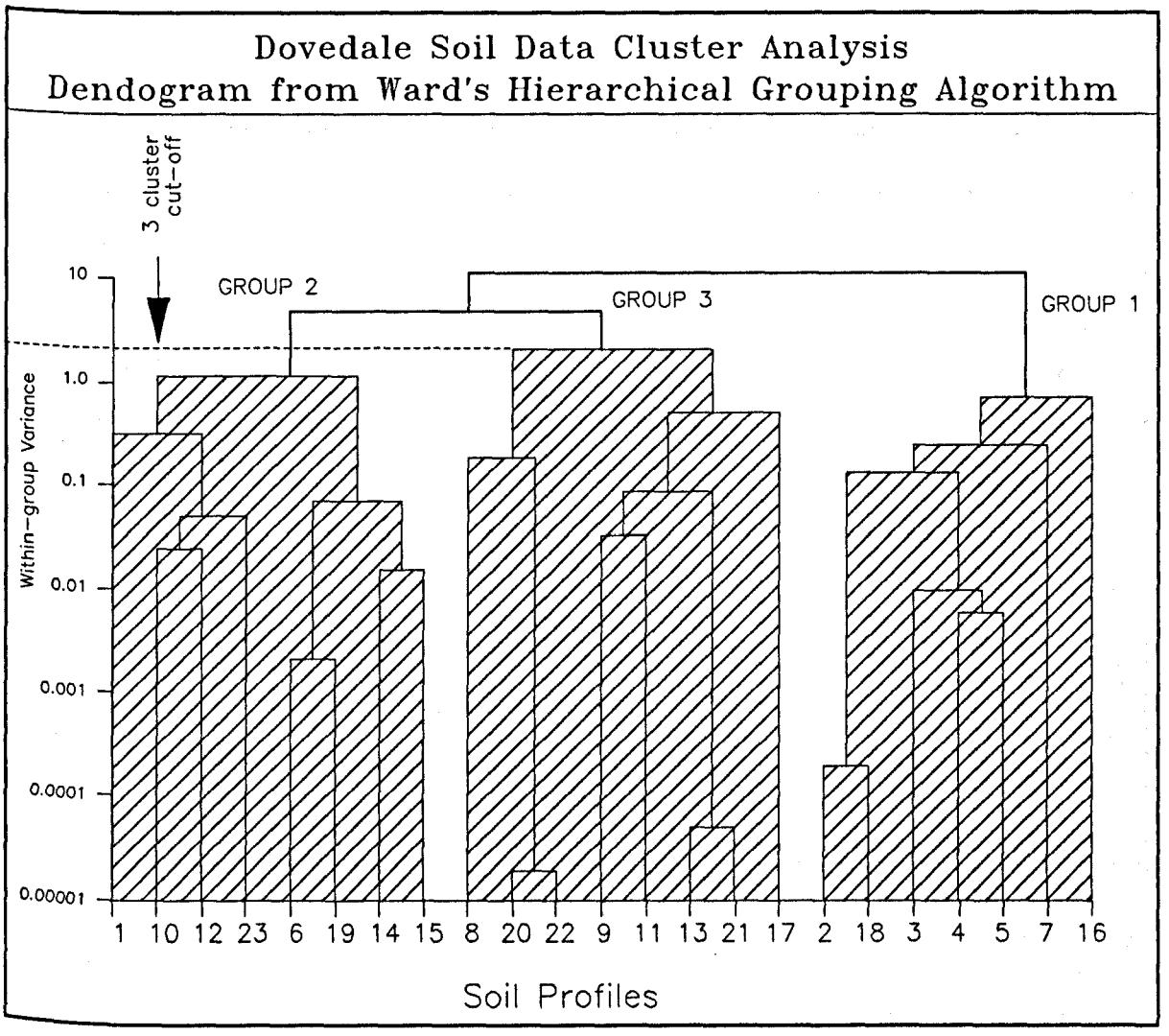

Dovedale Soil Data Cluster Analysis
Dendogram from Ward's Hierarchical Grouping Algorithm
3 cluster cut-off
GROUP 2
GROUP 3
GROUP 1
Within-group Variance
10
1.0
0.1
0.01
0.001
0.0001
0.00001
1 10 12 23 6 19 14 15 8 20 22 9 11 13 21 17 2 18 3 4 5 7 16
Soil Profiles

Figure 3.4

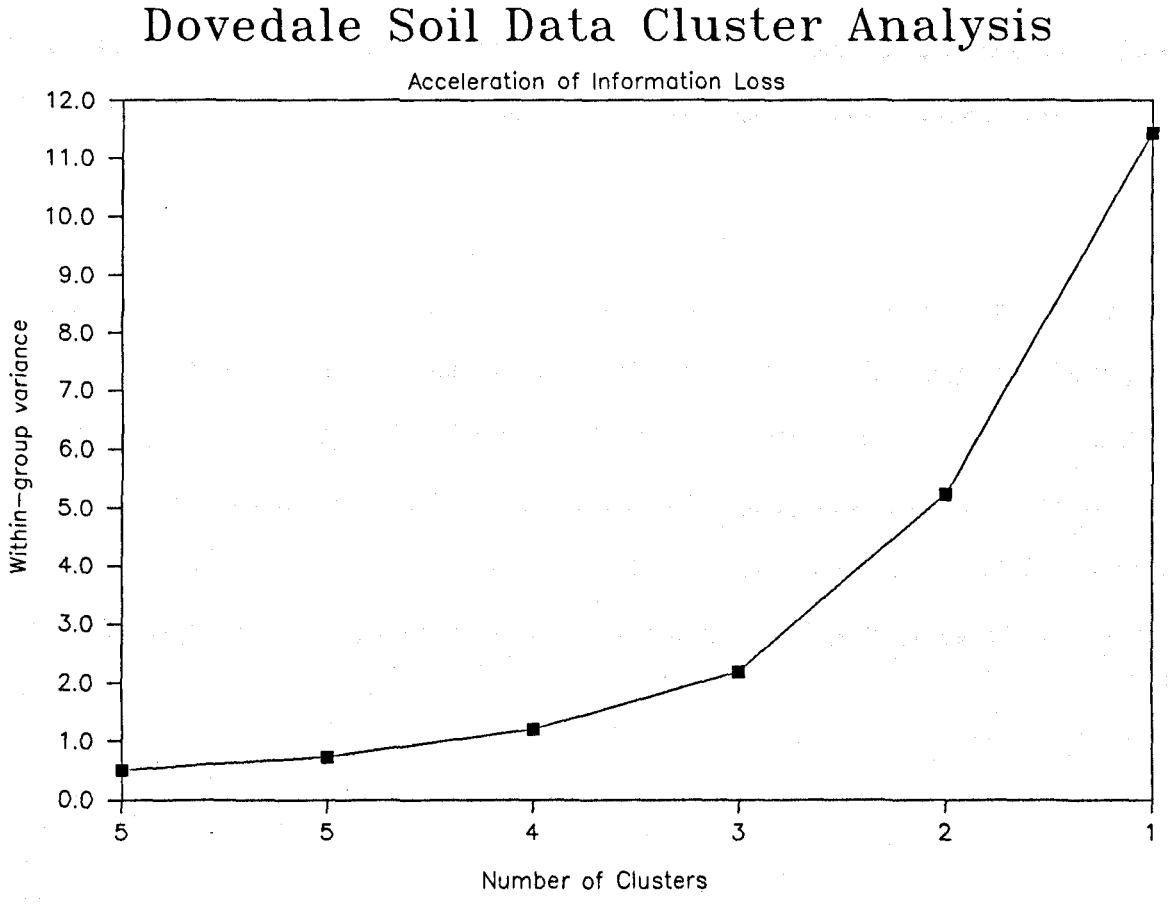

Dovedale Soil Data Cluster Analysis
Acceleration of Information Loss
Within-group variance
12.0
11.0
10.0
9.0
8.0
7.0
6.0
5.0
4.0
3.0
2.0
1.0
0.0
5
5
4
3
2
1
Number of Clusters

Figure 3.5

This would suggest, according to Ward's(1963) guide to the use of the method, that the level which best minimises the within-group variance and maximises the between-group differences is the three cluster grouping.

The cluster analysis has produced the same groups as those that were initially identified from the principal axis plot. Reference to Figure 3.3 shows that the clusters are not only separated on the plot, but they are also reasonably compact, suggesting that the grouping scheme produced by the cluster analysis constitutes an operational classification of the original data matrix.

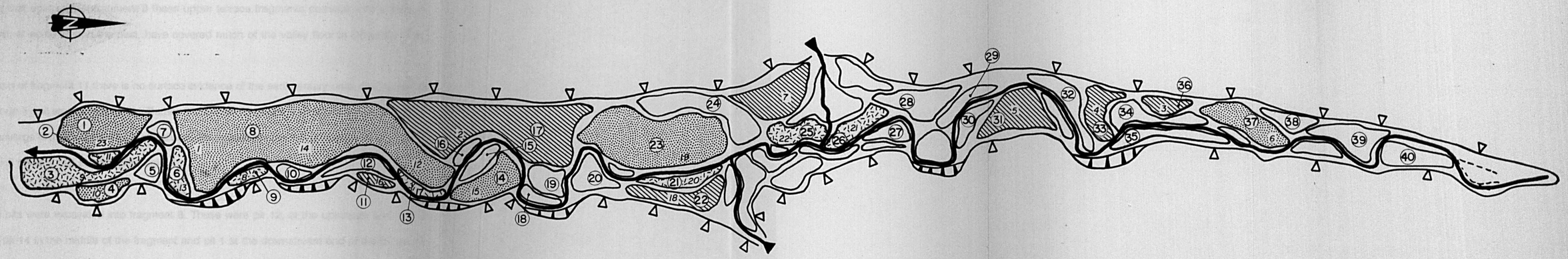
This analysis has defined three groups of surface soil profiles developed into the terrace fragments of Dovedale Griff. The principal component scores used in the analysis represent a compound index of degree of soil profile development with each group possessing a distinguishing range of scores. The Group 1 soils possess principal components scores that range from -1.65 to +1.1, the Group 2 soils possess principal component scores that range from -0.38 to +0.3 and the Group 3 soils are distinguished by scores that range from +0.75 to +1.65 thus suggesting three groups of soils each displaying differing degrees of soil profile development.

3.8 The Surface Soil Stratigraphic Units and the Dovedale Griff alluvial landforms

The spatial distribution of the soil profile clusters in Dovedale Griff is shown in Figure 3.6. The map shows that profile members from each of the three statistical clusters occur over much of the valley floor. Each cluster of soil profiles therefore has wide geographical distribution over the valley floor of Dovedale Griff. As demonstrated by the compound index of soil profile development represented by the first principal component, each of the 3 clusters of soil profiles also possesses distinctive physical and chemical pedological characteristics that permit their recognition as individual groups. As these characteristics constitute some of the primary requirements for defining a soil stratigraphic unit (Birkeland, 1974; Finkl, 1980) each cluster of soil profiles may therefore be regarded as representing one surface soil stratigraphic unit. As a soil stratigraphic unit is, by definition, found only at one stratigraphic interval, on a deposit of one age (Birkeland, 1974), and as each terrace surface is underlain by massive gravelly deposits, each surface soil stratigraphic unit should delimit a particular phase of sand and gravel deposition within the development of the Dovedale Griff valley fill.

Three surface soil stratigraphic units have been found to distinguish the terrace fragments in Dovedale Griff. The spatial significance of these soil stratigraphic units now needs to be assessed relative to the distribution of the alluvial landforms making up the valley fill of Dovedale Griff.

In Chapter 2 several trends were evident in the valley gradients of the terrace fragment slopes as they were represented on the height range diagram (Figure 2.5).The first of these is the presence of a series of steeply sloping higher terrace fragments which dominate the upstream and middle portions of the height distance diagram. As a consequence of the variation in terrace gradient between the higher terrace fragments and lower terrace fragments, the higher terraces converge downstream towards the lower levels. There is thus a contrast in the terrace sequence observed between a given cross-section upstream of fragment 17 and downstream of fragment 11. The question of the relationship between the terrace levels of the two sections of the stream may be resolved by examining the distribution of the surface soil stratigraphic units as they are shown in



0 Metres 100

KEY

①, ⑭, etc.	Terrace Fragments Numbered
16, 23, etc.	Soil Pits in Statistical Analysis
	Group I (Upper Terrace) Soil Stratigraphic Unit
	Group 2 (Middle Terrace) Soil Stratigraphic Unit
	Group 3 (Lower Terrace) Soil Stratigraphic Unit
	Ungrouped
	Edge of Valley Fill

DOVEDALE: TERRACE FRAGMENTS GROUPED USING AGE-CALIBRATED SOIL-STRATIGRAPHIC UNITS

Figure 3.6

Figure 3.6 and in relation to the terrace fragments shown on the height range diagram in Figure 2.5.

From the level of terrace fragment 17 upstream, all of the high terrace fragments possess massive sedimentary units whose surface soil profiles have the distinctive soil properties that combined to produce the Group 1 surface soil stratigraphic unit. Reference to the map in Figure 3.6 shows that upstream of fragment 8 these upper terrace fragments correlate into a surface which must, at some time in the past, have covered much of the valley floor in Dovedale Griff.

Downstream of fragment 11 there is no surface evidence of the sedimentary units distinguished by the Group 1 soil stratigraphic units. Rather the terrace fragment towards which fragment 17 and 11 converge is distinguished by surface soils which possess the soil properties distinctive of the Group 2 surface soil stratigraphic unit.

Three soil pits were excavated into fragment 8. These were pit 12, at the upstream end of the fragment, pit 14 in the middle of the fragment and pit 1 at the downstream end of the fragment (Figure 3.6).Reference to Figure 3.3,which gives the projection of the component 1 scores onto the principal axis, shows that although there is some variation in the scores of these soil profiles they all fall into the Group 2 soil stratigraphic unit. It is unlikely that variation in the scores of the three pits is interpretable in any other way than between site variability that would be expected for soils in the field, so it may be inferred that this fragment formed a part of the fluvial sedimentary unit that developed with the phase of sand and gravel accumulation associated with the Group 2 soil stratigraphic unit. The significance of the convergence of the upper terrace surface towards the surface distinguished by the Group 2 soil stratigraphic unit is discussed in Chapter 5.

Reference to the map in Figure 3.6 shows that the sedimentary units which are distinguished by the Group 2 soil stratigraphic unit occur extensively over the valley floor of Dovedale Griff. They are present both above the confluence with the Bridestones Griff and below the area where the upper terrace surface converges towards fragment 8. Terrace fragments whose surface soils

belong to the Group 2 soil profiles are present on both banks of the stream, although, as with the landform units associated with the Group 1 soil stratigraphic unit, not necessarily on both sides of the stream at a single cross-section. These terrace fragments are referred to as the middle terrace.

The distribution of the terrace fragments associated with the Group 3 soil stratigraphic unit are also shown on Figure 3.6. Reference to the height range diagram shows that there is sometimes less than 0.5m height difference between these terrace fragments and those associated with the middle terrace distinguished by the Group 2 surface soil stratigraphic unit. As with the landforms associated with the Group 2 soil profiles, the terrace fragments associated with the Group 3 soils are distributed throughout the length of the valley. However, these fragments have a much more limited areal distribution relative to the terrace fragments defined by the Group 2 and Group 1 soil stratigraphic units. The terrace fragments distinguished by the Group 3 soil stratigraphic unit are referred to as the lower terrace.

At the tributary junction of Egg Griff and Dovedale Griff a compound alluvial fan has been deposited. The fan is made up of a number of landform units and has a complex fan-in-fan structure (Figure 2.4) suggestive of several phases of sedimentation and incision. Soil pits were excavated into the various units making up the fan in order to relate the properties of the soils developed on the fans to the soil stratigraphic units on the Dovedale terraces. Exposures through the fan deposits revealed no evidence of overlapping stratigraphy or cut and fill.

Soil pit 7 in the outer, and highest, fan deposits revealed a mature soil profile which grouped with the Group 1 soil profiles in the cluster analysis. Soil pits 21 and 22 were located on the innermost fan unit. These sites revealed immature soil profiles and were clustered with the Group 3 soil profiles. In between the outer and inner fan units is an additional, quite extensive section of the fan, the middle fan unit. Unfortunately attempts to examine the soil stratigraphy of this middle section of the fan were unsuccessful. The deposits making up this section of the fan are extremely coarse and soil development on these deposits has been extremely limited. It seems

logical to argue, however, that as the outer, and highest, fan units are correlated with the upper terrace surface, and as the innermost fan units appear to correlate with the Group 3 terrace fragments, that the middle fan units may be correlated with the Group 2 terrace fragments.

3.9 The Morphological and Chemical Characteristics of the Soil Stratigraphic Units - A Discussion

Figure 3.7 is a diagrammatic representation of a typical soil profile from each of the three statistically-derived surface soil stratigraphic units. Plate 3.1 in Section 3.2 above showed a soil profile typical of the Group 1 soils whilst Plates 3.4 and 3.5 show a representative soil profile from Groups 2 and 3 respectively. Table 3.6 gives a representative field soil profile description from each soil group. The soil profile description for the Group 1 soils is seen to be very similar to that presented in Section 3.4 above, but is reproduced here so comparison can be made with the soil profile descriptions of the Group 2 and Group 3 soils.

Table 3.6 Representative Field Soil Profiles

Dovedale Soil Group	Group 1
Slope	0°
Vegetation	Grass, bracken, bilberry, heather
Soil drainage	Free
Parent material	alluvial gravels and sand
Major soil subgroup	brown podzolic soil

LF : 12.5 - 0cm; black 10YR 2.5/1; no mineral content; semi-fibrous; moist.

Ah : 0 - 14cm; very dark greyish brown 10YR 3/2; mineral-organic sandy loam; crumb structure; abundant medium roots and a few thick woody roots; moist; friable; many bleached grains; a few stones; gradual boundary.

Bw : 14cm - 19cm; dark brown 10YR 4/3; loamy sand; weak sub angular blocky structure; moist; friable; many medium roots; a few thick roots; a few stones; gradual boundary

Bs : 19cm - 35cm; strong brown 7.5YR 5/6; loam; some medium roots; many sub-angular to sub-rounded medium stones; moist; friable; fine, weak sub-angular blocky structure; merging boundary.

B/C : 35 - 50cm: yellowish brown 10YR 5/6; fine sand; very few fine roots; many sub-angular to sub rounded stones; moist; friable; single grain structure; merging boundary.

Cu: 51+cm; yellowish brown 10YR 5/4; fine sand; some sub-angular to sub-rounded medium stones; friable; massive.

GENERALISED SOIL PROFILE MORPHOLOGIES OF THE THREE DOVEDALE SOIL-STRATIGRAPHIC UNITS

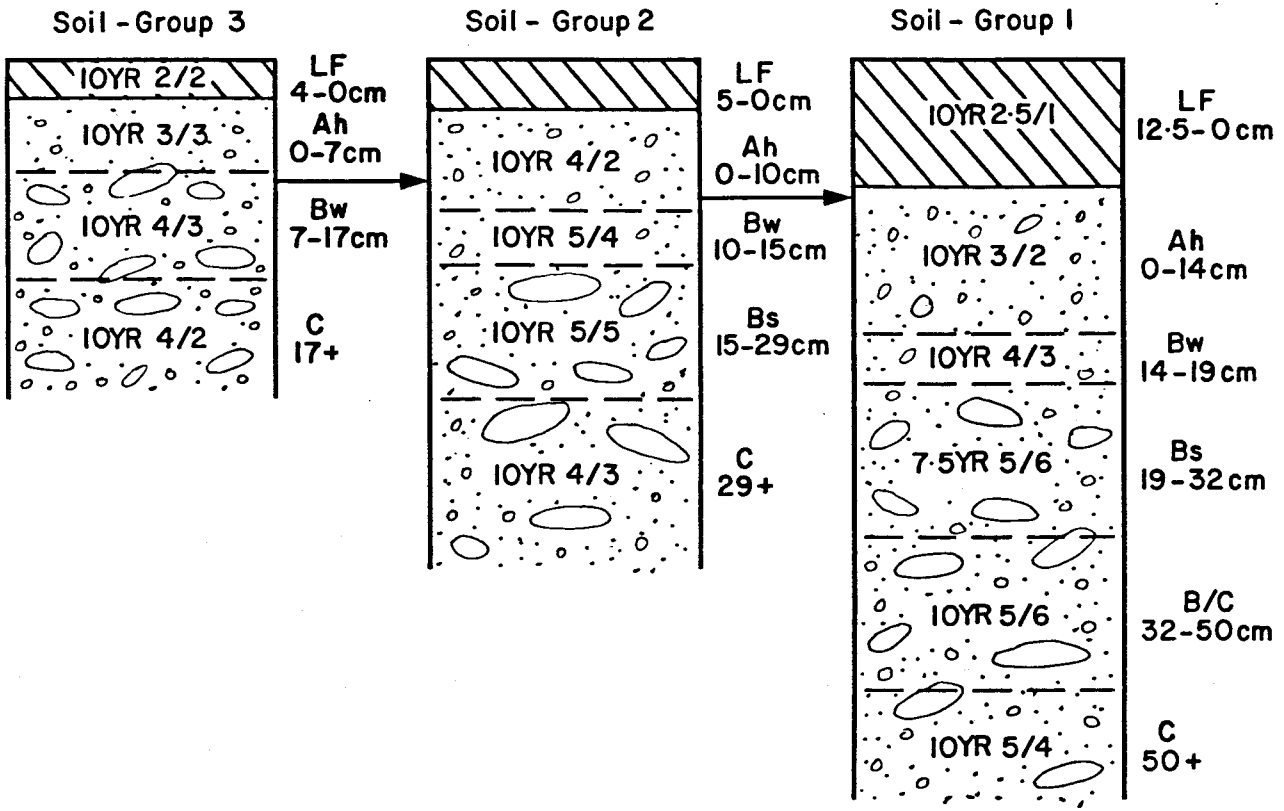


Figure 3.7

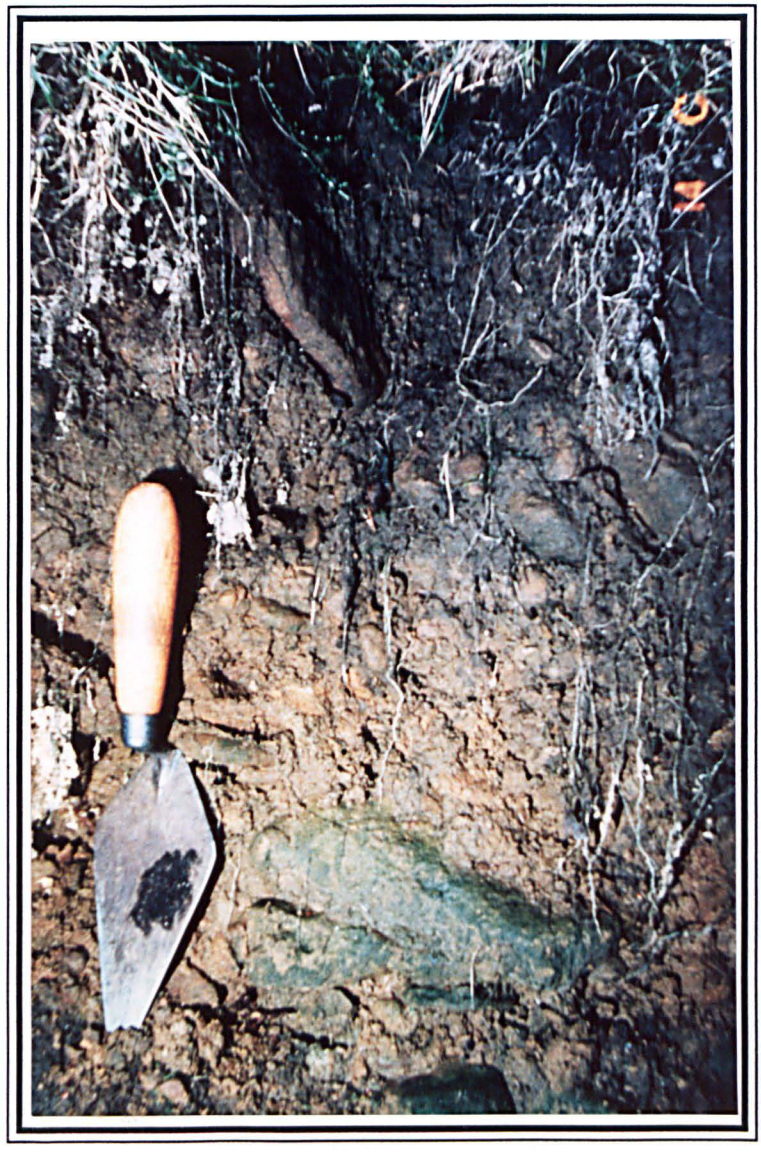


PLATE 3.4



PLATE 3.5

Dovedale Soil Group	Group 2
Slope	0°
Vegetation	Grass, bracken, bilberry, heather
Soil drainage	Free
Parent material	alluvial gravels and sand
Major soil subgroup	brown podzolic soil

LF : 5cm - 0cm; very dark brown 10YR 2/2; no mineral content; semi-fibrous; moist.
Ah : 0 - 10cm; dark greyish brown 10YR 4/2; mineral-organic loamy sand; crumb structure; abundant fine roots and a few thick woody roots; moist; friable; gradual boundary.
Bw : 10cm - 15cm; yellowish brown 10YR 5/4; sandy loam; crumb structure; moist; very friable; many fine roots; a few thick roots; some stones; gradual boundary.
Bs : 15cm - 29cm; yellowish brown 10YR 5/5; sandy loam; a few medium roots; many sub- angular to sub-rounded medium stones; moist; very friable; very weak crumb structure; merging boundary.
Cu : 30cm +: brown 10YR 5/3; fine sand; very few fine roots; many sub-angular to sub rounded stones; moist; friable; single grain structure.

Dovedale Soil Group	Group 3
Slope	0°
Vegetation	Grass, heather
Soil drainage	Free
Parent material	alluvial gravels and sand
Major soil subgroup	mineral alluvial soil

LF : 4cm - 0cm; very dark brown 10YR 2/2; no mineral content; semi-fibrous; moist.
Ah : 0 - 7cm; dark brown 10YR 3/3; mineral-organic sandy loam; weak crumb structure; many fine and medium roots; moist; very friable; sharp boundary.
Bw : 8cm - 17cm; brown 10YR 4/3; sandy loam; some fine and medium roots; very weak crumb structure; medium stones; moist; very friable to loose; moist; merging boundary.
Cu : 19cm +: dark greyish brown 10YR 4/2; fine sand; very few fine roots; many sub-angular to sub rounded stones; moist; friable.

Soil profile morphology is seen to vary between the three soil profile groups. The Group 1 soils are the most mature soil profiles. These soils have an LF/Ah/Bw/Bs/BC/C horizonation. The Group 2 soils typically possess an LF/Ah/Bw/Bs/C sequence of horizons, although the Bw horizon was not present at all the sites sampled. The Group 3 soils are weakly developed mineral soils with an LF/Ah/Bw/C horizon sequence. There is therefore a general increase in horizonation from the Group 3 soils to the Group 1 soils.

Horizon development, that is the thickness of individual horizons, the number of horizons in the profile and the distinctiveness of the horizons in the profile, can give a qualitative indication of soil

age as the development of an increasingly complex soil profile is partly, although not wholly, a function of the length of time available for the operation of the soil-forming processes.

Many soil chronosequence studies demonstrate that the development of an increasing number of horizons and increasing differentiation of surface individual horizons in the profile is a function of soil maturity. The soil stratigraphic studies carried out by Mahaney (1974, 1978) and Mahaney et al.(1981) demonstrate a marked change in horizon sequence from the weakly developed Gannet Peak soils of about 300-100bp in age to the well developed Pinedale soils of about 10,000bp age. The soils were part of a podzolic chronosequence and varied in horizon sequence from an A/Cox/Cn horizon sequence for the 300bp soils, to an A/B/C horizon sequence for the 2000-1000bp soils, to an A/Aeh/Bs/Cox/Cn horizon sequence for the mid Holocene soils and a complex A/Aeh/Bh/Bs/Cox/Cn sequence for the 10000bp soils.

Examining soil development on Quaternary terraces in Cajon Pass, California McFadden and Weldon (1987) show that soils of about 300bp have an A1/A2/Ac/Cox/Cu horizon sequence. Soils of about 5900bp have an A1/A2/Bw/Cox/Cu horizon sequence whilst soils of about 7500bp develop an additional B horizon possessing an A1/A2/BA/BW/Cox/Cu horizon sequence. Soils of about 8350bp have an even more complex sequence which includes an A1/A2/AB/2Bw1/2Bw2/2BC/2Cox/2Cu profile.

Similar changes in horizon sequence have been noted for soils in New Zealand. Here Birkeland (1984) examined soils from the Ben Ohau and Mount Cook areas. He found that in both areas the soils developed an increasing number of horizons with soil age. For example, in the Mt. Cook area soils of about 500bp had an A/Cox/Cu horizon sequence, soils of about 1200bp had an A/Bw/Cox/Cu horizon sequence whilst soils of about 8000bp had a sequence of complex horizons, A/E/Bs1/Bs2/Bs3/.

In upland Britain a change in number of horizons with age of soil has been noted for podzolic soils (Robertson-Rintoul, 1986a). An horizon sequence ranging from an Ah/BC/C horizon

sequence for 80bp soils, to an HA/Bs/C sequence for 1000bp soils, to an H/A/Bs/C sequence for 3500bp soils and an H/Aeh/Bhs/Bs/C sequence for 10,000bp soils was described.

These studies have been carried out from a wide range of environments on differing soil types and possess differing methods of soil horizon classification. Nevertheless, in combination they indicate that an increasingly complex horizon sequence is a characteristic of the length of time available for the operation of the soil-forming processes. In general it may be suggested that youthful soils of only a few hundred years in age tend to have only weakly developed profiles, late Holocene soils begin to develop recognisable B horizons whilst soils of mid-to- early Holocene age possess multiple soil horizons and well developed soil profiles.

As soil profiles develop more pronounced horizonation B horizon thickness and total solum depth generally increase. This is illustrated in podzolic soils by two studies with well dated soil chronosequences. In a podzolic soil chronosequence in Norway, Ellis and Richards (1984) show an increase in total solum depth from 21cms for a soil about 55 years old, to about 32cms for a 500 year old soil and 45cm for a soil about 9000 bp in age. For the Glen Feshie podzolic soils, the youngest soil-stratigraphic unit possessed soil depths of about 10cm. This unit was dated to about 80bp. The soil-stratigraphic unit dated to about 1000bp had total solum depths of about 20cm, whilst the unit dated to about 3500bp had depths of about 35 to 45 cms. The 10000bp unit had total solum depths of about 70-80 cms and that of the 13000bp soils about 175cms, the latter depth including a Bx horizon (Robertson-Rintoul, 1986a).

B horizons were also shown to thicken as total solum depths increased. In the Glen Feshie podzolic soils B horizons increased from about 6cm in the 80bp soils, to about 10cm for the 1000bp soils, to about 21cm for the 3,500bp soils, and to about 40cm and 55cm for the 10000bp and 13000bp soils respectively. Similar trends have been observed by McFaddon and Weldon (1986), Mahaney (1974, 1978) Mahaney et al.(1981) and Birkeland (1984) who also showed increases in total solum depth and B horizon thickness with length of time available for the operation of the soil-forming processes.

In Dovedale Griff the average total solum depth for the soil stratigraphic unit 3 is about 15-20cm whilst that for the Group 2 soils is about 30cms. The Group 1 soils are considerably deeper than those for the other groups and average total soil depths of about 50cm. B horizons show similar changes. The average B horizon depth for the Group 3 soils is about 9-10cm, for the Group 2 soils about 15cm and for the Group 1 soils about 20-25cm.

Considering these data together with that concerning the horizon development and published chronosequence data, the Group 3 soils are likely to very young, probably only a few hundred years old at the most whilst the Group 1 soils are likely to be considerably older, probably mid-to-early Holocene in age. The degree of profile development exhibited by the Group 2 soils suggests that these soils are likely to be of late Holocene age.

The changes in soil depths and horizon sequence from the Group 3 to the Group 1 soils are accompanied by increasing distinction in the individual horizons making up the profiles. This change in status of the horizon boundary is reflected in the field variable, Relative Horizon Distinctiveness (RHD) defined in Section 3.5 above.

RHD indices were derived for the A : B horizons of the Dovedale soils. The average value for the RHD for the Group 1 soils was 5.5. The Group 2 soils averaged values of 3.5 whilst the Group 3 soils had a mean value of 1.5. There is thus a clear distinction in value of RHD between the soil profiles of the 3 soil stratigraphic units.

The between group differences in soil profile morphology are reinforced by an examination of the Colour Development Equivalents (CDE's) derived for the soil profiles. The average value for the B horizon CDE's for the Group 3 soils is 8, for the Group 2 soils is 13 and for the Group 1 soils is 20. Principal colouring agents in the soil are generally thought to be iron, released by weathering of iron-bearing minerals, and organic matter, incorporated into the soil material by faunal mixing and/or translocation. The colour of the B horizon may therefore result from the operation of either or both of the above processes and be expected to be reflected in the value of the CDE's

calculated for the soil profiles. According to Bockheim's use of the the CDE variable the between group differences in value of this variable would suggest that the Group 3 soils are still in the early stages of development whilst the rise in value for the CDE's from the Group 2 to the Group 1 soils may be suggestive of increasing intensity of soil development and soil age.

The morphological differences between the 3 groups of soil profiles are accompanied by changes in the selected chemical properties of the soils analysed in this study. Several parameters were used to represent variation in iron with the soil profiles. These include the magnetic susceptibility of the surface soil horizon, % of pyrophosphate extractable iron in the A horizons, the ratio of B to C horizon pyrophosphate extractable iron, and the ratio of B to C horizon dithionite extractable iron.

Magnetic susceptibility measurements were carried out on each surface horizon for the Dovedale soils. Magnetic susceptibility of the surface horizons of the soils was included as a quantitative parameter of soil development for several reasons. First it is a variable that can be measured easily in the field and could therefore be combined in a quantitative index of soil profile development based on properties measurable in the field. Second, and as suggested by Thompson and Oldfield (1986) it is possible to detect changes in magnetic minerals at concentration orders of magnitude below detection limit of conventional methods, so it may be a useful complement to traditional geochemical analyses of soil profiles.

Magnetic susceptibility is a measure of the ease with which a material can be magnetised. The magnetic susceptibility of the topsoil, or organic mineral horizon is often higher than that of the subsurface horizons. These topsoil horizons have experienced magnetic enhancement and this seems to be a characteristic of many soils under temperate conditions. Probably one of the most important ways in which magnetic enhancement takes place in the topsoil is through the formation of microcrystalline maghaemite or magnetite from weakly magnetic iron oxides and hydroxides via the oxidation-reduction cycles which occur during the operation of the soil-forming processes. Although the processes are poorly understood it seems likely that the formation of

organo-metallic complexes in the topsoil may be important. Magnetic enhancement may also take place as a result of burning. However, Thompson and Oldfield (1986) suggest that the relative importance of the operation of the soil-forming processes in contributing to magnetic enhancement of topsoils may be indicated by the high enhancement of many old forest soils and by the evenness of topsoil magnetic enhancement over wide areas with comparable lithology. Certainly the observation of consistent enhancement of surface profiles in which the build up and decomposition of organic matter is one of the major processes, would support the suggestion that magnetic enhancement must be associated with the accumulation of organic material in the soil.

Values for magnetic susceptibility and pyrophosphate extractable iron for each A horizon sample are plotted on Figure 3.8. The plot shows that as the amount of Fe_p in the A horizon of the soil increases there is a corresponding rise in the magnetic susceptibility of the topsoil. This variable loaded less highly onto the first conponent, therefore suggesting that its trend with age is less clear than those of the other iron variables. However, the variation of magnetic susceptibility with pyrophosphate extractable iron, that is the iron associated with the formation of organo-metallic complexes in the soils, lends support to the observation that magnetic enhancement of the topsoil is associated with accumulation of organic material in the upper horizon and the formation of organo-metallic complexes.

Dearing et al. (1985) suggest that the factors controlling soil magnetic mineral assemblages are essentially the same as those controlling the development of soil profiles as given in Jenny's (1941) equation. These are the factors of parent material, climate, organisms, relief, and time. To date little work has been carried out to assess the effects of the length of time available for the operation of the soil-forming processes. The preliminary findings presented here suggest that there could be a trend with respect to age of the soil and the magnetic enhancement of topsoils in brown podzolic soils.

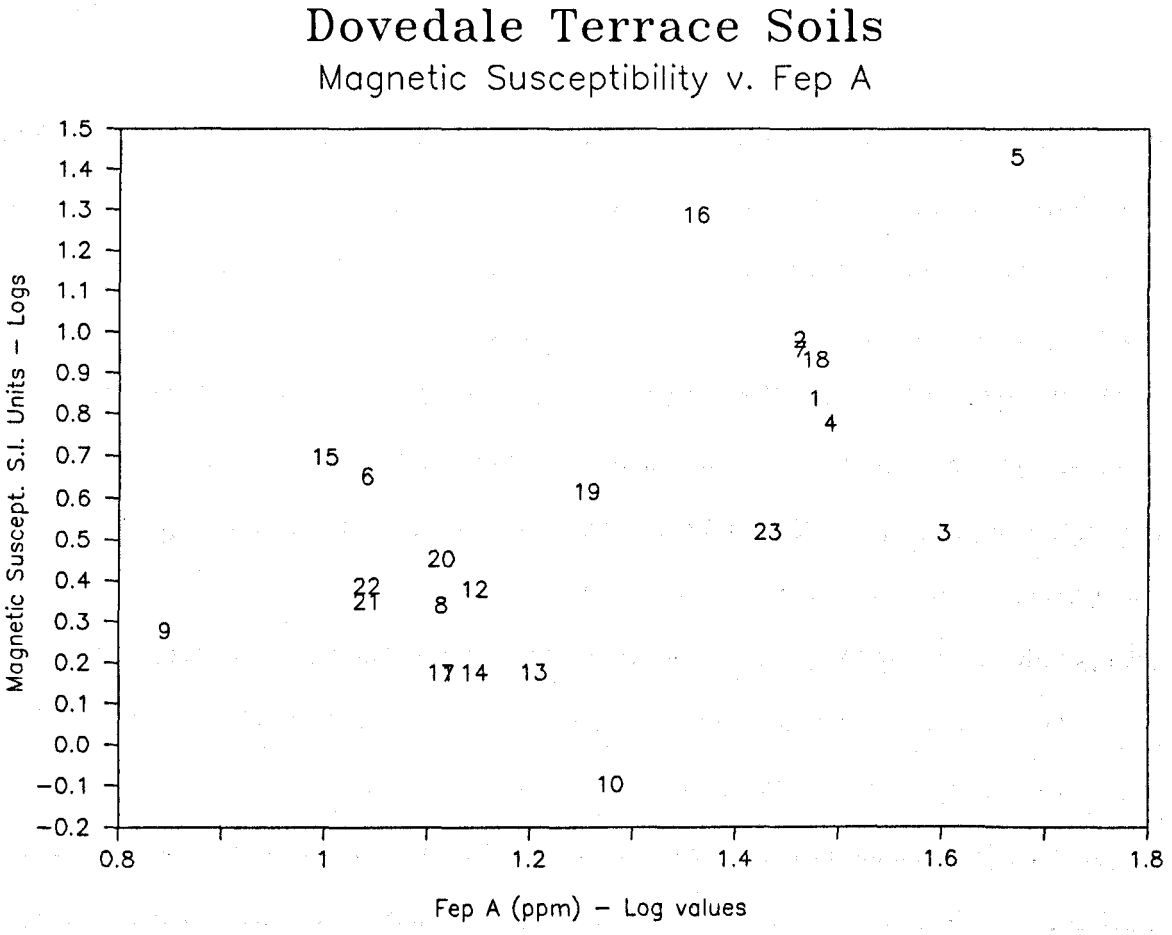

Dovedale Terrace Soils
Magnetic Susceptibility v. Fep A
Magnetic Suscept. S.I. Units – Logs
Fep A (ppm) – Log values
1.5
1.4
1.3
1.2
1.1
1.0
0.9
0.8
0.7
0.6
0.5
0.4
0.3
0.2
0.1
0.0
−0.1
−0.2
0.8
1
1.2
1.4
1.6
1.8
5
16
2
7
18
1
4
15
6
19
23
3
20
22
21
12
8
9
17
14
13
10

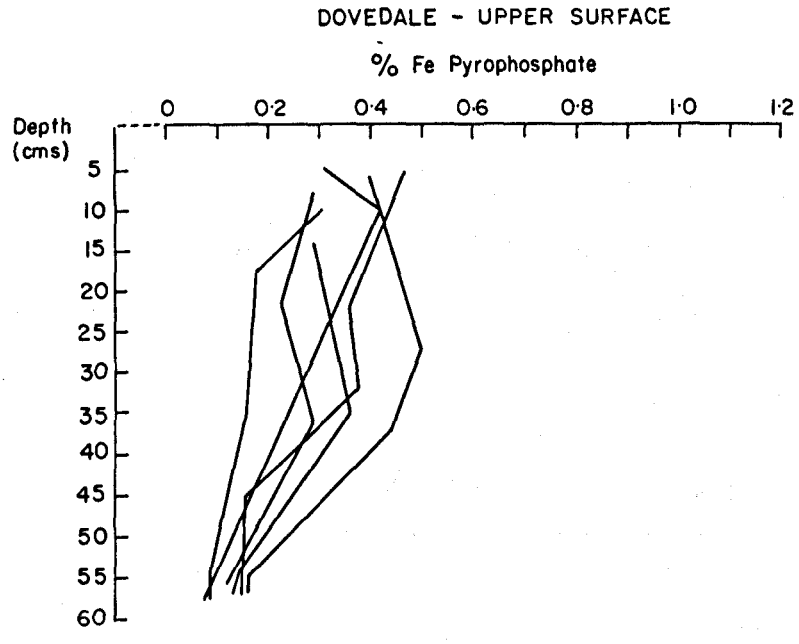
Figure 3.8

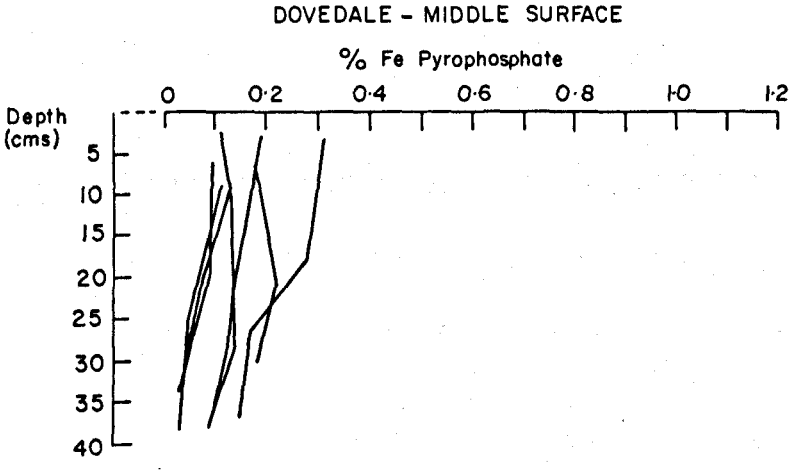
Figure 3.9 and 3.10 show depth function plots of pyrophosphate and dithionite extractable iron for the 23 soil profiles used in the analysis to derive the soil stratigraphic units in Dovedale Griff. These plots show marked differences in the depth functions between the 3 soil groups for both pyrophosphate extractable and dithionite extractable iron. Quantities of Fe_p are consistently lower than the values for Fe_d which may perhaps reflect a dominance of inorganic translocation of iron in these soils.

For the Fe_p plots there is generally an increase in the area under the iron curves from the Group 3 to the Group 1 soils. This suggests an increase in the amount of Fe_p present within the soil profiles from the Group 3 to the Group 1 soils, as was demonstrated with the % Fe_p in the A horizons of the soils. Most of the profiles, however, show evidence of accumulation of Fe_p in the B horizon although there is variation in the location of the peak of Fe_p within the soil profiles. Most of the Group 1 and some of the Group 2 soils exhibit a subsurface peak of Fe_p, although amounts of Fe_p in the Group 2 soils are lower than those for the Group 1 soils. The increase in Fe_p in these horizons suggests the formation of organo-metallic complexes whose mobility may be responsible for the transfer of these soil constituents from the upper soil horizons through the profile. Morphological evidence of translocation from the upper horizons does not take the form of a bleached horizon as in podzols. However, the presence of bleached grains in the upper organic-mineral horizons may be suggestive of depletion of material from this horizon. Peaks of Fe_p in the Group 1 soils range around 0.4%-0.45% which is slightly lower than the value of 0.6% recorded for the Howard Series soil analysed in Section 3.4 above. Some of the Group 2 and all of the Group 3 soils show a surface maxima of Fe_p and decreases with depth below the organic-mineral horizon. Quantities of Fe_p in the Group 3 soils are lower than those of the Group 2 soils. Surface maxima of Fe_p have been reported for young podzolic and brown podzolic soils where it has been suggested that organically related processes tend to be concentrated near the soil surface (Mellor, 1985; Robertson-Rintoul, 1986a).

The index used to represent accumulation of sesquioxides in the B horizon, the ratio of B to C horizon iron, suggests that there is a trend of accumulation and build up of organically-bound

DEPTH FUNCTION PLOTS FOR FeP
DOVEDALE TERRACE SURFACE SOILS





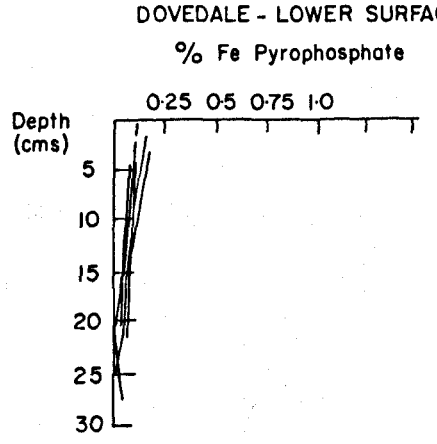
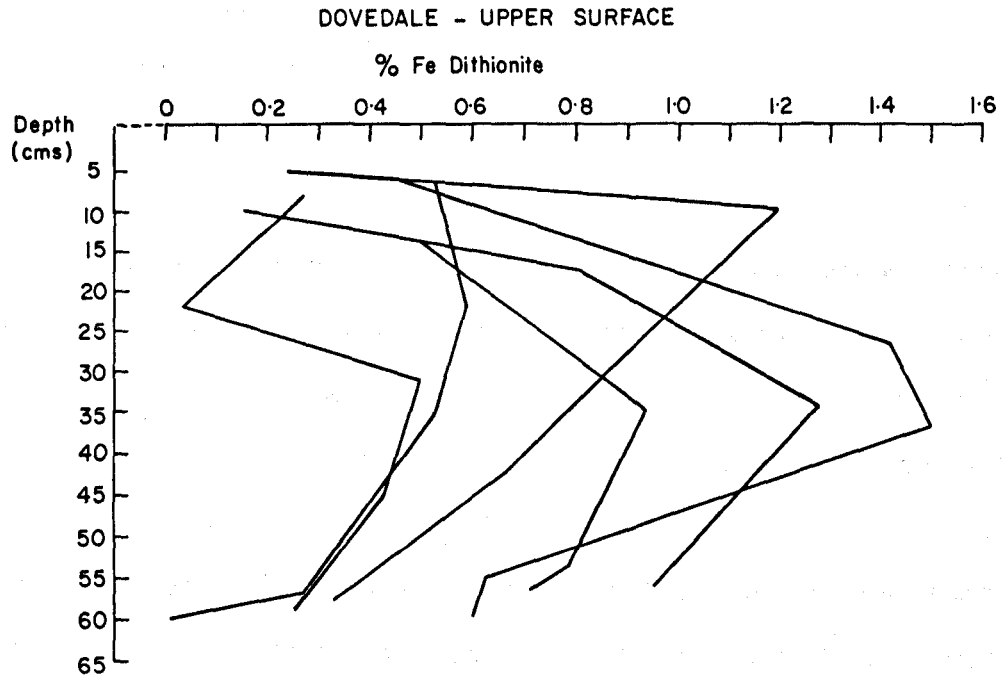
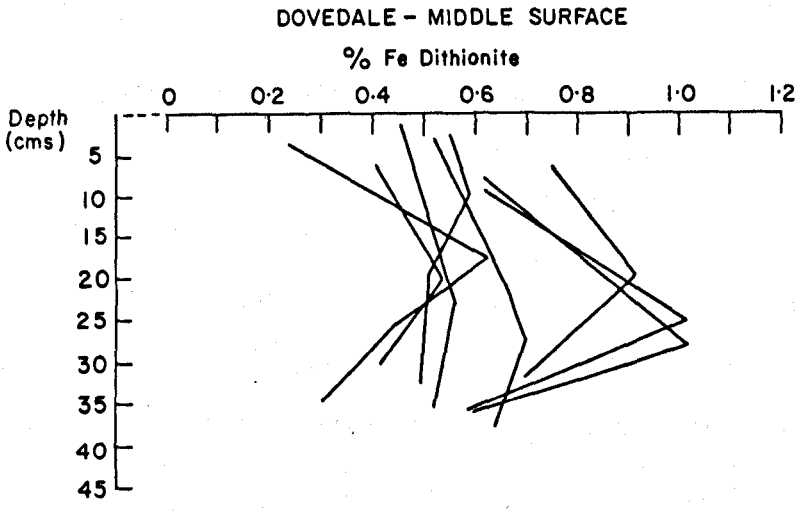


Figure 3.9

DEPTH FUNCTION PLOTS FOR FeD DOVEDALE TERRACE SOILS





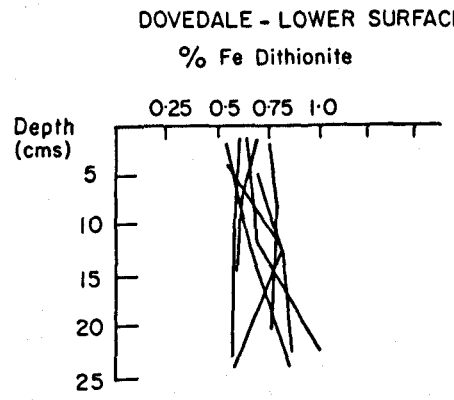


Figure 3.10

iron in the Dovedale profiles. Values for the accumulation index for the Group 1 soils range from about 4.9 to 2.24, whilst those for the Group 2 soils range from about 1.59 to 1.2. Those of the Group 3 soils vary from about 1.0 to 1.2. Overall, the accumulation index shows an increasing amount of organically-bound iron accumulating in the B horizons of the soils from the Group 3 to the Group 1 profiles.

Dithionite extractable iron data provide a measure of the more crystalline components of iron, the inorganic iron, in the soil profile (Childs et al., 1983). The depth function plots for Fe_d show that in the majority of profiles there are increases with depth below the surface organic mineral horizon. Maxima of Fe_d occur most frequently in the B horizons, and with some of the Group 3 soils in the C horizon. As with the depth functions of Fe_p, the Fe_d depth functions show marked differences in the area under the curves for the three groups of soils. The Group 1 soils show a markedly greater area under the curve than the Group 2 soils, suggesting a much greater amount of Fe_d present in the Group 1 soil profiles.

The accumulation index, the B to C horizon ratio of Fe_d suggests that Fe_d is accumulating in the B horizons relative to the C horizons. Indices of greater than 1 show that there is a greater amount of Fe_d in the B horizons relative to the C horizons. Group 1 soils have values that range from 3.6 to 2.2, whilst those for the Group 2 soils range from 1.3 to 1.15. The Group 3 soils show indices that range around 1 to less than one indicating C horizon maxima of iron. The iron enrichment of some of the C horizon samples from the Group 3 soils may possibly be due to ground water alteration rather than pedogenesis. Some of these profiles showed evidence of mottling and some gleying in the C horizons, probably due to their close proximity to water level.

Variation in iron content of soil profiles is one of the most common variables used to assess variation of soil profiles in a chronosequence. This is because, as pointed out by Yaalon (1971) and Birkeland (1978) iron, and particularly the aged or crystalline iron represents a slowly adjusting property which does not reach a steady state by 10^3 years. A number of studies including those of Mahaney (1974, 1978), Mahaney et al. (1981), and Mcfadden and Weldon

(1987) show trends in Fe_d that are comparable with the findings from Dovedale. Ellis and Richards (1985) in their examination of a chronosequence of podzolic soils in Norway demonstrated a trend of illuviation of organically-bound and inorganically translocated iron in the B horizons of the soils they examined. Fe_d B to C horizons ratios of 1.1 were achieved for the 55 year soil, 1.29 for the 500 year old soil and values of 2.37 for the 9000bp soil. In the Cairngorms chronosequence, Robertson-Rintoul (1986a) found a progressive trend in Fe_d from the group 5 (youngest) to the group 1 (oldest) podzolic soils. Depth function curves show a marked increase in the area under the curve from the 80bp through to the 13,000bp soils. Ratios of B to C Fe_d calculated for these soils showed a variation in value from about 7.2-6.6 for the group 1 soils (13,000bp), 3.8-2.5 for the group 2 soils (10,000bp), 1.5-1.75 for the group 3 soils (3,500bp), to about 1.3 for the group 4 soils (1000bp) and 1.1-1.2 for the group 5 soils (80bp).

Examination of the between group differences for the data for the iron variables from Dovedale and comparison of these data with published soil chronosequences again supports the argument raised above that the Group 1 Dovedale soils are likely to be considerably older than either the Group 2 or Group 3 soils. However, these data also suggest a significant difference in maturity of the Group 2 soils over those of the Group 3 soil profiles.

3.10 Conclusion

The surface soils developed into the massive gravelly deposits of the Dovedale Griff terrace fragments have been divided statistically into three groups of soils using a combination of Principal Components Analysis and Cluster Analysis. The Principal Components Analysis abstracted the main variance trends from the data matrix of soil properties whilst the Cluster Analysis statistically allocated the soil profiles into groups on the basis of their principal component scores. The first principal component was shown to be a compound index of soil properties that are representative of some of the main morphological and chemical properties of evolving brown podzolic soils.

Several of the profiles making up the Group 1 soils are coincident with the upper terrace soils discussed in Section 3.4 which were shown to be mature brown podzolic soils. The Group 2 soils share some of the characteristics of the Group 1 soils but are less mature profiles. The Group 3 soils are immature and probably very youthful soils. It is possible to suggest that the sequence of soils described above represent an age sequence of soils the end members of which are brown podzolic soils.

Each cluster of soil profiles may be regarded as representing one soil-stratigraphic unit. These units may be distinguished one from the other on the basis of a number of morphological and chemical characteristics with each group of profiles possessing a distinguishing range of values. Although absolute ages have not yet been assigned to the soil stratigraphic units in Dovedale, the discussion in Section 3.9 above strongly suggested that the soil profiles forming the Group 1 soil-stratigraphic unit are likely to be mid-to-early Holocene in age whilst the Group 2 and Group 3 surface soil stratigraphic units are likely to be considerably younger, probably late Holocene and very recent. This suggestion would be compatible with both the wide separation in principal component scores between the Group 1 soils and the Group 2 and 3 soils.

Three principal alluvial surfaces may be inferred from the development of the three surface soil stratigraphic units. These three surfaces together make up the valley fill landforms of Dovedale Griff. The phases of aggradation associated with the fluvial sediments making up the alluvial landforms distinguished by the Group 1 and Group 2 soil stratigraphic units are widespread over the valley floor. Although the sedimentary units associated with the Group 3 soil profiles show only very small height differences with the terrace fragments associated with the Group 2 soils, the soil-stratigraphic evidence discussed in Section 3.9 above suggested that the age differences between units 2 and 3 is likely to be significant. The landforms associated with the Group 3 soil-stratigraphic units are more restricted in areal extent, although they may be found the length of the valley floor in Dovedale. These three alluvial surfaces are associated with three phases of terrace development in Dovedale Griff and may also be associated with three phases of alluvial fan development at the junction between Egg Griff and Dovedale Griff.

Chapter 4

Dating Control, Discriminant Analysis and the Soil Stratigraphy of Jugger Howe Beck

4.1 Introduction

In the previous chapter three surface soil stratigraphic units were identifed using the surface soil profiles developed on the terrace fragments in Dovedale Griff. Comparison of soil horizonation together with several morphological and chemical characteristics of the soils with published data suggested that the Group 1 soils probably began to develop about the early-to-mid Holocene period, whilst the Group 3 soils probably began to develop very recently, within the last few hundred years. The Group 2 soils were suggested to be of late Holocene age. However, no absolute dating control was presented for the soil-stratigraphic units.

The present chapter is therefore concerned to develop some absolute dating control which will enable the surface soil stratigraphic units to be placed within the context of the Holocene time scale. The chapter begins with a discussion of the available C^{14} dating control which will be used to estimate the approximate ages of the three soil groups. The stratigraphy of the C^{14} sites is described and the significance of the C^{14} dates is discussed in the context of the soil sequence.

Only three sites with C^{14} dating control are available, so any conclusions made regarding the ages of the surface soil stratigraphic units must be regarded as tentative. Further, very little C^{14} dating control is available from Dovedale Griff itself, with two of the three C^{14} sites being located in the study reach in Jugger Howe Beck. For this reason the C^{14} dates are supported by some additional dating control from soil pollen extracted from two soil profiles in Dovedale Griff and by a C^{14} date from an infilled bog in Bridestones Griff, a tributary to Dovedale Griff.

Following the discussion of the dating control available for the soil groups the chapter develops a statistical procedure for allocating new, ungrouped soil sites to one or other of the previously recognised soil stratigraphic units. Discriminant analysis is used to allocate the soil sites with C^{14} dating control to an established soil group with the smallest probability of error or misclassification. This procedure will then provide some age calibration for the three soil stratigraphic units derived from the Dovedale Griff soil sites.

The age-calibrated surface soil stratigraphic units from Dovedale Griff are then used to interpret the alluvial surfaces of the Jugger Howe Beck study reach. Data from the soil profiles developed into the deposits of the Jugger Howe Beck landforms are discussed and classified using the discriminant analysis procedure. This enables the landforms into which the soils are developed to be correlated with surfaces of the same relative age, and also enables estimates to be made of the ages of undated valley floor surfaces. An additional set of mature soil profiles is also identified on the main alluvial fan and upper bench which forms a dominant surface in the study reach of Juggerhowe Beck. It is proposed that these soil profiles constitute a fourth soil stratigraphic unit and an estimate is made of its age.

4.2 Dating Control for the Soil Stratigraphic Units

4.2.1 The Group 1 Soils

Some dating control for the Group 1 surface soil stratigraphic unit comes from a C^{14} dated site in Dovedale Griff. At the downstream end of the Dovedale Griff study reach the stream is confined by a valley constriction (Chapter 2). As the stream emerges from the narrow constriction it flows towards Staindale through gravelly terrace deposits. The terrace deposits on the east bank of the stream have been trenched by Dovedale Griff which has therefore revealed a section through the deposits. The location of the section is shown on Figure 2.3 above.

Stratigraphy of the Site

Richards (1981) suggested that the section could be divided into two main stratigraphic units, a basal unit consisting of sub-fossil wood set in a mixture of sand, pebbles and silt lenses, and an upper unit about 1.5m thick. The upper unit was suggested to show some lateral variation but basically was comprised of two layers of pebbles separated by a mixture of sand and gravel.

Although there is lateral variation of the deposits in the section, re-examination of the whole section exposed by Dovedale Griff has revealed three main stratification units (Figure 4.1). At the base of the exposure, at present river level, and as identified by Richards (1981) is Unit 1. This is comprised of in-situ sub-fossil wood set in gravelly deposits with a sand and silt matrix. The wood in the unit includes in-situ stumps of willow and alder, and some detrital wood including large fragments of oak.

Unit 2 is a massive layer consisting of imbricated alluvial gravels with an abundant fine sand matrix. The lower 1m of the unit is olive brown in colour, with a moist Munsell Chart colour of 2.5YR 4/4. Some fining upwards of clast size is evident towards the top of the unit. The upper 30-40cms of the unit exhibits a marked difference in colour to the lower part of the unit. This upper part of the unit is well drained and shows no evidence of gleying or iron pan formation. The characteristics of the upper part of Unit 2 suggest that it is likely to represent the truncated profile of a formerly well developed brown podzolic soil, and this is accordingly identified in Figure 4.1 as Unit 3.

Unit 4 is a gravel layer set in a sandy matrix. Generally the clasts in Unit 4 are matrix supported, although in some sections of the unit they are clast supported. The clasts show marked imbrication with the dip of the A/B planes indicating deposition by a former Dovedale Griff flowing in a southerly direction (Richards, 1981). The lower 30cm of Unit 4 has a dark yellowish brown colour, a moist Munsell Colour of 10YR 4/4. Developed into the upper 35cm of the deposit is the modern or surface soil of the deposit.

DOVEDALE GRIFF C^{14} SITE STRATIGRAPHY

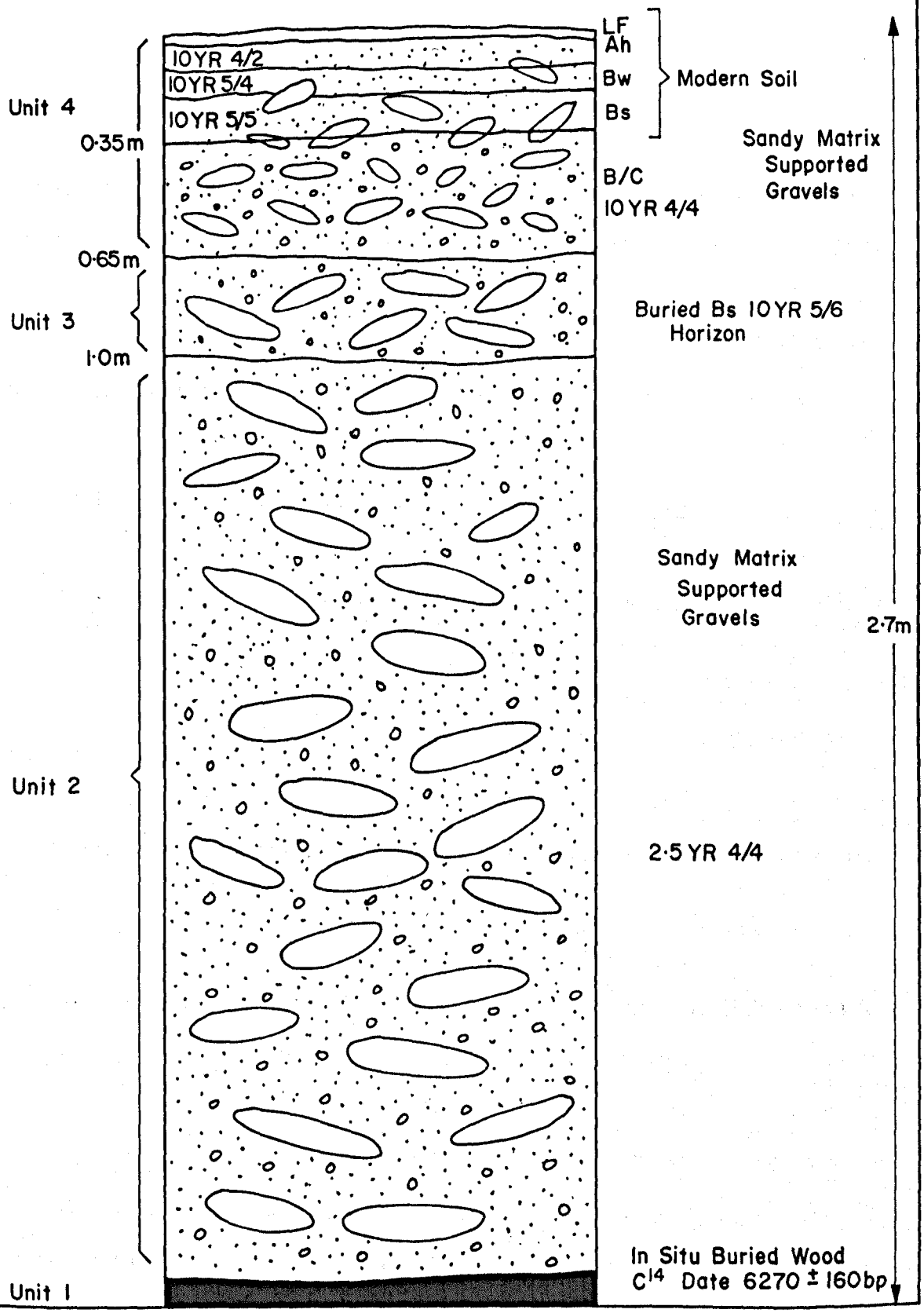


Figure 4.1

As it is the significance of the radiocarbon date that is the present focus of interest, the characteristics and significance of the stratigraphic units of the C^{14} section, and their relationship to the development of the terraced surfaces upstream of the valley constriction in Dovedale Griff is deferred until Chapter 5.

Radiocarbon dating

A C^{14} date obtained from one of the in-situ alder stumps from the basal unit was submitted for radiocarbon assay and yielded a date of 6270+/-160bp (Richards, 1981). Clark's calibration curve converts this to a calendar date of approximately 7140BP, or 5160BC and provides a date for the phase of alluviation responsible for burying the sub-fossil wood and the floodplain into which the trees were growing.

Significance of the date in the context of the soil sequence

Richards (1981) suggested that the Holocene sediments which bury the dated wood are probably related to a terrace surface upstream of the valley constriction. If this is the case then the C^{14} date which provides the date of burial of the wood can provide an approximate date for one of the terrace surfaces in Dovedale Griff. Assessment of the significance of the C^{14} date from the buried wood and its relationship to the terrace fragments upstream of the valley constriction requires further reference to the height range diagram developed in Chapter 2, the slope changes it reveals and the soil stratigraphy from the terrace surfaces.

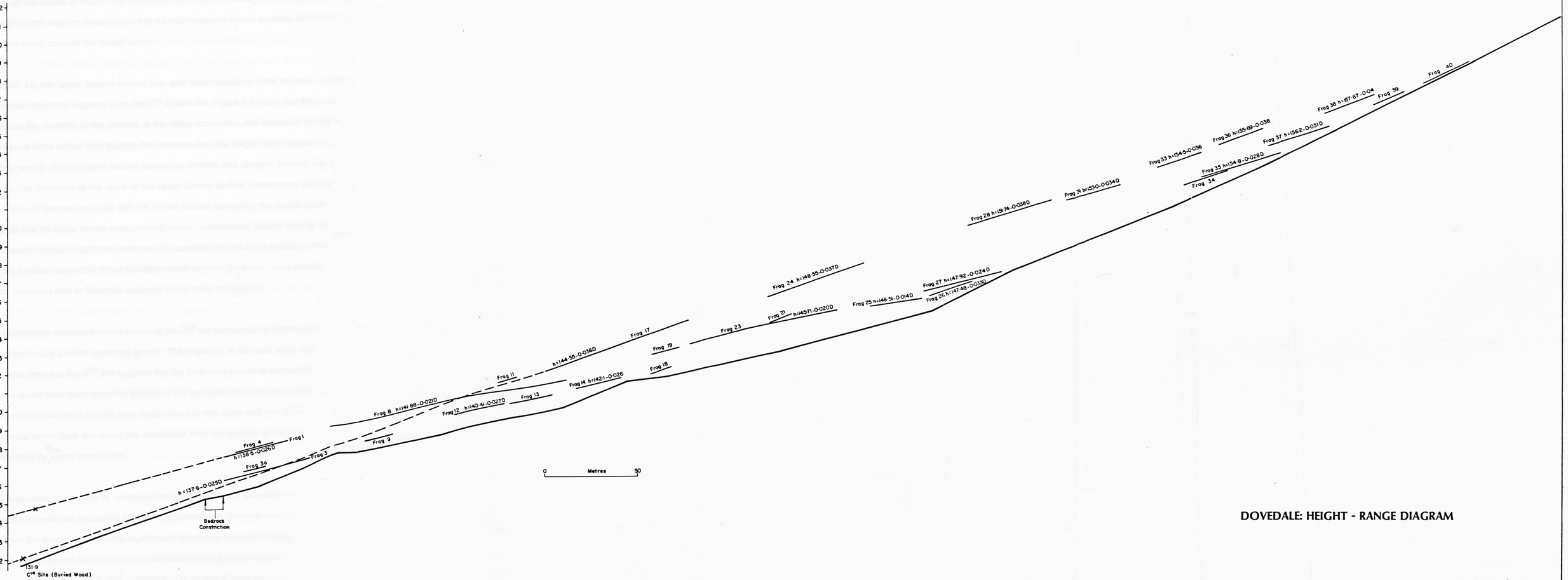
Examination of the soil properties of the surface soil at the C^{14} site revealed that it has an LF/AH/Bw/Bs/C soil profile comparable with that of the Group 2 soils further upvalley. The total soil depth is about 30cm with a Bs horizon thickness of 15cm. Moist Munsell soil colours vary from 10YR 4/2 (dark greyish brown) for the Ah horizon to 10YR 5/5 (yellowish brown) for the Bs horizon. The colour of the C horizon is 10YR 4/4 (dark yellowish brown). Iron ratios for this soil are 1.52 for Fe_p and 1.4 for Fe_d. Reference to Chapter 3 reveals that these soil characteristics are

more comparable with the Group 2 rather than the Group 1 soils developed on the terrace fragments upvalley. Inclusion of the soil data for this surface soil at the C^{14} site into the statistical analysis below (see Section 4.3) confirms the grouping of this surface soil with the soils which make up the Group 2 soil stratigraphic unit.

As a soil stratigraphic unit is, by definition, found only at one stratigraphic interval, on a deposit of one age (Birkeland, 1974) the soil stratigraphic evidence from the Dovedale Group 2 soils suggests that the parent materials of the Group 2 soils upvalley and the Group 2 soil at the C^{14} site are likely to belong to one phase of gravel deposition. This is further confirmed by reference to the height range diagram, (Figure 4.2).

During the course of the surveying for the height range diagram in the Dovedale study reach, the downstream section of the stream and the terraced gravels which cut across the bedrock constriction were also surveyed. The height of the base of the section which contains the dated alder stumps, as well as the top of the section were surveyed. The survey data showed that the cut section varied in vertical extent from about 2.2m to 2.8m. At the dated site the surface was 2.7m above the buried wood. The absolute height of the deposit which contains the tree stumps is 131.9m above sea level and the height of the present day land surface is 134.6m above sea level.

In Figure 4.2, the two height points from the section containing the buried wood have been added to the height range diagram. The height range diagram shows that the most downstream expression of the middle terrace which sustains the Group 2 soils above the valley constriction is fragment 1. In Figure 4.2 the slope of this fragment has been projected downstream to the C^{14} site section. At the C^{14} section site this projected line has a height of 134.8m. This is 20cm higher than the surveyed height for the surface of the section which contains the buried wood. The soil evidence and the evidence from this projection strongly suggests that the present land surface at the C^{14} site section is the downstream continuation of the middle terrace gravels upstream. The combination of the soil stratigraphic evidence, the stratigraphic units identified as



DOVEDALE: HEIGHT - RANGE DIAGRAM

FIGURE 4.2

making up the section at the C^{14} site as well as the terrace morphology as it is represented by the height range diagram demonstrates that the middle terrace cannot correlate with the former floodplain which contains the buried wood.

In Figure 4.2 the upper terrace surface has also been projected from its most extensive downstream fragment, fragment 17, to the C^{14} section site. Figure 4.2 shows that this projection lies above the elevation of the bedrock at the valley constriction and intersects the surveyed height point of the buried alder stumps. This evidence from the height range diagram suggests that the steeply sloping upper surface converges towards and plunges beneath the middle terrace. The projection of the slope of the upper terrace surface downstream and the close intersection of the projected line with the former surface containing the buried alder stumps suggests that the upper terrace most probably formed a continuous, steeply sloping, floodplain that extended the full length of the valley from the upstream reaches of the stream to the C^{14} site. It would therefore appear the former floodplain which contains the buried wood correlates with a former floodplain level in Dovedale upstream of the valley constriction.

The stratigraphic evidence from the section at the C^{14} site shows that the dated wood has been buried by the Unit 2 matrix supported gravels. The projection of the valley slope represented by the upper terrace to the C^{14} site suggests that the most likely source of sediment for the Unit 2 gravels would have been upstream incision of the floodplain and deposition of the evacuated sediment downstream in a valley wide readjustment of river slope and bed elevation. Thus the sediments which bury the wood are associated with the incision of the former floodplain represented by the upper terrace level.

The suggested mechanism of upstream channel incision and associated bed lowering and downstream sediment deposition and bed aggradation has historical analogues. For example, the River Eel in northern California experienced substantial changes in channel slope and bed elevation as a result of the redistribution of large quantities of unconsolidated Holocene alluvial fill deposits (Patrick et al. 1982). This redistribution of sediment occurred in response to the 1964

flood which had a return period of greater than 100 years. This flood resulted in the river degrading its bed in the upper and middle reaches of the river and aggrading its bed in the downstream reaches where the transported sediment was deposited as a wedge over the former floodplain. In Walker Creek, California, Haible (1980) has described how the creek has, in historical times and over a period of about 60 years, incised about 1.5m in its upstream reaches and deposited the evacuated sediments in the downstream reaches burying two former terrace levels in the process. Similarly, discussing arroyo cutting and filling in the semi-arid south-west USA, Patton and Schumm (1981) observed that erosion and incision in one river reach is frequently balanced by aggradation in a downstream reach.

The C^{14} date from the buried wood stumps indicates that the phase of aggradation responsible for burial of the alder at the downstream site took place at about 6270bp. This date therefore gives an approximate date for the phase of upstream incision which would have produced the upper terrace surface in the upper and middle reaches of Dovedale Griff. It also gives a minimum date for the onset of soil formation for the surface soils developed into the terrace surface sediments. This date would be compatible with the early-to-mid Holocene age suggested in Chapter 3 for the degree of soil development shown by the Group 1 soils.

Some supportive evidence for the probable date of around 6200bp for the onset of pedogenesis of the Group 1 soils may be derived from a pollen analysis of the basal layers of the A horizons of the upper terrace soils. A pollen analysis of the basal layers of a Group 2 soil was also undertaken in order to compare the pollen assemblages found in Group 1 and Group 2 soils as well as to provide some indication of the timing of onset of pedogenesis of the Group 2 soils.

Soil Pollen Investigation

In an attempt to obtain further evidence of the age of the terrace soils in Dovedale, pollen spectra from each of an upper and middle terrace soil were investigated. A sample for pollen analysis was taken from a very thin slice of organic material from the base of the organic horizon of soil pit site

2, a Group 1 soil on an upper terrace fragment, and at soil pit site 1, a Group 2 soil on a middle terrace fragment. Preparation of the samples for pollen analysis followed standard techniques as described in Appendix 3. Counting was undertaken until 100 tree pollen were identified.

Analysis of pollen from soils may be problematic because of differential preservation of pollen and the possibility of translocation of grains during pedogenesis (Dimbleby, 1961). Further, examination of the pollen from the base of the organic layer may not necessarily indicate the pollen assemblage at the onset of pedogenesis at the site. This is because older organic material, indicated by the presence of organic carbon in Bh horizons for example, may be found at depth in the profile (Matthews and Caseldine, 1987). Caseldine and Matthews (1987) note that the stratigraphic integrity of pollen sequences derived from the organic horizons of soils will vary with factors that include the characteristics of the immediate vegetation cover which can vary over short distances, local differences in soil properties which can affect pollen incorporation into the soil below the surface organic horizon and variation in soil hydrology. Nevertheless soil pollen can provide information about the relationship between vegetation change and pedogenic change in a soil sequence and is being used increasingly in soil studies to establish the vegetation of the area at the time of initiation of the LF horizon and onset of pedogenesis, as well as to establish changes in vegetation in a soil sequence (Caseldine and Matthews, 1987).

An examination of soil pollen may provide useful palaeoenvironmental information. For example, by examining pollen analytical evidence from the organic horizon of an arctic brown soil from Vestre Memurubreen in the Jotunheimen Mountains of Norway, Matthews and Caseldine (1987) were able to demonstrate a single vegetation change from a low alpine dwarf-shrub heath to a mid-Alpine grass heath. This was suggested to reflect an altitudinal lowering of vegetation belts and a possible climatic cooling of 2-4 °C. Caseldene and Matthews also examined soil pollen in several humo-ferric podzols close to the "Little Ice Age" outer moraine of Haugabreen, southern Norway. A combination of C^{14} dating and soil pollen analysis of the organic horizons of the soils was used to establish the timing and nature of podzol development and relate it to known environmental changes established through regional pollen diagrams. Very high values for

Betula were used as evidence that HF initiation at the soil sites took place beneath Betula woodland and that the inception of the FH horizon preceded vegetation change from birch woodland to low alpine heath. Soil pollen extracted from higher levels in the organic horizon indicate a phase of woodland recession at the site with expansion of a low alpine heath, a phase of woodland regeneration following the "Little Ice Age" and a phase of woodland recession indicated in the uppermost centimetres of the soils which was attributed to the "Little Ice Age" cooling.

Analysis of soil pollen was also used by Brazier et al. (1988) in a study of Holocene debris cone evolution in Glen Etive, western Grampians. Pollen analysis was used to provide evidence of the destruction of the natural vegetation cover by man at about 550bp, this destruction of the vegetation cover leading to fluvial incision and reworking of part of an extensive debris flow deposit. The result of this phase of instability was the development of an alluvial fan that buried the lower part of the debris flow deposit.

Brazier et al. (1988) recognise the potential interpretative difficulties of soil pollen but suggest that these difficulties may be minimised if attention is focussed on gross changes in the type and concentration of the pollen assemblages in the analysis. In the Dovedale analysis attention is centred on the possible gross differences between the pollen spectra extracted from the basal layers of the organic horizon with a view to providing some information on the vegetation of the sites at the onset of pedogenesis on the upper terrace and middle terrace soils.

On the basis of the C^{14} date from the mouth of Dovedale and the height range projection of the upper terrace surface, it has been proposed that the upper terrace soil dates from about 6270bp (Atlantic) times. Several characteristic features in the Holocene pollen record from the North York Moors have been recognised by a number of workers to have regional applicability as major chronological markers of Holocene vegetation change. Of particular relevance to this study are the Alnus rise at 7,000bp, the Ulmus decline at c. 5,000bp and the widespread development of the Callunetum after about 1500bp. The dates at which these features occur have been well

documented, and therefore they can provide excellent indications of the approximate age of stratigraphic units within which they are identified. A major feature of the regional pollen spectra from the Atlantic period is the domination of the pollen sum by trees, as this period of the climatic optimum is associated with the Quercetum Mixtum, when mixed oak forest dominated the landscape. A major feature of the late Holocene period is the replacement of tree pollen by shrub and herb pollen (Chapter 6).

Pollen counting for the upper and middle terrace soils was therefore undertaken to establish any gross differences in the proportion of the pollen sum accounted for by trees, and the species composition of the tree pollen between the two sites. Non-arboreal pollen was recorded as herbs or shrubs. The shrub pollen was further divided into Corylus\Myrica, Ericales and others; Corylus\Myrica were recorded in the event that the tree pollen suggested a Boreal date for the upper terrace pollen assemblage, as a high Corylus\Myrica record would provide confirmation of such an estimated date. Ericales type pollen were recorded because it has been widely established that they provide a major component of late Holocene pollen. Considering these differences, a low tree pollen count from the upper terrace soil for example, together with high values for Ericales pollen, would suggest a late Holocene date for the upper terrace soil whereas a pollen count with a dominance of tree pollen is more likely to suggest an Atlantic age for the pollen at the base of the organic horizon of the upper terrace soil.

Upper Terrace Soil Pollen Record

Tree pollen accounts for 57% of the dry land pollen sum. This figure suggests a well-wooded, although not dense, forest cover. Table 4.1 gives the different tree taxa percentage figures.

Table 4.1 : Tree Pollen as % of Total Dry Land Pollen Sum

Species	%TDLP
Alnus	22.0
Quercus	13.5
Ulmus	9.5
Betula	5.5
Tilia	3.5
Fraxinus	1.0
Pinus	0.5

These percentages suggest that woodland at the site may have been dominated by Alnus and Quercus with significant amounts of Ulmus. The relative importance of Alnus and Quercus is the reverse of that reported for the Atlantic period (Pollen Zone VIIa) by Atherden (1976) from the Fen Bogs site, which is the closest pollen site to Dovedale. This is probably due to local Alnus dominance at the Dovedale site, the in-situ buried wood stumps in Unit 1 at the C^{14} site suggesting the prevalence of alder on the floodplains bordering the stream. There is also the possibility of Alnus pollen being derived from the Staindale valley riparian environment upwind from the Dovedale site. The pattern for the other tree species is however remarkably similar to that discussed by Atherton (1976) for the Fen Bogs Zone VIIa. Significantly Ulmus from Dovedale reaches 9.5%, a higher value than that obtained at Fen Bogs. This may be due to the less exposed more southerly location of Dovedale, closer to the probably denser Ulmus stands on the more favourable soils and lower elevations of the Tabular Hills.

This pattern for the tree pollen spectra and the tree pollen sum supports the interpretation of the upper terrace soil as of probable early Atlantic age. The dominance of Alnus strongly suggests that the Dovedale upper terrace soil had not begun to form much before the Alnus rise at 7000bp, while the high Ulmus counts demonstrate that the soil had started to form prior to the Ulmus decline at c. 5,000bp. The absence of Ericales pollen also indicates that the soil is older than late Holocene. A closer inspection of the values for Pinus, Betula and Corylus\Myrica types, together with a comparison with the Fen Bogs pollen diagram, permits the suggestion that the pollen in the Dovedale upper terrace soil dates from a period no later than the latter part of the Atlantic period, about 6000-5000bp and no earlier than the opening of the Atlantic at about 7000bp.

It was suggested above that the date of 6270bp provided a minimum age for the onset of pedogenesis. The pollen data from the base of the upper terrace soil provides correlative evidence that soil formation had begun on the upper terrace surface by about 6270bp and probably not much before this time.

The combination of the C^{14} date, the stratigraphy of the C^{14} site, the evidence from the height range diagram and some supportive evidence from soil pollen spectra together suggest that a date of around 6000bp may be tentatively advanced for the onset of pedogenesis for the soils belonging to the Group 1 soil-stratigraphic unit.

Middle Terrace Soil Pollen Record

Tree pollen accounts for 16.5% of the dry land pollen sum. This figure suggests a very sparsely wooded landscape. The table below gives the tree taxa percentage figures.

Table 4.2 : Tree Pollen as % of Total Dry Land Pollen Sum

Species	% TDLP
Alnus	10.0
Betula	3.25
Ulmus	1.5
Quercus	1.5

These data suggest that by the time the middle terrace soil had started to form, large-scale removal of trees had occurred in the vicinity of Dovedale. The dominance of Alnus in the tree pollen spectra is probably indicative of colonies of this tree surviving upwind of Dovedale, probably in the Staindale valley, as well as the possibility of the presence of Alnus along parts of the floodplain bordering the stream in Dovedale itself.

Ericales individually accounted for 37% of the total dry land pollen sum, while 38% was herb pollen. This high proportion of Ericales indicates that the middle terrace soil from which this sample was taken had started to form when the Callunetum was established. Ericales is identified

in pollen records from the North York Moors during the Bronze Age, at approximately 3,500bp (Chapter 6). At this early date, however, it is considered to have been growing only on the most exposed and least fertile areas of the central watershed of the North York Moors, some distance to the north and downwind of Dovedale. Atherden's (1976) C^{14} dated pollen record from Fen Bogs, only 10km to the northwest of Dovedale showed that the major expansion of Calluna heathland took place after massive Iron/Roman Age deforestation at c.2,000bp. The degree to which the subsequent Saxon regeneration of trees was limited is indicative of the deterioration of soil conditions that had taken place during the Iron/Roman Age. As a result, colonisation of abandoned Iron/Roman Age agricultural areas and re-growth in areas stripped of woodland was characterised by a large expansion of Ericales type plants. Atherden (1976) considers that the Saxon period was thus the actual origin of the "Callunetum" (extensive Calluna heathland) in the North York Moors.

The soil pollen evidence therefore suggests that the middle terrace soil probably did not start to form until Saxon times. The transition in the Fen Bogs pollen record from the period of Iron/Roman Age clearances to Saxon recovery (Atherden, 1976) is C^{14} dated to c.1500bp. This may therefore approximate to the date about which there was the onset of pedogenesis on the middle terrace surface in Dovedale.

The soil pollen analysis suggests that the onset of pedogenesis on the surface sediments making up the middle terrace probably began not much before 1500bp. This then implies a relatively long time interval between the onset of pedogenesis for the soils which distinguish the upper terrace fragments and the soils belonging to the Group 2 middle terrace soils. This pollen evidence is supported by the soil evidence discussed in chapter 3 which pointed to differences in both soil morphology and chemical properties between the Group 1 and Group 2 soils as well as a probable late Holocene age for the Group 2 soils. Further evidence for a date of no more than 1500bp for the onset of pedogenesis for the Group 2 soils and the phase of terracing which produced the middle surface in Dovedale is given below.

4.2.2 The Group 2 Soils

A site in Jugger Howe Beck with C^{14} dating may be used to provide an estimate of the ages of the Group 2 soils. C^{14} Site 1 in Jugger Howe lies at the junction of Jugger Howe Beck and Hollin Gill. The location of the section is shown as A on Figure 2.7. The C^{14} site is situated on the south bank of Hollin Gill where the stream changes direction to flow eastwards towards Jugger Howe Beck. Here Hollin Gill has cut through the deposits of the small terrace unit which abuts the toe of the large Hollin Gill alluvial fan. The exposure of the terrace deposits runs from the fan/terrace junction to the present day confluence of Jugger Howe Beck and Hollin Gill. The section is about 20m in extent.

The Stratigraphy of the Site

The stratigraphy of the section is given in Figure 4.3. This shows a contrast in the sedimentary sequence between the upstream portion of the section which contains the C^{14} site and the downstream section. The upstream sediment sequence at the C^{14} site consists of four stratigraphic units. At the base of the exposure Unit 1 is comprised of a massive silt and clay layer. Unit 2 consists of a silty clay deposit which exhibits pronounced horizontal stratification. This unit is bounded on both its upper and lower surfaces with organic rich material. Lying above the upper organic band is Unit 3 which consists of poorly sorted angular to sub-angular fluvial gravels with an abundant sand infill. Unit 4, the uppermost unit, is made up of a shallow layer of sand which provides the parent material for a weakly developed surface soil.

About 7.5m downstream from the C^{14} site the stratigraphy of the deposits changes (Figure 4.3). The lower unit, Unit 1 consists of a massive silt-clay layer which is laterally continuous with Unit 1 at the C^{14} site. The sediments which make up Unit 1 are found extensively as basal deposits for the fluvial sediments throughout the reach of the valley under consideration. These basal deposits are discussed in more detail below, but are suggested to represent soliflucted/debris flow deposits which probably have a Late Glacial/very early Holocene age.

JUGGER HOWE BECK: STRATIGRAPHY OF C^{14} SITE 1

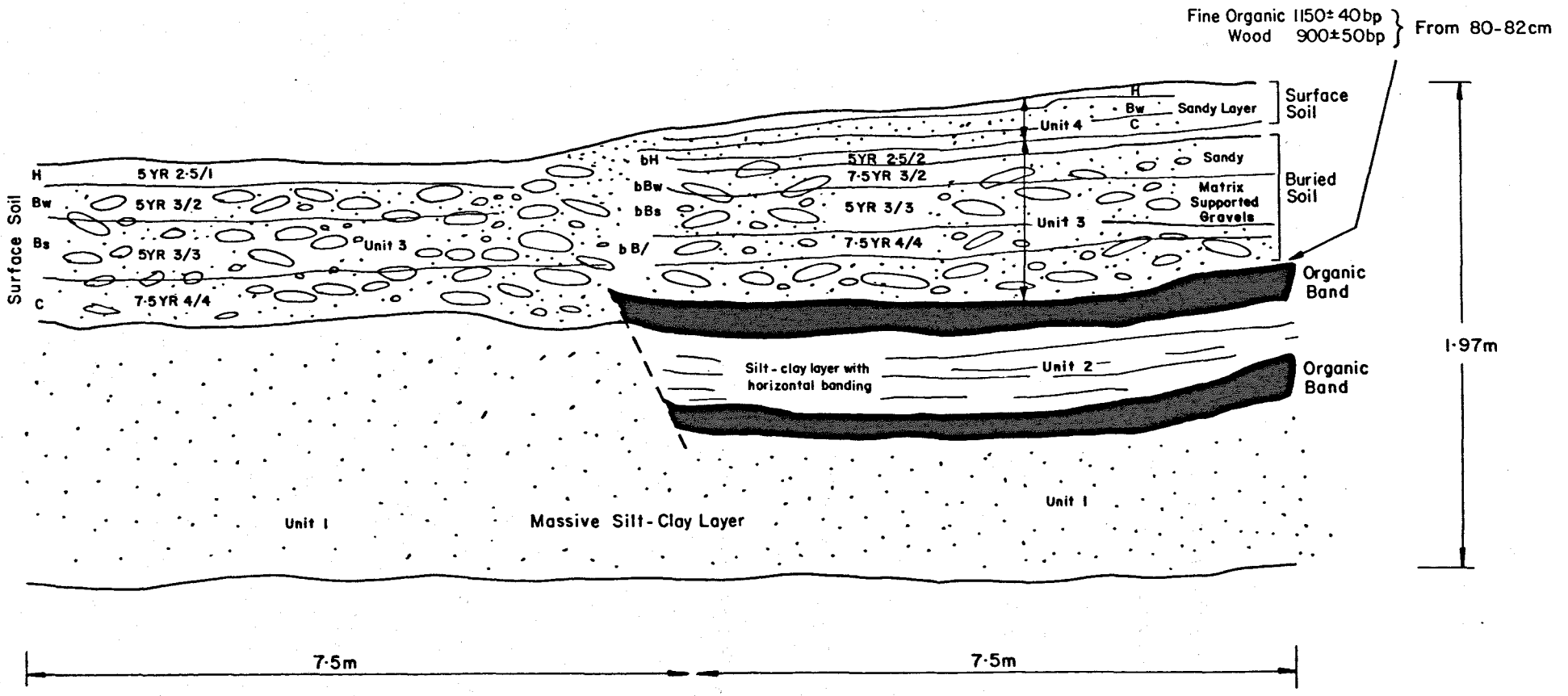


Figure 4.3

Overlying the Unit 1 deposits is Unit 3 which forms a laterally continuous deposit with the gravels at the upstream section. At the downstream site the organic rich layer found at the upstream site is absent, as is the thin sand layer which forms Unit 4 at the C^{14} section.

At the C^{14} site the organic layers curve upwards and merge at the upstream end of the section towards the Hollin Gill fan stopping abruptly at the junction of the fan and the terrace section. The organic bands extend for about 7.5m downstream from the fan/terrace junction. The stratigraphic sequence above the basal deposits for the 7.5m of the exposure at the C^{14} section suggests that the accumulation of the fine sediment and organic layers which make up the curved Unit 2 deposits occurred as infill of an old backwater channel which flowed between the toe of the fan and the main north to south flowing Jugger Howe Beck which deposited the Unit 3 gravels.

Alternation of fine grained deposits and organic layers is common in backwater channels which are infilled as a result of the accumulation from suspension during floods in more protected areas where current velocity is reduced (Lewin, 1983). Organic detritus may be carried along the water surface during floods and is usually the last sediment to be deposited in the backwater channels as floodwaters recede. In this way alternations of fine grained sediment and organic rich layers may be built up in slack water sediments (Baker et al. 1983).

Subsequent to the infilling of the channel there must have been either a period of higher runoff and bedload discharge or a high magnitude event which resulted in substantial bedload transport in the stream. This phase of activity resulted in the formation of Unit 3 at the C^{14} site and at the downstream exposure. This deposit consists of imbricated matrix supported gravels.

Some time after deposition of the gravels the palaeochannel must have been reactivated and this resulted in the deposition of the upper unit in the sediment sequence, Unit 4. This is a sand layer which does not extend over the whole section, but rather just the old channel section of the terrace unit. Soil development in this sand layer is limited to some organic accumulation at the sand surface.

Radiocarbon dating

Two samples were obtained from the upper organic band for radiocarbon dating. The organic material in this band consists of a mixture of silt- clay material which is rich in finely divided organic debris as well as many large alder fragments. Material was extracted from the top 2 cms of the band from 0.80 - 0.82 cms from the surface of the exposure. Radiocarbon dating of the samples was carried out at the Scottish Universities Research and Reactor Centre under the direction of Dr. D.D. Harkness. Radiometric dating of both the organic material and the woody debris was undertaken with the fine fraction being prepared for dating according to the method outlined by Kihl (1975).

The results of the radiocarbon analyses are summarised in Table 4.3 below and are shown in the appropriate stratigraphic position in Figure 4.3.

Table 4.3 **Juggerhowe Beck - Site 1 Radiocarbon Dates**

Sample No.	Laboratory Code	Material dated	Radiocarbon Age	Calibrated Age*
1.	SRR-2374	Alder frag.	900+/-50 BP	690-1000 BPCal
2.	SRR-2375	Fine organic	1150+/-40 BP	960-1230 BPCal

* Calibration using curves of Stuiver (1982); the range includes +/-2 standard errors.

The C^{14} date for the organic fraction is slightly older than that for the wood, this probably reflecting the residence time of the carbon eroded from topsoil A horizons in the catchment and incorporated into the deposited organic rich layer (Richards et al. 1987).

Significance of the date in the context of the soil sequences.

The radiocarbon dates indicate the timing of the phase of sediment aggradation which resulted in the deposition of the imbricated gravels overlying the upper organic band. Developed into the upper 40cms of the Unit 3 deposits is a brown podzolic soil. This soil is overlain by a thin accumulation of sand which makes up Unit 4.

In the downstream part of the section beyond the infilled backwater channel the buried podzolic soil is continuous with the modern podzolic soil. This brown podzolic soil is shown in Plate 4.1. Marked similarity in soil colour and horizon thicknesses as well as total solum depth between the buried soil and the modern surface soil strongly suggest that burial of the soil was likely to have been very recent.

As it is known that the phase of gravel aggradation which produced the parent material for the podzolic soil occurred about 900bp, this also provides a maximum date for the onset of pedogenesis of the brown podzolic surface soil. The soil profile description for the surface podzolic soil is given in Table 4.4 below.

Table 4.4 ***Soil Profile Description Jugger Howe Beck 900bp Surface Soil.***

Slope	0°
Vegetation	Grass, bilberry, heather
Soil drainage	Free
Parent material	alluvial gravels and sand
Major soil subgroup	brown podzolic soil

LF : 5cm - 0cm; very dark brown 10YR 2/2; no mineral content; semi-fibrous; moist.

H : 0 - 5cm; black 5YR 2.5/1; well humified organic horizon; crumb structure; abundant fine roots and a few thick woody roots; moist; many bleached grains; friable; gradual boundary.

Bw : 5 - 15cm; dark reddish brown 5YR 3/2; sandy loam; crumb structure; moist; very friable; many fine roots; a few thick roots; some stones; gradual boundary.

Bs : 15cm - 29cm; dark reddish brown 5YR3/3; sandy loam; a few medium roots; many sub- angular to sub-rounded medium stones; moist; very friable; very weak crumb structure; merging boundary.

Cu : 30cm +; brown 7.5YR4/4; fine sand; very few fine roots; many sub-angular to sub rounded stones; moist; friable; single grain structure.



PLATE 4.1

Comparison of this Jugger Howe Beck soil with the soils developed into the terrace surfaces in Dovedale shows that the Jugger Howe Beck soil is most comparable in degree of soil profile with the Dovedale Griff Group 2 soils. The Jugger Howe Beck soil has an LF/H/Bw/Bs/C horizon sequence which is comparable to the LF/Ah/Bw/Bs/C horizon sequence for some of the Dovedale Group 2 soils. The total solum depth of the Jugger Howe soil is about 35cm, whilst the average value for the Dovedale Group 2 soils was seen to be about 30cm. Average B horizon thicknesses for the Group 2 soils are about 18-20cm, which is comparable to the 20cm for the Jugger Howe Beck soil. In terms of total solum depth, thickness of the B horizon and degree of horizonation the soil in Jugger Howe Beck which began forming at a maximum date of about 900bp is comparable with the Group 2 terrace soils in Dovedale Griff. Although values for B horizon Munsell chart soil colours differ between the Jugger Howe Beck and Dovedale soils (5YR 3/3 in Jugger Howe Beck and 10YR 5/5 in Dovedale Griff), Colour Development Equivalents for the 900bp soil in Jugger Howe Beck are comparable with those for the Group 2 soils in Dovedale. In Dovedale Griff Group 2 CDE's range from about 12-16, whilst that for the 900bp soil in Jugger Howe Beck is 15.

The B:C horizon ratios of iron in the soils are useful indices when comparing soil profiles as they take into account any slight differences in parent material between sites. This is particularly useful if they are to be used to compare soil profiles between valleys. B to C horizon ratios of dithionite extractable iron for the Group 2 soils in Dovedale average 1.3 to 1.15 whilst values for pyrophosphate extractable iron are about 1.59 to 1.2. These data are comparable to those from the Jugger Howe Beck site which gave values of 1.7 and 1.2 respectively. Fep ratios are slightly higher for the Jugger Howe Beck site.

The greatest differences between the Jugger Howe Beck 900bp soil and the Dovedale Group 2 soils lie in the upper soil horizon. In Dovedale the horizon below the litter layer is an organic-mineral Ah horizon with typical soil colours of 10YR 3/4. In Jugger Howe Beck it is an organic H horizon with soil colours of 5YR 2.5/1. These differences together with the slightly more acid Jugger Howe Beck soil (pH of 4.5 for the Ah in Dovedale and a pH of 4.0 in the Jugger Howe Beck

surface horizon) may imply differences in rates of opertion of the translocation processes operative at the Jugger Howe Beck site and in Dovedale. Nevertheless, the degree of soil profile development at the Jugger Howe Beck 900bp soil site and the Dovedale Griff Group 2 soils appears comparable.

4.2.3 The Group 3 Soils

Some dating control for the Group 3 soils comes from a second C^{14} site in Jugger Howe Beck. This site is located about 300m downstream from the junction of Hollin Gill and Jugger Howe Beck (Figure 2.7) and represents an infilled palaeochannel on the low terrace described in Chapter 2.

The Stratigraphy of the Site

The stratigraphy of the second C^{14} site is shown in Figure 4.4. Unit 1 consists of a massive layer of waterlogged silty-clay with mottles. Lying above this unit is an organic rich band made up of twigs, alder branch fragments and fine derived organic matter. Unit 2 is made up of a silty sand layer with pronounced horizontal stratification. The stratification is the result of the accumulation of fine organic bands between the silty- sandy deposits. There are also occasional thin accumulations of fine gravel. This unit is bounded on its upper surface by an in-situ organic soil horizon. There is no evidence of further soil profile development beneath this organic horizon. Above this horizon is a sandy-silt unit, Unit 3, which, as with Unit 2, exhibits some horizontal stratification again as a result of the accumulation of thin organic bands between the silty-sand layers. This unit exhibits mottling as a result of oxidation around root holes. Unit 3 is bounded on its upper surface by a further thin organic horizon. The upper unit, which, although in-situ also appears to contain some derived organic material, is made up of a sandy layer with a further very thin organic layer just above the organic band. An immature surface soil is developed into the sandy deposits of Unit 4. The stratigraphy at this site is repeated in infilled palaeochannels further downstream, on both the west and east banks of the stream.

JUGGER HOWE BECK:
STRATIGRAPHY OF C^{14} SITE 2

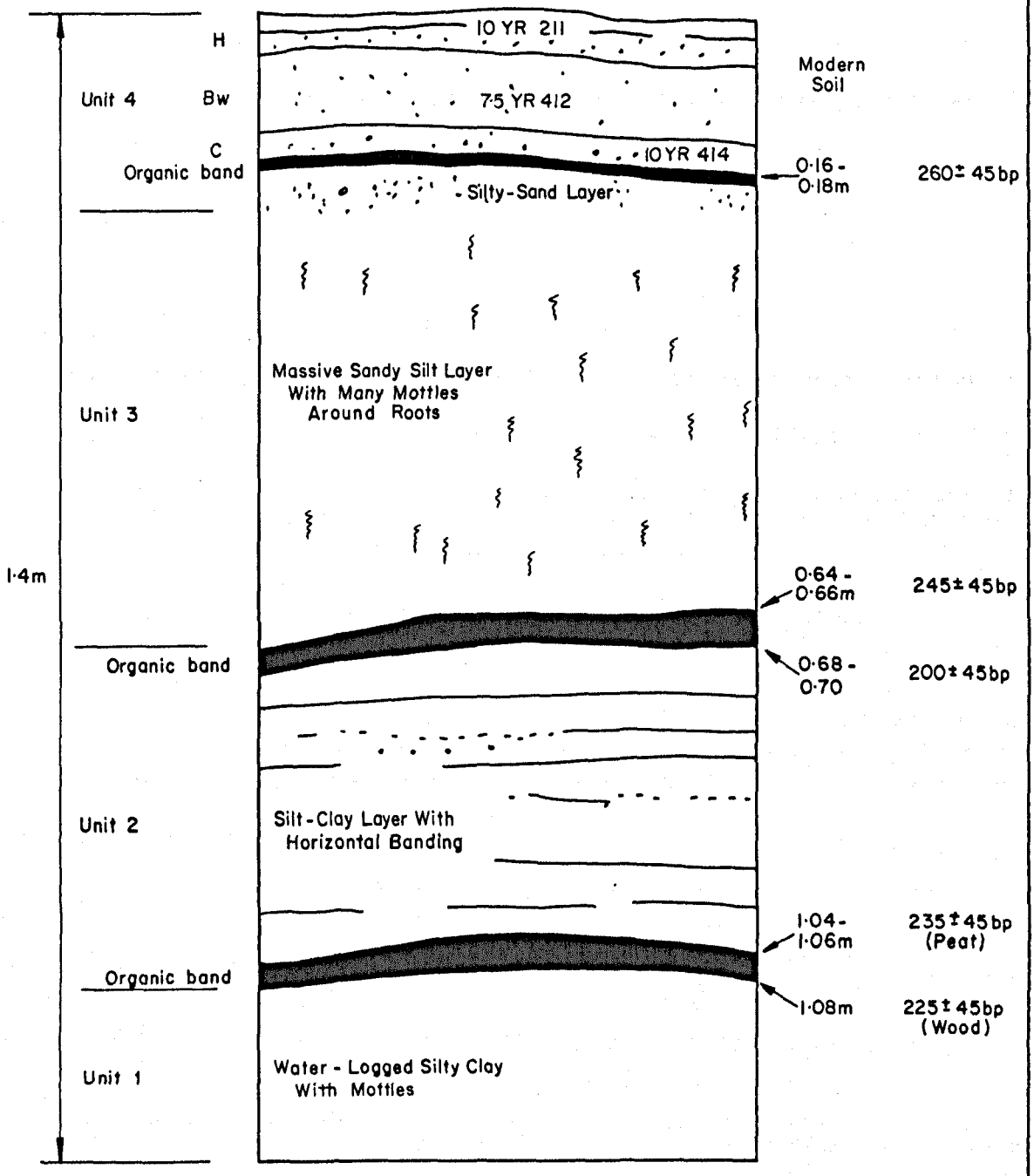


Figure 4.4

The stratigraphic sequence at the C^{14} palaeochannel site suggests that the accumulation of fine sediment units occurred as infill of an old channel. Fine grained deposits may be laid down in palaeochannels as a result of the deposition of sediment carried in flood waters. Massive sedimentary units, such as that of Unit 2, are commonly ungraded and are structureless. These features suggest very rapid deposition from suspension whilst horizontal stratification may be associated with concentrations of fine grained organic detritus (Baker et al., 1983). In-situ development of immature soil horizons marks temporary pauses in the infilling of the channel.

Radiocarbon dating

Sampling sites for the extraction of organic material for radiocarbon dating were taken from the lowest organic band. Dates were obtained on the wood fragments from 1.08m below the surface, and fine organic material taken from the top of the organic band at 1.04-1.06m below the surface. Samples were also taken from the in-situ organic layer at both the top and base of the layer. Finally samples were taken from the upper organic layer from 0.16-0.18cm from the surface.

Radiocarbon dating of the samples was carried out at the Sub-Department of Quaternary Research, University of Cambridge under the direction of Dr. V. R. Switsur. The results of the radiocarbon analyses are summarised in Table 4.5 below and are shown in the appropriate stratigraphic position in Figure 4.4.

Table 4.5 **Juggerhowe Beck - Site 2 Radiocarbon Dates**

Sample No.	Laboratory Code	Material dated	Radiocarbon Age	Calibrated Age*
1.	Q-2466	Fine organic	235+/-45 bp	140-430 BPCal
2.	Q-2467	Wood	225+/-45 bp	135-425 BPCal
3.	Q-2468	Insitu organic	200+/-45 bp	90-325 BPCal
4.	Q-2469	Insitu organic	245+/-45 bp	140-430 BPCal
5.	Q-2470	Insitu organic	260+/-45 bp	140-465 BPCal

* Calibration using curves of Stuiver (1982); the range includes +/-2 standard errors.

The dates all fall into a narrow range from 260+/-45bp to 200+/-45bp, with the age range of the dates being statistically indistinguishable. The limited range of dates obtained for the samples, together with the relatively wide age ranges implied by these determinations, make interpretation of the dates in terms of periodicity of phases of deposition unrealistic. Taken together, however, these 5 dates provide consistent evidence of a period of very rapid sedimentation around 260-200bp.

These results are interesting not only because they indicate very rapid infilling of the palaeochannel but also because they demonstrate that there appears to have been remarkably little time between episodes of sedimentation for the accumulation of in-situ organic layers. This suggests that these organic layers form very quickly, in a matter of a few years.

Significance of the dates in the context of the soil sequences.

At the base of the channel the date of 225bp from the alder wood provides a date for sedimentation in the channel alluvial is not likely to be contaminated by older or younger carbons. As accumulation of the sediments has proceeded rapidly the date derived fom the wood provides a maximum possible date for onset of pedogenesis at the top of the infill. The soil profile description for the modern soil at this site is given below in Table 4.6 and the soil is also shown in Plate 4.2.

Table 4.6 **Soil Profile Description Jugger Howe 225bp Surface Soil.**

Slope	0°
Vegetation	grass, heather
Soil drainage	Free
Parent material	alluvial sand
Soil type	mineral alluvial soil

H : 0 - 5cm; black 10YR 2/1; no mineral content; semi-fibrous; moist; a few woody roots and medium fibrous roots; gradual boundary.

Bw : 5cm - 12cm; dark brown 7.5YR 4/2; sandy loam; single grain structure; moist; very friable; a few fine roots; boundary very gradual;

Cu : 12cm +: dark yellowish brown 10YR 4/4; fine sand; moist; friable; single grain structure.



PLATE 4.2

Comparison of this profile description with that for the surface soil dated to about 900bp at the upstream site near Hollin Gill reveals a marked difference in degree of soil profile development. Comparison of the younger soil at Jugger Howe Beck with the Dovedale Griff soils reveals that the soils which it most closely resembles are the Dovedale Griff Group 3 soils. The Group 3 Dovedale soils have an Ah/Bw/C horizon sequence with average total solum depths of about 15-20cm of which about 9-10cm is visual B horizon. The Jugger Howe Beck soil profile is comparable to the Group 3 soils in Dovedale with its H/Bw/C horizon sequence, total solum depth of 18cm and a B horizon thickness of 8cm. As with the Group 2 soils and the Jugger Howe Beck 900bp soil, the main difference in profile morphology lies with the presence of the H horizon with its 10YR 2/1 soil colour. This contrasts with the mineral organic Ah horizon of the youthful Dovedale soils and its typical 10YR 4/4 colour. pH of the Dovedale surface soil horizon is about 5.0 whilst that from Jugger Howe Beck is 4.6.

Values for B horizon colour variables and iron accumulation indices for the Jugger Howe Beck soils and the Dovedale Group 3 soils are comparable. Values for CDE in the Dovedale soils are typically 8 whilst that for the Jugger Howe Beck soil is also 8. Accumulation indices for pyrophosphate extractable iron for the Dovedale soils are about 1.0 - 1.2 and Howe for dithionite extractable iron are about 0.89 to 1.0. Comparable values of 1.3 and 1.03 were measured for the Jugger Howe Beck soil.

Two C^{14} dates are therefore available from Jugger Howe Beck that give maximum ages for the onset of pedogenesis at two sites in the valley of differing soil age. Chemical and morphological data from these two sites will be compared statistically with the Group 2 and Group 3 soils in Dovedale Griff in the following discriminant analysis in order to allocate these two Jugger Howe Beck soil sites to one or other of the established Dovedale soil groups with the smallest probability of error or misclassification.

4.3 Discriminant Analysis

Discriminant analysis is a statistical technique that distinguishes significant differences between distinct a priori groups by forming a linear combination of a set of independent variables (Klecka, 1980).

Discriminant analysis has been used in a range of geomorphological studies. In an early study Thomas (1969) used a two group discriminant analysis in a study of glacial and periglacial sediments from slope deposits, one group consisting of solifluction deposits and the other of interbedded gravels. The aim of the discriminant analysis was to separate the groups in terms of parameters describing particle size, sorting and shape and to provide a classification which could be used to allocate future samples to either solifluction or interbedded gravel deposits using these parameters. Mather and Doornkamp (1970) used multiple discriminant analysis to separate groups of drainage basins of different order using a set of morphometric and basin relief variables.

One of the most well known uses of discriminant analysis has been to define functions which distinguish between braided and meandering rivers on the basis of parameters such as discharge, slope and an index of bed material size (Leopold and Wolman, 1957), or a stream power index and median bed material size (Richards, 1982). In these studies the discriminant function defines the threshold between one channel pattern type and another.

Considering the uses of discriminant analysis in soil studies, Webster (1977) has remarked that discriminant analysis may be a valuable technique for identifying soil types from laboratory data. It may also prove to be a valuable tool for allocating soil profiles to soil groups using routine soil survey data.

More recently discriminant analysis has been used in studies of late Quaternary relative age data as a statistical technique for testing groups of deposits clustered on the basis of principal components scores derived from lichenometric and relative weathering variables (Dowdsewell,1982; Dowdeswell and Morris, 1983). However, Harbor (1986) has pointed out the circularity of combining cluster analysis and discriminant analysis. This arises because sites grouped together using a cluster analysis based on a distance coefficient will join the group which has the closest group mean. The groups from the cluster analysis cannot therefore overlap in terms of variable scores. Under these circumstances sites entered into a discriminant analysis which have already been grouped by cluster analysis on the basis of their principal components scores cannot fail to show good separation between the a priori groups.

Further, the use of principal component scores derived from relative weathering or soil profile data as the input variables for discriminant analysis does not allow the allocation of new sites to an a priori group without first carrying out a new principal components analysis. This then limits the utility of a powerful statistical technique.

Discriminant analysis provides a powerful methodology not only for defining thresholds between groups but also for predicting the probability of group membership for new data sets or sites using a set of discriminating variables. Used in this way, allocation of new sites to an a priori group uses the raw data for the new sites and does not require a re-analysis of the data to produce a set of standardised variables in the form of principal component scores.

The linear discriminant equation

$$D = b_0 + b_1 X_1 + b_2 X_2 + \ldots b_p X_p \qquad \text{Equation 4.1}$$

is similar to the multiple regression equation. The X's are the values of the independent variables and the b's are the coefficients estimated from the data set. Based on the unstandardised b coefficients it is possible to calculate discriminant scores for each case in the analysis. The b's are calculated so that the values of the discriminant function differ as much as possible between the groups, or so that, for the discriminant scores, the ratio

$$\frac{\text{between groups sum of squares}}{\text{within group sum of squares}}$$

is a maximum. Any other linear combination of the variables will have a smaller value.

Utilised in soil stratigraphic techniques in which soil profiles have been grouped into a number of distinguishable soil stratigraphic units, discriminant analysis may be used to test the significance of the group differences by selecting the best combination of discriminating variables. On the basis of this selection those soil parameters best suited to discriminating between the soil groups of different age may be readily identified. The discriminant analysis therefore provides an objective indication of the importance of the individual soil parameters in discriminating between the groups of profiles which define the soil stratigraphic units.

More significantly however, by examining differences between the groups with respect to several variables simultaneously, discriminant analysis also helps to assign or classify any case to the group which it most closely resembles. It therefore provides a procedure for predicting group membership for new cases whose group membership is unknown. The unknown cases are allocated to groups on the basis of probabilities. Each new site is classified as belonging to that group for which it has the highest probability of membership. New soil sites can therefore be objectively assigned to a soil group using the original soil data set and the data for the new soil sites. Considering a linear discriminant function, the information contained in the independent variables is summarised in a single index, the discriminant function. The unstandardised coefficients of the function are used to calculate a single discriminant score for each soil site.

That score represents the position of the soil profile along an axis defined by the linear discriminant function. The positions of the points along this axis can then be used to assign individual sites to their most probable class.

Discriminant analysis requires an existing classification or a set of a priori groups. In the following analysis the a priori groups are the three groups of soil profiles making up the surface soil stratigraphic units in Dovedale. The discriminant analysis is independent of the statistical analyses conducted in Chapter 3 and therefore uses raw data selected from the data base established for 23 soil sites in Dovedale.

As the purpose of the analysis is to allow new sites to be allocated to a soil group which shows a similar stage of profile development over the Holocene time scale, variables which are likely to show an age dependent trend over the time scale of at least the Holocene were included. These are likely to be variables related to the development of the B horizon as A horizon variables frequently reach a steady state with 10^3 years (Yaalon, 1971; Birkeland, 1978; Harden, 1982; Ellis and Richards, 1985). A combination of four morphological and chemical variables was therefore selected to be entered into the analysis. These were:

- $\%Fe_p$ B:C
- $\%Fe_d$ B:C
- CDE of the B horizon
- B horizon thickness

Data for the 4 variables for each of the 23 Dovedale sites were entered into the analysis as known cases in three a priori groups. Data for 3 unknown cases were also put into the data matrix but as ungrouped sites. These ungrouped sites included the 2 Jugger Howe Beck C^{14} sites; in addition the soil data from the modern soil at the C^{14} site in Dovedale Griff was included in the analysis as an ungrouped site. A total of 26 sites was therefore included in this stage of the discriminant analysis.

In discriminant analysis as in multiple regression, if there are independent variables that are highly correlated a unique solution is not possible (Norusis, 1988). To prevent computational difficulties a predetermined level of tolerance may be set. Tolerance is a measure of the degree of linear association between the independent variables. For the ith independent variable, tolerance is 1 - R_i2_y, where R_i2_y is the squared multiple correlation coefficient when the ith independent variable is considered the dependent variable and the regression equation between it and the other independent variables is calculated. Small values for the tolerance indicate that the ith independent variable is almost a linear combination of other variables. The tolerance level in this study was set at 0.70. This means that a variable will not be permitted to enter the analysis if more than 30% of its within group variance is explained by the variables already in the analysis.

The 4 soil parameters measured from the Dovedale and Jugger Howe Beck soils were used in an SPSSx stepwise linear discriminant analysis procedure. The stepwise procedure selects parameters one at a time on the basis of their combined power to discriminate between group members. When a number of variables are being entered into the analysis two or more of the variables may share the same discriminating information, even although individually they are good discriminators. A stepwise procedure eliminates unnecessary variables and produces an optimal set of discriminating variables. This analysis uses minimisation of Wilk's lambda for variable selection. Wilk's lambda is the ratio of the within groups sum of squares to the total sum of squares (Klecka, 1980; Norusis, 1988). A Wilk's lambda value is calculated for each variable at each step of the analysis. Values of Wilk's lambda which are near zero denote high discrimination, that is, the group means or centroids are well separated and very distinct relative to the amount of dispersion within the groups. As lambda increases towards its maximum value of 1.0 the group centroids are identical, that is there are no group differences.

In the stepwise procedure Wilk's lambda is converted into an F statistic for the test of group differences, with a partial F computed as the F-to-enter being used. The F-to-enter statistic is a partial multivariate F statistic which tests the additional discrimination introduced by the variable

being considered after taking into account the discrimination achieved by the other variables. If the F-to-enter is very small the additional discrimination that it would introduce into the analysis is not statistically significant so additional variables are not selected.

Table 4.7 gives the entry statistics for the stepwise selection of variables in the discriminant analysis. At step 1 the tolerance is 1.00 because no variables have been entered and for the same reason the F-to-enter corresponds to the univariate F statistic. The first variable to be included in the analysis was B horizon thickness. At step 1 B horizon thickness recorded the lowest Wilk's lambda 0.20, and an F-to-enter of 36.4. At the first step in the analysis the F test is equal to the test of the null hypothesis that there is no difference in the group means of the groups in the analysis. With an equivalent F of 36.4 at 2 and 19 degrees of freedom, Wilk's lambda is significant at greater than the 0.001 level and the null hypothesis is rejected. B horizon thickness therefore represents the soil parameter with the highest amount of discriminating capability. At the second step the variable selected in the stepwise procedure was Fe_p B:C which when combined with B horizon thickness produced the smallest Wilk's lambda 0.11 and the next largest F-to- enter. At this step the F-to-enter is the partial F for the discrimination added by Fe_p B:C, and the null hypothesis being tested is that Fe_pB:C does not add significantly to the discrimination between the groups. With an equivalent F of 18.2 and at 4 and 36 degrees of freedom Wilk's lambda is significant at greater than the 0.001 level and the null hypothesis is rejected.

After step 2 of the analysis the tolerance level of Fe_d B:C was still sufficient to allow the variable to enter, but the Wilk's lambda and F-to-enter were very small. For CDE the tolerance level fell below 0.70 meaning that the variance of this variable was already taken up by one of the other variables in the analysis. After step 2 variable selection in the stepwise procedure stopped. Two out of the four soil parameters were therefore objectively selected by the stepwise procedure to discriminate between the 3 soil groups, one morphological parameter, B horizon thickness and one chemical parameter representing the accumulation index of pyrophosphate extractable iron.

Table 4.7 **Entry statistics for stepwise selection of variables in discriminant analysis 1**

Variable	Tolerance	F-to-enter	Wilk's lambda
At step 1			
Fe_p B:C	1.000	18.01	0.345
Fe_d B:C	1.000	11.03	0.456
CDE	1.000	23.12	0.291
Bhor.thick	1.000	36.44	0.206
At step 2			
Fe_p B:C	0.999	8.07	0.109
Fe_d B:C	0.956	1.49	0.177
CDE	0.801	1.92	0.170
After step 2			
Fe_d B:C	0.891	0.176	0.106
CDE	0.652		

The discriminant function providing maximum separation between the three a priori groups is

$$D = -5.23 + 0.19Bhor + 4.26Fe_p \qquad \text{Equation 4.2}$$

where D is the discriminant score for the soil profile. The coefficients in the equation are the unstandardised discriminant function coefficients used to calculate the discriminant scores. The discriminant function table (Table 4.8) gives a measure of the success of the discriminant function in providing the maximum separation between the groups. The eigenvalue can be representated as a relative percentage of the total possible discriminating power. In this analysis the function has an eigenvalue of 5.42 and accounts for a very high 92.7% of the total discriminant power of the variables in the analysis. The canonical correlation coefficient also gives a measure of the utility of a discriminant function in providing maximum separation between the groups. This coefficient is a measure of the degree of association between the discriminant scores and the groups (Norusis, 1988). A high value for the coefficient indicates that a strong relationship exists between the groups and the first discriminant function, whilst conversely a low coefficient demonstrates only a weak association between the function and the a priori groups.

In this analysis the canonical correlation coefficient of 0.92 indicates a strong association between the derived discriminant function given in equation 4.2 and the 3 a priori groups and suggests that the first function acts as a powerful discriminator between the groups.

Table 4.8 **Discriminant function table for analysis 1**

Eigenvalue	% Variance	Can. Corr. Coeff.
5.4	92.7%	0.92

The contribution of each variable to the discriminant function may be assessed by referring to the standardised canonical coefficients. Those contributing the greatest amount to the function have the highest correlation coefficient. The standardised coefficients for equation 4.2 are given below and demonstrate that B horizon thickness makes the greatest contribution to the function.

Variable	Standardised Coefficient
Fe_p B:C	0.56
Bhor thick.	0.84

Table 4. 9 below gives a summary of the classification results based on the discriminant scores calculated for each of the 23 Dovedale sites and the 3 ungrouped sites. The classification results give the simplest measure of the discriminating power of the variables which make up the discriminant function by indicating the percentage of known cases correctly grouped. In the Dovedale case the results show that the discriminant function is very successful at discriminating between the soils making up the three soil stratigraphic units. The table indicates that for the Dovedale data set a very high 95.5% of the cases were correctly classified into their original a priori groups. One Group 1 soil was misclassified.

Table 4.9 **Classification Results for discriminant analysis 1**

Actual group	No. of cases	Predicted Group Membership		
		1	2	3
1	7	6 85.7%	1 14.3%	0 0.0%
2	7	0 0.0%	6 100%	0 0.0%
3	9	0 0.0%	0 0%	9 100%
Ungrouped Cases	3	0 0.0%	2 66.7%	1 33.3%

Of the previously ungrouped cases two were grouped into the Group 2 soil profiles and 1 was allocated to the Group 3 profiles. Table 4.10 gives a more detailed breakdown of the group allocations for the 2 Juggerhowe Beck C^{14} sites and for the modern soil at the Dovedale C^{14} site. The group allocation is given in the column "highest group." This is the group to which the case is more likely to belong based on its posterior probability. Using the discriminant score it is possible to work out the probability that a case with a discriminant score of D belongs to group I. When the group membership is unknown, that is for ungrouped cases, what is required is an estimate of how likely group membership is given the available information. This is the posterior probability (P [G/D]) and a case is classified, based on its discriminant score D, in the group for which the posterior probability is largest. Thus the higher the posterior probability the more likely the case is to belong to that group, and therefore the closer the case is to the group centroid or mean.

Table 4.10 **Group allocation of previously ungrouped sites**

Site Details	Allocated gp	highest P [G/D]	2nd Group	P[G/D]	Score
900bp site	2	0.811	3	0.182	-0.197
225bp site	3	0.995	2	0.004	-2.854
Dovedale site	2	0.823	1	0.140	0.375

Both the Jugger Howe Beck 900bp site and the surface soil at the Dovedale C^{14} site have been allocated to the Group 2 soil units. The Jugger Howe Beck 225bp soil profile has been allocated to the Group 3 soil units. The posterior probabilities for each of the ungrouped cases are all very

large. The posterior probabilities for allocation into the next most likely group are also shown in Table 4.9. Comparison of the probabilities for the 900bp Jugger Howe Beck soil indicates that the soil has a probability of 0.811 of belonging to Group 2 and a probability of only 0.18 of belonging to Group 3. The values for the probabilities for each of the 3 ungrouped sites indicate that the likelihood of allocation into another group other than the "highest group" is extremely unlikely.

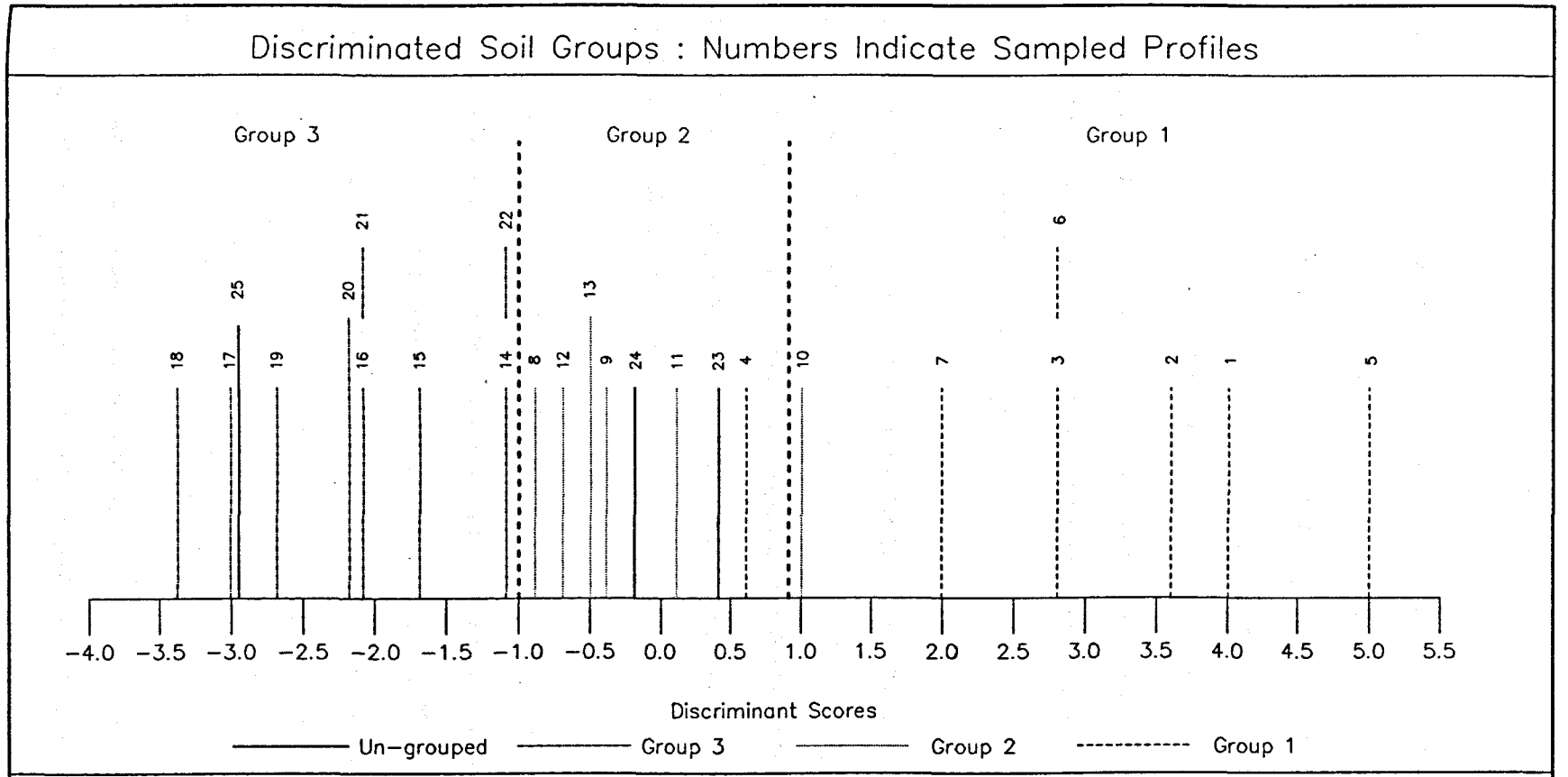
The discriminant function evaluated at the group centroids (group means) is shown below:

Group	Function 1
1	2.958
2	-0.233
3	-2.145

Comparison of the function evaluated at the group means with the discriminant scores for each of the ungrouped cases shows that they are all relatively close to the group means. Figure 4.5 shows a plot of the discriminant scores for each of the Dovedale soil sites projected onto the axis of the first discriminant function. The 3 previously ungrouped sites also plotted on the axis. From the plot it can be seen that the three previously ungrouped sites plot towards the centre of the Group 2 and Group 3 scores for these units.

Interpretation of the Discriminant Analysis

In Section 4.2 above it was suggested that the Unit 4 deposits at the downstream C^{14} site for Dovedale Griff were continuous with the deposits forming the middle terrace surface in the middle and upper reaches of the valley. Insertion of the soil data into the discriminant analysis for the modern soil at this site resulted in the allocation of this soil into the Group 2 soil unit. This then



Dovedale Soils

PLOT OF FIRST DISCRIMINANT FUNCTION SCORES

Figure 4.5

provides additional stastistical evidence to support the suggestion that the Unit 4 deposits at the downstream site were accumulating at about the same time as the deposits making up the middle terrace surface in the middle and upper reaches of the valley.

The allocation of the two ungrouped Jugger Howe Beck sites to the a priori Groups 2 and 3 provides some tentative absolute dating control for these groups. The 900bp Jugger Howe Beck brown podzolic soil has been grouped with the Group 2 brown podzolic soils from Dovedale. The 900bp date was seen above to give a maximum age for onset of pedogenesis at the Jugger Howe Beck site. The grouping of this 900bp soil with the Group 2 Dovedale soils therefore gives a tentative date of about 900bp for gravel accumulation and onset of pedogenesis for the terrace sediment in Dovedale characterised by the Group 2 soils. Several additional lines of evidence would support this date for the Dovedale site.

First, the pollen evidence discussed above suggested an age of no greater than about 1500bp for the accumulation of pollen in the basal layers of the Group 2 soil profile at soil site 1. Onset of pedogenesis could have been later than this, but is unlikely to have been much earlier. Had onset of pedogenesis been earlier then larger amounts of tree pollen might have been expected in the basal pollen of the soil.

Second, the phase of valley floor instability that accompanied the development of the middle terrace in Dovedale was likely to have been a period when there was large scale sediment mobilisation and redistribution within the Dovedale catchment. C^{14} evidence from a bog in the Dovedale catchment suggests that a significant phase of catchment instability was occurring about 1100bp. Although a discussion of the Bridestones Griff slack is deferred to Chapter 6 some reference to the slack is relevant to the present discussion.

At the head of the deeply incised gully of Bridestones Griff is an infilled slack, the Bridestones Griff slack. The slack has been infilled with a complex sequence of interstratified organic layers and sand inwash layers. A C^{14} date from an in-situ organic horizon at the base of the slack

indicates that infilling of the slack with eroded material from the surrounding catchment began about 1125bp. The first phase of filling in the slack may have continued until about 900-850bp. As there is no record of an earlier period of catchment instability, apart from the much earlier 6270bp terrace surface, it seems likely that this phase of catchment instability which resulted in the onset of the slack infilling was coincident in time with the onset of instability in the valley floor which resulted in the aggradation of the gravels which form the middle terrace surface in Dovedale and the Unit 4 gravels at the downstream C^{14} site.

As the dating control for the Dovedale Griff surface soil stratigraphic units has been drawn from a variety of sources, including soil profiles from another valley, the conclusions reached must be regarded as tentative. Nevertheless, supportive evidence from pollen analysis of the soils of Dovedale Griff, the date for onset of sediment accumulation in the Bridestones Griff slack as well as comparison with other dated soil chronosequences suggests that the dating control established for the three soil groups may provide a reliable estimate for onset of pedogenesis on the three main alluvial surfaces in Dovedale Griff. For the 6250bp date, this age estimate gives an approximate date for the phase of incision that produced the upper terrace upstream and aggradation of fluvial gravels downstream. It therefore gives a date for stabilisation of the surface upstream and a minimum date for gravel accumulation. The soil pollen evidence suggests that this date is probably a maximum date for onset of pedogenesis on the upper terrace surface. The 900bp date gives a maximum date for onset of pedogenesis as it is a date for gravel accumulation of the phase of gravel deposition that produced the Unit 3 gravels at the upstream C^{14} site in Jugger Howe Beck. The 225bp date also gives a maximum date for onset of pedogenesis at the downstream C^{14} site as this date gives an age estimate for sediment accumulation at the site.

4.4 The Juggerhowe Beck Surface Soil Stratigraphic Units

There are two sites within the Jugger Howe Beck study reach which have some C^{14} dating control. These sites were discussed in some detail in Section 4.2 above and were used in the discriminant analysis above to establish some age calibration for the Dovedale Griff surface soil stratigraphic units. The Jugger Howe C^{14} dates gave quite different ages for a phase of mainstream aggradation of fluvial sands and gravels in the upper reach of the stream and the accumulation of sediments at a palaeochannel site in the lower reaches of the stream. The C^{14} date for the former gave a maximum age of about 900bp for gravel aggradation whilst fine grained sedimentation was occurring further downstream about 225bp.

Further investigation of the soil stratigraphy of additional landform elements in the Jugger Howe Beck study reach should enable an assessment to made as to the extent to which these dated events from the two landforms are representative of the landform sequence in the Jugger Howe Beck study reach. Dating of the alluvial surfaces in Jugger Howe Beck is also necessary to enable an assessment of the extent to which phases of sediment accumulation are synchronous between Dovedale Griff in the Tabular Hills and Jugger Howe Beck in the Central Moors region. In the following section the age-calibrated surface soil stratigraphic units are therefore extended to the alluvial surfaces of the Jugger Howe Beck study reach. Data from the soil profiles developed into the deposits of the Jugger Howe Beck landforms will be inserted into the discriminant analysis data set as ungrouped sites. Estimates may then be made for the ages of the undated valley floor landforms.

The Jugger Howe Beck Soil Sample Sites

In Chapter 2 the landforms making up the valley floor sequence were seen to consist of three main groups of forms:

1. The landform elements of the Hollin Gill fan in the upper section of the study reach, and the terrace deposits at the toe of the Hollin Gill fan.
2. The low terrace deposits that occupy much of the valley floor downstream of the confluence of Hollin Gill and Jugger Howe Beck;
3. The upper bench along the western margin of the valley side.

Soil pits were excavated into the main landform elements making up each of the 3 groups of landforms in the Jugger Howe Beck study reach and described in the field using the methods outlined in Chapter 3. Bulk samples were taken on an horizon basis and analysed in the laboratory using the methods described in Chapter 3.

The Soil profiles developed in the low terrace deposits and the lower Hollin Gill fan elements

A number of exploratory pits were excavated in the deposits of the bars and channels making up the low terrace deposits downstream of the confluence of Hollin Gill and Jugger Howe Beck and in the lower fan elements of the Hollin Gill fan to ensure continuity of soil profile development for each major landform unit. Some of the infilled channels were found to be subject to seasonal waterlogging and showed evidence of gleying, but others were quite well drained, at least in the upper sections of the deposits. Where sites in channels were found to be well drained they were found to have sandy deposits forming the uppermost sediments. Bar deposits comprised of sand and gravel (Chapter 2) were generally well drained. Soil pits were excavated at nine sites from both west and east bank landform elements making up the low terrace and fan landform elements. These were sites 28-36 in Figure 4.6. These soil pits all exhibited a marked degree of similarity in profile morphology. Plates 4.3 and 4.4 are representative soil profiles from these landform elements. Table 4.11 below is a typical soil profile description for the soils developed into the low terrace deposits and lower fan elements in Jugger Howe Beck.



PLATE 4.3



PLATE 4.4

Table 4.11 **Soil profile description for low terrace deposits Jugger Howe Beck**

Slope	0°
Vegetation	heather, grass, lichens
Soil Drainage	Free
Parent Material	Alluvial sands
Major soil subgroup	Mineral alluvial soil

LF : 4cm - 0cm; very dark brown 10YR 2/2; no mineral content; semi-fibrous; spongy structure; moist.

H : 0 - 5cm; black 10YR 2/1; well defined organic horizon; many fibrous roots; moist; crumb structure; sharp boundary.

Bw : 5 - 14cm; dark brown 7.5YR 4/2; sandy loam; some fibrous roots; moist; very friable; no structure; moist; merging boundary.

Cu : 14cm+; dark yellowish brown 10YR 4/4; sand; no structure; very few roots.

Total solum depths for these soils range from about 15cm to about 20cm and B horizon thicknesses vary from about 6cm to 11cm. Values of 8 were recorded for the CDE variable. The soils were all remarkably consistent in values for this variable as there is little variation in soil colour between the profiles sampled on the bars and channels or on the Hollin Gill fan. Accumulation indices for pyrophosphate extractable iron ranged from 1.1 to 1.3 and values for dithionite extractable iron from 0.89 to 1.1.

The degree of soil profile development illustrated in Plates 4.3 and 4.4, together with the shallow solum depths and thicknesses of the individual horizons are indicative of immature, youthful soil profiles.

The Soil Profiles of the terrace deposits at the toe of the fan

The surface soil profile developed into the Unit 3 gravels of the terrace deposits at the toe of the fan constitutes the surface brown podzolic soil described in Table 4.4 and shown to have a maximum age of about 900bp.

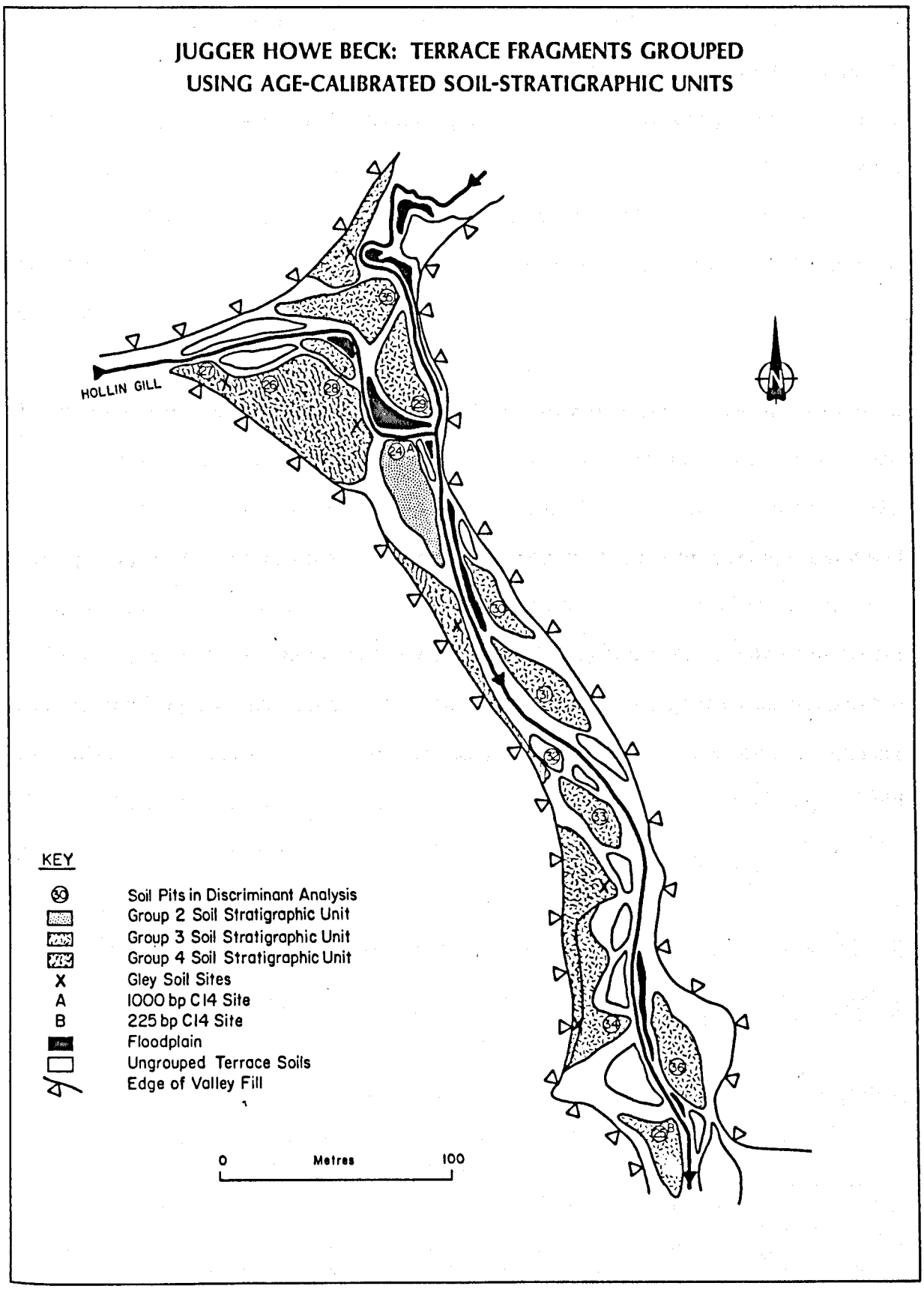

JUGGER HOWE BECK: TERRACE FRAGMENTS GROUPED
USING AGE-CALIBRATED SOIL-STRATIGRAPHIC UNITS
HOLLIN GILL
N
KEY
Soil Pits in Discriminant Analysis
Group 2 Soil Stratigraphic Unit
Group 3 Soil Stratigraphic Unit
Group 4 Soil Stratigraphic Unit
Gley Soil Sites
1000 bp C14 Site
225 bp C14 Site
Floodplain
Ungrouped Terrace Soils
Edge of Valley Fill
0
Metres
100

Figure 4.6

The Soil profiles developed in the upper bench and main fan unit.

The profiles developed into the upper bench along the western side of the channel and the soils developed on the main part of the fan unit are considered together because they display a notable degree of consistency in degree and type of soil development. Soil pits were dug in five locations along the upper bench which abuts the low terrace deposits on the western side of the stream. Two pits were excavated into the main fan unit. Gleyed soil pit sites are shown as X on Figure 4.6. The pits revealed a markedly different soil profile to those developed on the bar and channel complexes below the bench.

There are no exposures through the deposits of the bench so pits were dug well into the C horizon, usually about 1m in depth to allow an examination of the sediments making up the bench. The sediments were found to be consistent between sections. In all five pits the deposits forming the parent material for the surface soil profile consisted of poorly drained, massive and stiff grey silty-clay deposits. As discussed in Chapter 2, the deposits in the main fan unit are more varied than those of the upper bench. Exposures in the toe and northern margin of the fan indicate massive platy slabs of rock embedded in a dense stiff silty clay. In places however the slabs of rock are overlain by about 1m of silty clay deposit. In isolated exposures through bar deposits along the northern margin of the fan the deposits change to freely drained gravel and boulders set in a sandy matrix.

The silty- clay deposits of the upper bench and main fan unit are all poorly drained and have given rise to groundwater gley soils in all cases. Plates 4.5 and 4.6 show the soil profiles developed into the upper bench and into the silty- clay deposits of the fan unit respectively. As the groundwater gleys developed into the upper bench and the main fan unit are very similar, Table 4.12 gives a description of a soil profile developed into the upper bench.

Table 4.12 **Upper bench soil profile description Jugger Howe Beck**

Slope	0°
Vegetation	heather
Soil Drainage	Poor
Parent material	alluvial silts and clay

LF : 10cm - 0cm; heather litter.

O : 0 - 12cm; very dark brown 10YR 2/2; peat; blocky; moist; some woody and fibrous roots.

Ah : 12 - 17cm; black 5YR 2/1; organic- mineral horizon with many bleached grains; blocky structure; moist; friable; some woody roots; gradual boundary.

Bw : 17 - 25cm; light reddish brown 10YR 6/3; clay loam; moist; fairly firm; some blocky structure; merging boundary.

Bg : 25 - 60cm; light grey 10YR 7/1 with mottling of yellowish brown 10YR 5/7 on the ped faces and root channels; ped faces and roots channels also have organic staining; clay loam; strong prismatic structure; very moist; firm; some roots and humus on ped faces;

Cg : 60+; grey 10YR 6/1 clay; massive structure; very firm.

The Bg horizons that characterise gleyed soils such as the gleys of the upper bench and main fan unit are formed as a result of prolonged periods of anaerobism (Fitzpatrick, 1980). The mottled horizon forms in a zone of the soil that is saturated with water for a part of the year, but is partially (or completely) aerated during drier periods of the year. As a result oxidation of iron takes place locally along those surfaces that receive a supply of oxygen. These are usually fissures or cracks formed upon drying as well as root channels and ped faces. When horizons at or near the surface are saturated the products of organic matter decomposition are dissolved in the water and may be redeposited in lower horizons along root holes and ped faces (Fitzpatrick, 1980).



PLATE 4.5



PLATE 4.6

The gleyed soils are formed in response to different soil-forming processes from the soils described in Chapter 3 and the earlier part of this chapter. As a consequence it is not possible to include data from these gley soils in the statistical analyses involved in deriving the soil stratigraphic units. However, the gleys examined from both the upper bench and the main fan unit all display a consistent degree of soil profile development in terms of total solum depth, depth and degree of horizonation, soil colour and development of soil macrostructures.These soil profiles have been mapped from the north of Hollin Gill fan which represents the upper boundary of the study reach, over the main fan unit and along to the southern end of the study reach.

Examination of the morphological characteristics of the soils suggest that they are mature profiles exhibiting a high degree of soil profile development. The profiles on the fan and the bench do not differ in profile morphology. The five profiles developed into the silty- clay deposits of the bench vary in profile depth from 60cm to 70cm with Bw horizon thicknesses of 5-8cm. Bg horizon thicknesses vary between about 31 - 40cm. All profiles possess strongly developed prismatic peds in the Bg horizon. The two profiles from the main fan unit had total solum depths of 69 and 67cm respectively. Bw horizon thicknesses were 7 and 8cm and Bg horizons were 31cm and 38cm, this horizon displaying strong prismatic peds at both sites.

These soils display a consistent stratigraphic relationship to the fine grained deposits making up the upper bench and the matrix supported deposits of the main fan unit. In Chapter 3 it was seen that in order to qualify as a surface soil stratigraphic unit a soil profile must possess features that are pedogenic in origin, display a consistent relationship to associated stratigraphic units in the local succession, and posses soil properties which together with its stratigraphic relations to other units enable it to be traced and mapped in the field as a single marker unit. The mature gleyed soil may therefore be distinguished as a distinctive surface soil stratigraphic unit which defines a distinctive valley floor surface in Jugger Howe Beck.

As these gley soils differ in soil-forming processes from the freely drained brown podzolic soils making up the chronosequence of soils in Dovedale Griff their stage of development cannot be readily compared to the Dovedale soils. However, examination of two soil profiles developed on the freely drained gravel and boulders at the northern margin of the main fan unit revealed mature brown podzolic soils. These soils were the freely drained brown podzolic soils described in Chapter 3.3 above. One freely drained soil (Soil site 27 on Figure 4.6) is developed on a bar of the main fan unit less than 5m away from Site X which is a mature gley soil. The freely drained brown podzolic soil is therefore developed on the same landform element as the gley soil. The second soil was located on the main fan unit, but further downstream, soil site 26 on Figure 4.6.These freely drained soils were considered important ones to examine because they represent the freely drained phase of the soil stratigraphic unit defined by the gleys. An analysis of the morphological and chemical characteristics of the profiles can give an indication of the degree of freely drained soil profile development on this valley floor surface which can then be compared with the freely drained soils in the chronosequence. The soil profile description of one of these freely drained soils given in Chapter 3.3 is reproduced here as Table 4.13 for ease of reference.

Table 4.13 **Main fan unit soil profile description Jugger Howe Beck**

slope	4°
Vegetation	heather
Soil Drainage	Free
Parent material	alluvial gravels and sand

LF : 6 - 0cm; very dark brown 10YR2/2; spongey; moist.

H : 0 - 6cm; dark reddish brown 5YR2/2; organic horizon; well humified; moist fibrous roots; many bleached grains; friable; sharp boundary.

Bw : 6 - 19cm; dark brown 7.5YR 3/3; sandy loam; moist; crumb structure; very friable; many fine roots; some large stones; gradual boundary.

Bs : 19 - 59cm; strong brown 7.5YR5/6; sandy loam; crumb structure; very friable; moist; many fine fibrous roots; many large stones; gradual boundary.

B/C : 59-69cm; yellowish brown 10YR5/4; sand loam; no structure; loose; many large stones; merging boundary.

Cu : 69cm+; dark yellowish brown 10YR4/4; sand; no structure; loose; many large stones.

Reference to Chapter 3.3 above showed that this soil shares many of the characteristics of brown podzolic soils described from the upper terrace soils in Dovedale and the Howard Series soil. These characteristics include an H/Bw/Bs/BC/C horizon sequence, the presence of a Bs horizon with a fine structure, and the presence of a dark surface horizon with bleached grains. However, comparison of the Jugger Howe Beck soil with the upper terrace soils in Dovedale, dated to about 6270bp, demonstrates some significant differences between the oldest Dovedale soils and these freely drained brown podzolic soils from the Jugger Howe Beck fan. The Jugger Howe Beck soil is deeper than the upper terrace Dovedale soils. Total solum depth in the Jugger Howe Beck soil is 69cm with a Bs horizon thickness of 40cm. Average values for the upper terrace soil in Dovedale are 60cm for total solum depth and 20-25cm for Bs horizon thickness. CDE values from the Jugger Howe Beck soil are 24 whilst the average value for the upper terrace soils is 20.

In Figure 3.2 iron data from the Jugger Howe Beck brown podzolic fan soil described above were added to the depth plots of Fe_p and Fe_d extractable iron from published data on brown podzolics and for some of the upper terrace Dovedale soils. The plots for the Jugger Howe Beck soil show a marked increase in area under the curve in comparison to the upper terrace soils from Dovedale. There are also some differences in the iron accumulation indices. The B:C horizon ratio for pyrophospahte extractable iron for the Jugger Howe Beck soil is 3.05 which is at the upper range for the Group 1 soils and for dithionite extractable iron is 4.1 which is greater than the average value of about 3.3 for the Dovedale soils. These data in combination suggest that the Jugger Howe Beck soil shows a greater degree of soil profile development than the Dovedale upper terrace soils and is therefore likely to have been subject to soil-forming processes for a greater length of time. This soil may therefore make up a fourth and older member of the soil chronosequence developed in Chapter 3.

Discriminant Analysis

Data for the soils sampled from the valley floor landforms in Jugger Howe Beck were inserted into the discriminant analysis data set in order to allocate the new soil profiles into their most likely soil stratigraphic group. As discussed above the discriminant analysis data set is made up of 3 a priori groups. These groups consist of the 23 soil profiles from Dovedale Griff and in addition the 3 sites that were allocated to the group 2 and 3 soils in the previous discriminant analysis. This second discriminant analysis will allocate the new soil sites from Jugger Howe Beck to one or other of the age-calibrated a priori groups. Soil stratigraphic data from the brown podzolic soils of the main fan unit, soils from the lower Hollin Gill fan unit and from the low terrace deposits were included in the analysis. Data from the lower Hollin Gill fan and the low terrace deposits were entered into the analysis as ungrouped sites.

Data for the main fan unit brown podzolic soil sites were entered into the analysis as an additional, and therefore fourth, a priori group. The morphological and chemical data for the brown podzolic soils indicate that these soils are at a more advanced stage of soil profile development than the Group 1 terrace soils in Dovedale. The main fan soils are therefore unlikely to belong to one of the three groups within the 6270bp-225bp age range defined by the original a priori groupings of the discriminant analysis. In consequence the brown podzolic soils from the main fan unit were entered as an additional a priori group. The validity of including these soils as a fourth a priori group will be assessed statistically by the discriminant analysis, for the classification results table will show the soils as either correctly classified or misclassified. The most likely group for these soils will be indicated as the cases with the largest posterior probability. Posterior probability values for first and second group membership will therefore indicate whether there should be a change of group membership for the soils entered into the fourth group.

Table 4.14 gives the entry statistics for the stepwise selection of variables in the discriminant analysis. As with the previous analysis the first variable to be included was B horizon thickness. At step 1 B horizon thickness recorded the lowest Wilk's lambda 0.11, and an F-to-enter of 61.1. With an equivalent F of 61.1 at 3 and 23 degrees of freedom, Wilk's lambda is significant at greater than the 0.001 level and the null hypothesis of no differences between the group means is rejected. At the second step, as with the first analysis, the variable selected in the stepwise procedure was Fe_p B:C which when combined with B horizon thickness produced the smallest Wilk's lambda 0.07 and the next largest F-to enter. At this step the F-to-enter is the partial F for the discrimination added by Fe_p B:C and the null hypothesis being tested is that Fe_pB:C does not add significantly to the discrimination between the groups. With an equivalent F of 20.31 and at 6 and 44 degrees of freedom Wilk's lambda is significant at greater than the 0.001 level and the null hypothesis is rejected.

Table 4.14 **Entry statistics for stepwise selection of variables in discriminant analysis 2.**

Variable	Tolerance	F-to-enter	Wilk's lambda
At step 1			
Fe_p B:C	1.000	13.36	0.364
Fe_d B:C	1.000	12.52	0.379
CDE	1.000	28.32	0.213
Bhor.thick	1.000	61.10	0.111
At step 2			
Fe_p B:C	0.997	4.28	0.071
Fe_d B:C	0.942	2.13	0.086
CDE	0.805	2.74	0.081
After step 2			
Fe_d B:C	0.909	0.870	0.062
CDE	0.711	0.870	0.062

After step 2 of the analysis the tolerance level of both Fe_d B:C and CDE was still sufficient to allow the variables to enter, but the Wilk's lambda and F-to-enter were very small. After step 2 variable selection in the stepwise procedure stopped.

The discriminant function providing maximum separation between the four a priori groups is

$$D = -5.93 + 0.22Bhor + 2.93Fe_p \qquad \text{Equation 4.3}$$

where D is the discriminant score for the soil profile. The discriminant function table (Table 4.15) shows that for this analysis the eigenvalue is 9.7 and representated as a relative percentage of the total possible discriminating power of the variables accounts for a very high 96.7% of the total discriminating power of the variables in the analysis. In this analysis the canonical correlation coefficient of 0.95 indicates a strong association between the derived discriminant function given in equation 4.3 and the 4 a priori groups.

Table 4.15 **Discriminant function table for analysis 2**

Eigenvalue	% Variance	Can. Corr. Coeff.
9.7	96.7%	0.95

The standardised coefficients for equation 4.3 are given below and show that B horizon thickness makes the greatest contribution to the function, with the coefficient of 0.92 being even higher than it was for the first analysis.

Variable	Standardised Coefficient
Fe_p B:C	0.43
Bhor thick	0.92

The unstandardised coefficients in equation 4.3 are used to calculate the discriminant scores for each soil profile. Table 4.16 gives a summary of the classification results based on the discriminant scores calculated for each of the grouped and ungrouped sites. The classification results table shows that with the four group scheme for the Dovedale and Jugger Howe Beck podzolic soils only 2 sites were misclassified. These were site 4, a Group 1 soil, and site 17, a Group 3 soil. The posterior probabilities for these two sites indicate that they are more likely to

belong to Group 2. Of the 28 a priori cases 92.59% of the cases were correctly grouped. The classification results table also supports the Group 4 soils as forming a discrete group of soils as neither of the Group 4 sites were recorded as being misclassified.

Table 4.16 Classification Results for discriminant analysis 2

Actual group	No. of cases	Predicted Group Membership			
		1	2	3	4
1	7	6 85.7%	1 14.3%	0 0.0%	0 0.0%
2	8	0 0.0%	8 100%	0 0.0%	0 0.0%
3	10	0 0.0%	1 10%	9 90%	0 0.0%
4	2	0 0.0%	0 0%	0 0	2 100%
Ungrouped cases	9	0 0.0%	0 0.0%	9 100%	0 0.0%

The canonical discriminant function evaluated at the group centroids is given below and shows a large difference between the group means for the Group 1 and Group 4 soils and as such emphasises the difference in stage of soil formation between the two groups:

Canonical Discriminant Function Evaluated at Group Centroids

Group	Function 1
1	2.506
2	-0.371
3	-2.849
4	6.961

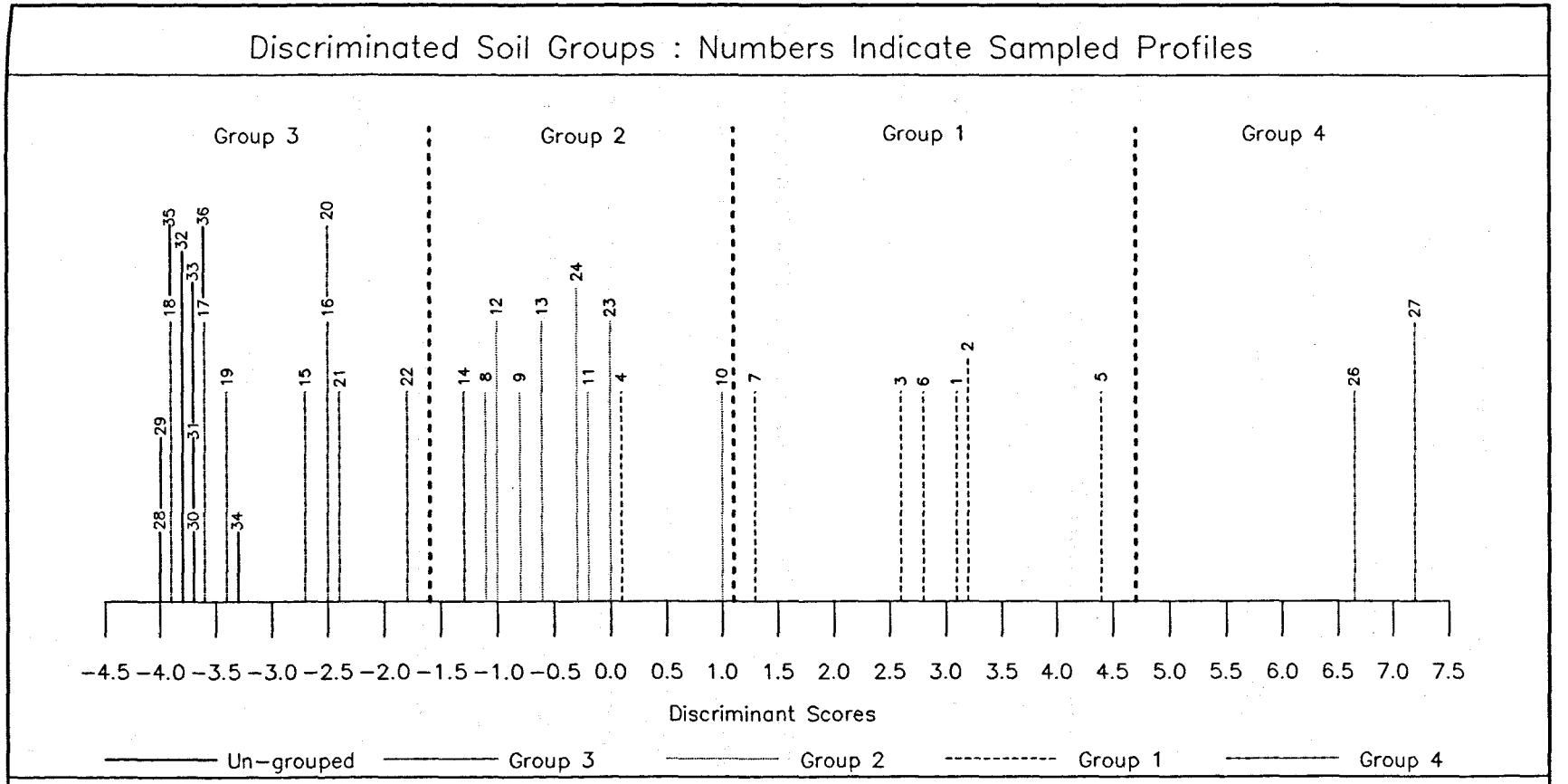
The plot in Figure 4.7 is a projection of the discriminant scores for each soil site projected onto the axis of the first function. This shows that the two group 4 soils, sites 26 and 27 are well separated from the Group 1 Dovedale soils. As the combined first function represents degree of soil profile development as represented by the maturity of the B horizon, the analysis supports the suggestion made on the basis of an assessment of the field and morphological data that the two freely drained brown podzolic soils from the main unit of the Jugger Howe Beck fan are at a different and more advanced stage of soil profile development than the Group 1 Dovedale brown podzolic soils. The posterior probabilities for the soils belonging to group 4 are 0.99 and 1.0 respectively, whilst the probabilities of belonging to the next most likely group, the group 1 soils extremely small, 0.0002 and 0.00 respectively.

The classification table also gives the allocation of the ungrouped sites to an a priori group. Reference to this table shows that all the 9 sites from the bar and channel deposits of the low terrace and the sites from the lower Hollin Gill fan have been assigned to the Group 3 soils. Table 4.17 gives a more detailed breakdown of the group allocations for these Jugger Howe Beck sites.

Table 4.17 **Group allocation of previously ungrouped sites**

Site Details	Allocated Group	highest P [G/D]	2nd Group	P [G/D]	Score
Site 28	3	0.997	2	0.003	-3.951
Site 29	3	0.997	2	0.002	-4.066
Site 30	3	0.994	2	0.005	3.732
Site 31	3	0.996	2	0.005	-3.751
Site 32	3	0.994	2	0.003	-3.847
Site 33	3	0.994	2	0.005	3.732
Site 34	3	0.984	2	0.015	-3.291
Site 35	3	0.997	2	0.003	-3.948
Site 36	3	0.993	2	0.006	3.632

The posterior probabilities for each of the ungrouped cases belonging to its allocated group are all very large. The posterior probabilities for allocation into the next most likely group are also shown in Table 4.17. Comparison of the probabilities for the allocated and next highest group that the likelihood of allocation into another group other than the "highest group" is extremely unlikely.



Dovedale and Jugger Howe Beck Soils

PLOT OF FIRST DISCRIMINANT FUNCTION SCORES

Figure 4.7

Interpretation of the discriminant analysis

The landforms in Jugger Howe Beck correlated on the basis of the surface soil stratigraphy are shown on Figure 4.6. The allocation of the low terrace bar and channel soils and the lower Hollin Gill fan soils to the Group 3 soils is not suprising given the very youthful soil morphology of the soil sites. The analysis therefore suggests that a large proportion of the soil units developed into the valley floor landforms have probably developed since about 225bp. This suggests that the valley floor landforms in the study reach are dominated by landforms which are very youthful and which radiocarbon evidence suggests have accumulated very rapidly (Section 4.2 above).

Despite the digging of numerous exploratory pits and examination of all available sections, no further evidence was found in the study reach of a modern soil with equivalent degree of soil profile development to that found at the 900bp C^{14} site in the terrace deposits at the toe of the main fan unit. This then suggests that the 900bp unit in Jugger Howe Beck has only very limited spatial expression.

The freely drained brown podzolic soils developed into the deposits of the main fan unit have provided evidence for a fourth soil-stratigraphic unit. The combination of the statistical analysis and the morphological and chemical properties of the soils suggest that this fourth unit is characterised by soils which exhibit a greater degree of soil profile development than the oldest terrace soils in Dovedale Griff. As the freely drained soils have been found on a landform element which is also characterised by a gleyed soil, the freely drained soils are able to provide some correlation with the gleyed soil which is found both on the main fan unit and on the upper bench the length of the study reach.

The Age of the Group 4 Soils

There is no dating control for this soil group although the characteristics of the soils show that they are at a more advanced stage of soil development than the Group 1 Dovedale soils, and are therefore likely to be older. However, some indirect evidence may suggest a possible maximum age for the soils belonging to the Group 4 soil unit.

Jugger Howe Beck lies in a position marginal to the last ice sheet (Gregory, 1964). During the period of the Dimlington Stadial the area in which Jugger Howe is situated would have been subjected to extensive periglacial conditions. The end of the Dimlington Stadial was about 13000 years bp. The Loch Lomond Stadial occurred about 11000 - 10000 years bp. During this time eastern England is likely to have experienced seasonally frozen ground, evidence for the severity of the climate in this area being supported by persistent disruption of existing horizonation in chalkland soils (Evans, 1966, 1968) and the local development of polar desert conditions associated with wind blown sands in the Vale of York (Matthews, 1970). If the sediments making up the parent materials for the Group 4 soils and their gleyed counterparts had been land surfaces during either of the cold periods evidence for soil formation during the severe conditions of the Stadials ought to be present.

Rose et al. (1985) have described the characteristics of Stadial soils and their relict features. Evidence of soil formation during Stadial conditions generally takes the form of isolated or discontinuous ground ice features. These may include involutions, frost cracks and ice wedges in the deposits. These features reflect the effects of periglacial soil-forming processes on land surfaces such as alluvial fans or terraces.

No evidence has been found in either the fan soils or the soils or sediments of the upper bench in Jugger Howe Beck of features suggestive of formation under periglacial soil-forming conditions. This is not to say that such features did not form in Jugger Howe Beck under stadial conditions. There is evidence in the literature to suggest that periglacial conditions were experienced in the

Tabular Hills area during the stadial conditions (Rose et al., 1985) with the existence of ice wedge and sediment-wedge polygons believed to have formed between about 26000bp and 13000bp. This evidence suggests that such features did form under stadial conditions in the North York Moors but have presumably only survived under favourable site locations such as plateau tops. In Jugger Howe Beck it seems likely that if soil formation had occurred on the slopes and on an old valley floor land surface, extensive soil removal would probably have occurred during the Loch Lomond Stadial when severe cold and a maritime location subjected the area to ground ice activity, much slope instability on the surrounding slopes and seasonal snowmelt runoff. Rose et al. (1985) suggest that such conditions are likely to have been common in areas subjected to stadial conditions and may explain the notable lack of survival of Lateglacial palaeosols. Such background environmental conditions in Jugger Howe Beck are likely to have produced extensive erosion of the steep slopes which even under present conditions show evidence of recent slope instability. Active aggradation and degradation in the valley bottom is likely to have accompanied this slope activity. Under these circumstances survival of features related to a stadial phase of pedogenesis is unlikely.

Considering this argument the most likely maximum age for the onset of pedogenesis on the main fan unit and the upper bench in Jugger Howe Beck is immediately post dating the Loch Lomond Stadial when the landsurface produced as a result of the periglacial conditions stabilised. This is likely to have been about 10000 years bp. This date then gives an approximate age for accumulation of the stratigraphic unit on which the Group 4 soils developed and a maximum age for the onset of pedogenesis.

The results from the discriminant analysis suggest that the Juggerhowe Beck brown podzolic soils may be added as an additional, and more advanced soil profile to the chronosequence of soils described in Chapter 3.9. A generalised soil profile morphology diagram of the four soil stratigraphic units making up this chronosequence of brown podzolic soils is shown in Figure 4.8.

GENERALISED SOIL PROFILE MORPHOLOGIES OF THE FOUR SOIL-STRATIGRAPHIC UNITS FROM DOVEDALE AND JUGGER HOWE BECK

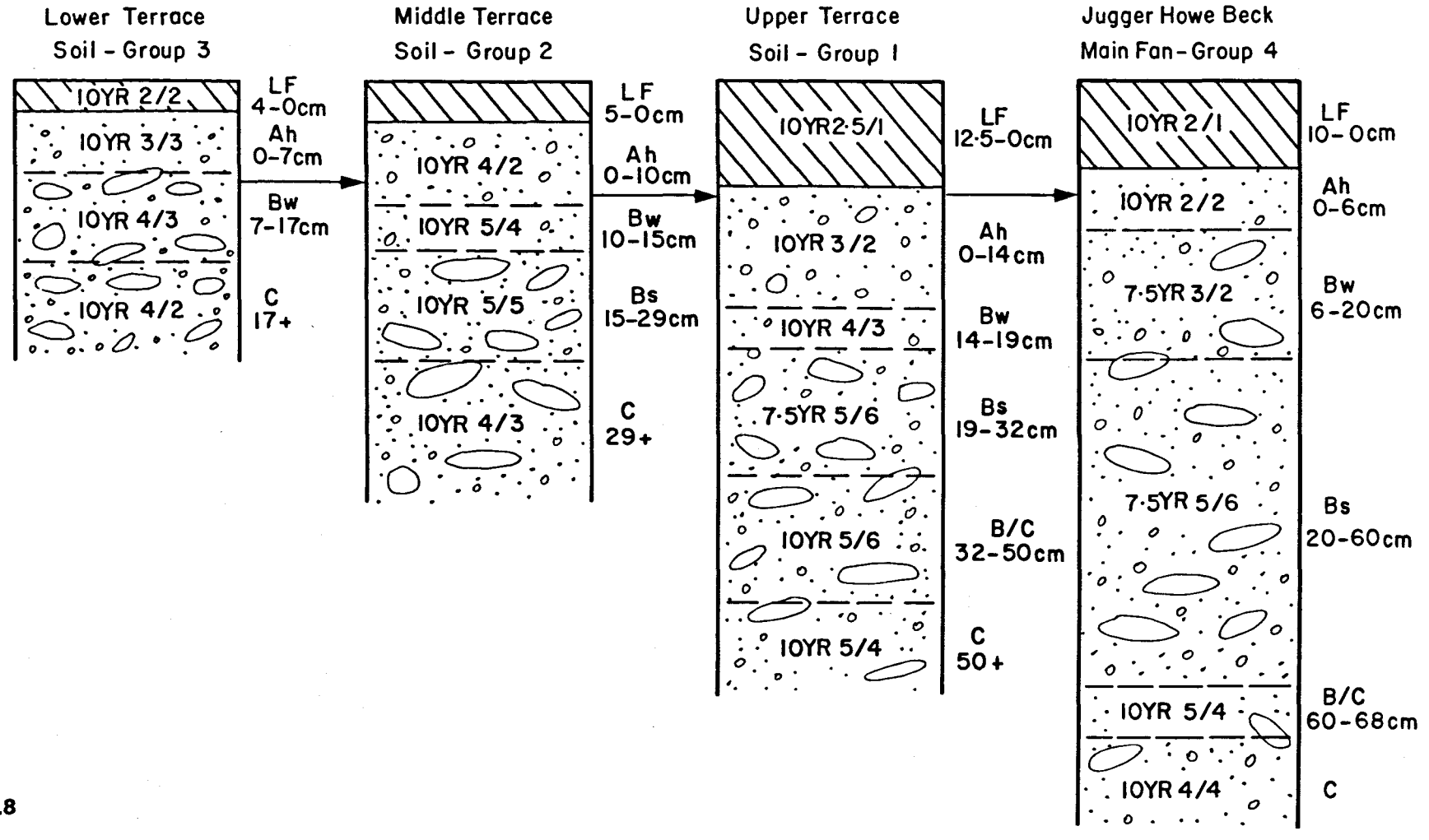


Figure 4.8

The occurrence of the freely drained soil and the well developed gley soil on an extensive valley floor of Jugger Howe Beck suggests that together these mature soil profiles form an additional surface soil stratigraphic unit developed into a land surface which marks the end of unstable slope and valley floor conditions at the close of the Loch Lomond Stadial at about 10000 years bp. As such the freely drained phase of the unit may be tentatively added to the discriminant analysis data set as an older soil group probably originating about 10000bp, thus extending the range of the soil chronosequence from about 6200bp to about 10000bp.

4.5 Conclusion

The combination of morphological and chemical soil data from the Dovedale Griff and Jugger Howe Beck soils has provided evidence of four surface soil stratigraphic units developed in freely drained alluvial sediments in two valleys in the North York Moors. One of these units, the fourth group, is correlated with a gleyed phase which shows extensive development in Jugger Howe Beck. Tentative correlation of three out of the four freely drained soilstratigraphic units with some absolute dating control suggests that the units may date from about 6200bp, 900bp and 225bp in age. The fourth unit is suggested to have a maximum age of about 10000bp. Evidence of all these units has not been found in one valley. Rather, in Dovedale three of these units appear to be present. These are the 6200bp, 900bp and 225bp units. In Jugger Howe Beck those present appear to be the 10000bp unit, the 900bp unit and 225bp unit.

In conclusion, for Dovedale Griff a combination of height range data, pollen analysis, C^{14} dating and surface soil stratigraphic data have provided evidence for at least three major alluvial surfaces in the evolution of the valley fill deposits. In Jugger Howe Beck a combination of soil-stratigraphic data, C^{14} dating and sediment stratigraphy have provided evidence for at least three ages of alluvial surfaces in the valley floor fill.

Chapter 5

Valley floor landform development in Dovedale Griff and Jugger Howe Beck

5.1 Introduction

The development of the surface soil stratigraphic units in Dovedale Griff and Jugger Howe Beck has enabled the identification of several phases of valley floor aggradation in both valleys. The various methods of absolute age determination discussed in Chapter 4 permitted the tentative assignment of absolute ages for the accumulation of the sedimentary units which have formed the parent materials for the soil profiles which make up the four surface soil stratigraphic units. These soil stratigraphic data have provided evidence for at least three major alluvial surfaces in the evolution of the valley fill deposits in Dovedale Griff. These surfaces have been tentatively dated to about 6200bp, 900bp and 225bp. Three alluvial surfaces have also been identified in the evolution of the valley fill deposits in Jugger Howe Beck. These have been tentatively dated to about 10000bp, 900bp and 225bp.

The aim of this chapter is to examine the development of these valley fill landforms within the temporal framework provided by these dated surfaces and the spatial framework provided by the individual catchments.

5.2 Dovedale Griff

The stratigraphic section at the Dovedale Griff C^{14} site (Figure 4.1), the terrace morphology as it is represented on the height range diagram (Figure 4.2) and the dating control of terraces developed in Chapters 3 and 4 constitute the available evidence with which to interpret the history of valley fill development as it is represented by the terrace surfaces in Dovedale Griff.

In Dovedale Griff the oldest terrace surface has been dated to about 6200bp, this date giving an approximate age for incision through the floodplain deposits. There is no available dating evidence to indicate when the gravels which form the upper terrace surface began to accumulate on the valley floor of Dovedale Griff, although this must have been some time before 6200bp. It is possible that the floodplain of the pre-6200bp stream, and the outer units of the compound fan, had been progressively aggrading during the early Holocene period at a time when the sediment yield: stream flow ratio was higher than it was at about 6200bp. Steep valley fill slopes such as that represented by the upper terrace surface suggest that aggradation and increasing bed elevation would have been occurring as a result of sediments entering the headwaters of the stream with sedimentation of the coarse sand and gravels steepening the overall floodplain slope (Richards, 1982).

In Chapter 4 it was established that the upper terrace surface is likely to correlate with the prior floodplain surface which contains the dated wood at the C^{14} site below the valley constriction in Dovedale. The evidence from the height range diagram strongly supported the hypothesis that the former floodplain represented by the upper terrace once formed a steeply sloping, continuous floodplain along the length of the valley including the reach downstream of the valley constriction (Figure 4.2). The height of the bedrock outcrop at the valley constriction shows that this floodplain is unlikely to have been interrupted by the bedrock outcropping on the channel bed. The existence of fragments of this upper terrace surface on both sides of the present stream channel upstream from fragment 11, and the continuation of these fragments to the hillslope/valley floor junction, suggest that this former floodplain is likely to have been very extensive, probably occupying the full width of the valley floor.

The evidence from Dovedale Griff indicates that burial of the alder at the C^{14} site occurred as a result of incision through the gravelly floodplain deposits in the upper and middle reaches of the river, liberating stored floodplain sediments which then resulted in downstream aggradation after their evacuation through the valley constriction. Thus the sediments which bury the wood are associated with the incision of the former floodplain represented by the upper terrace level. This

phase of channel instability would have resulted in lowering of the bed elevation in the upper and middle reaches of the stream and aggradation of the bed in the downstream reaches of the stream. Discussing the mechanisms of channel slope adjustment, Richards (1982) notes that decreasing bed elevation may be the result of a basin wide control on the sediment yield : stream flow ratio, with a decrease in the ratio resulting in incision. The suggested mechanism of upstream incision and downstream aggradation for Dovedale Griff thus implies a catchment-wide control of erosion resulting from a decrease in the sediment yield : stream flow ratio about 6200bp.

It is not possible to state with any certainty the channel pattern type of the prior Dovedale Griff. The terrace fragments making up the upper terrace surface are extensive in a downstream direction, but are restricted in areal extent in a cross-valley direction. This means that they do not exhibit palaeochannels with a complete enough channel network either to indicate the channel pattern of the prior Dovedale Griff or to undertake palaeohydrological analysis. Further, the lack of exposures in the terrace scarps precludes a sedimentological analysis of channel pattern, although as Bluck (1979) and Bridge (1985) have remarked, in coarse-grained streams the similarities between deposits of braided and meandering streams may be more significant than their differences. However, the combination of the steepness of the floodplain slope, the coarseness of the gravelly floodplain deposits and the possible extent of the floodplain do suggest the possibility that prior to incision through the floodplain deposits the pre-6200bp Dovedale was a braided stream.

The date of 6270bp from the buried wood gives an approximate date for the incision which produced the upper terrace surface. This correlates with a date during the Atlantic period (7000bp - 5000bp) suggested by the pollen assemblage at the base of the organic horizon of the upper terrace soil for onset of pedogenesis of the upper terrace surface soil. The suggestion of the onset of pedogenesis at about 6200bp implies not only that by about this time the upper terrace was a stable landsurface with little erosion or deposition occurring, but also that little significant pedogenesis had taken place on the floodplain prior to incision.

The lack of stratification in the downstream deposit forming Unit 2 at the C^{14} site in Dovedale suggests that the wedge of sediment overlying the dated wood was deposited rapidly thus implying that the phase of valley floor instability that resulted in the creation of the upper terrace upstream and aggradation of fluvial gravels below the valley constriction took place within a relatively short space of time. Modern studies describing bed elevation changes and slope changes that accompany artificial modifications such as dams illustrate a potentially rapid rate of river slope adjustment where input catchment conditions are substantially modified (Knighton, 1987). In the Eel River, northern California bed elevation changes similar to those proposed for Dovedale Griff were shown to have occurred very rapidly (Patrick et al., 1982). In the Eel River substantial modification to the long profile of the stream was produced as a result of bed lowering upstream and aggradation downstream, the large amount of redistribution of sediment implied by the scale of these changes occurring in response to one high magnitude flood.

In Chapter 4, Unit 3 of the stratigraphic section at the C^{14} site was identified as the truncated profile of a buried soil. Identification of buried soil horizons, particularly at sites where the profile has been truncated, should be made with great care. This is because features assumed to result from the operation of pedogenic processes may have origins which are open to interpretation (Fenwick, 1981). Comparison of buried horizons with their surface counterparts forms an important method of recognising the pedogenic origin of a buried B horizon (Birkeland, 1978; Catt, 1988). Bulk soil properties, such as chemical composition and particle size distribution should show characteristic changes with depth (Catt, 1987, 1988). Birkeland (1978) also suggests that the buried soil should have lateral continuity and may have redder or browner colours and possess better developed ped structure than the underlying C horizon. One other criterion used for recognising a buried soil is also suggested to be the abruptness of the horizon boundaries (Birkeland, 1979). If a B horizon is present the colour is usually redder in the upper part of the horizon, whilst the chroma diminishes with depth.

In the Dovedale section the truncated profile is laterally continuous along the length of the section and is easily detectable by its colour change from the underlying and overlying deposits. Although the possibility of post-burial alteration of soil properties should be borne in mind (Mahaney & Fahey 1988) field examination of the morphological properties of the buried horizon and chemical analyses of the sesquioxides suggests that the most comparable B horizons of the present day Dovedale surface soil profiles are the B horizons of the Group 1 soils (see Chapter 3).

Although it is not possible to know if some of the upper B horizon of the buried soil has also been removed, comparison of the buried horizon with the Group 1 Bs horizons certainly suggests that some of their characteristics are more comparable with the upper terrace soils than with the Group 2 soils of the middle terrace. The truncated soil is a yellowish brown, with a moist Munsell colour of 10YR 5/6 at its upper boundary merging to 10YR 5/4 at its lower boundary and then gradually merging to 2.5YR 4/4 which is the parent material colour of Unit 2. The CDE value for the upper part of the horizon of the buried soil horizon is 18 which is slightly lower that the average value of 20 for the Group 1 soils. The buried horizon has no roots. The matrix material possesses a weak sub-angular/crumb structure. Iron extractions suggest that the horizon is enriched with sesquioxides and comparison can be made with the accumulation indices of iron for the terrace soils. The Fe_p ratio between the buried horizon and the underlying parent material is 1.95 and the Fe_d ratio is 2.75. The Fe_d ratio of this horizon is comparable with the 3.6 - 2.2 range of the Group 1 Bs horizons. Values for the accumulation index of iron for the pyrophosphate extractable is lower than that for the Group 1 terrace soils. This ranged from about 4.9 to 2.2. There is no sedimentological or chemical evidence to suggest that the buried soil horizon is layered or cumulative.

Although detailed micromorphological evidence would be required to confirm the pedogenic origin of this horizon, the available evidence does suggest that Unit 3 is a buried B horizon of a soil profile that has been truncated. The morphological and chemical characteristics of the horizon suggest that it may be compared to the Bs horizons of the present day Group 1 surface soils although the Bs horizons of the Group 1 soils are probably slightly more mature.

The presence of the buried soil at the top of Unit 2 has several significant implications for the phase of valley fill development following sediment aggradation at about 6200bp. The presence of the soil as well as absence of evidence for cumulative soil profile development suggests that the onset of the phase of pedogenesis that produced the buried soil marks the end of the phase of sedimentation associated with the channel incision upstream and aggradation downstream. It also marks the beginning of a phase of relative landsurface stability at the site with the characteristics of the buried B horizon suggesting a relatively long period of pedogenesis at the site before burial. The presence of the soil also means that pedogenesis began at approximately the same time on the surface stabilised by incision upstream as on the depositional surface downstream.

However, examination of the thickness and characteristics of the buried B horizon also implies that after the phase of aggradation that produced the Unit 2 gravels there must have been a phase of downcutting through the Unit 2 deposits at the downstream site. This is implied because the thick podzolic B horizon of the buried soil is unlikely to have developed on a floodplain surface close to the water surface where it would have been subject to fluctuations of water level. The buried B horizon is about 30cm thick with a B/C horizon of about 20cm. Comparison with the upper terrace surface soils, which the B horizon of the buried soil most closely resembles, suggests that the upper soil horizons are likely to have been at least 20cm thick, so that the total solum depth of the buried soil must have been approximately 70-80cm. A well drained brown podzolic soil of this depth could not have developed close to the water surface.

Additional evidence from the downstream River Staindale indicates that downcutting along the reach of the C^{14} section must have followed aggradation of the Unit 2 gravels. There is no evidence in exposures in the banks of the River Staindale which Dovedale joins for aggradation of fluvial gravels either associated with the 6200bp phase of gravel aggradation or with any earlier or later phases of aggradation. Much of Staindale flows on bedrock and there is no evidence in any of the Staindale cut banks of phases of cut and fill, which suggests that the level of Staindale has changed little during the Holocene. As Staindale provides the baselevel for Dovedale,

downcutting through the 1.5m of aggraded gravels must have occurred so that Dovedale could grade to Staindale. As the level of Staindale has changed little, Dovedale must have cut down almost to the level of the floodplain which contains the buried wood and which must have previously graded to Staindale.

Incision of Dovedale through the aggraded deposits downstream of the valley constriction would have extended progressively upstream. However, upstream incision would have been arrested by bedrock control encountered at the valley constriction. The outcropping of a bedrock control at the valley constriction thus implies a significant spatial control on episodes of incision and aggradation between the reach of Dovedale upstream of the constriction and the downstream reach with this control in effect creating a complex response mechanism confined to the lower reach of the stream.

Complex response is a mechanism that has been invoked to explain multiple terrace development in response to a single external stimulus. Complex response usually involves downstream control by base level change (Born and Ritter, 1970; Schumm and Parker, 1973). This is then followed by coupling of main and tributary streams with tributary sediment supply steepening the main valley fill gradient until renewed incision is triggered and the cycle of incision and aggradation is repeated. In this way multiple levels of inset terraces can be generated by a single external stimulus. In the case of Dovedale the baselevel control is complicated involving not only the downstream baselevel control of Staindale to which Dovedale grades, but also the baselevel imposed by the bedrock outcrop at the valley constriction. In Dovedale Griff the external stimulus that was responsible for the incision through the floodplain deposits in the upper reaches of Dovedale at about 6200bp resulted in terracing upstream but aggradation downstream. Terracing of the wedge of sediment at the downstream reach was a response to baselevel controls imposed by Staindale, this response being a consequence of the initial phase of basin wide instability at 6200bp. The difference in behaviour between the upstream and downstream reaches imposed by the bedrock outcrop serves to emphasise the spatial complexity of valley fill development even in a small valley such as Dovedale Griff.

After upstream incision and a cycle of aggradation and incision at the downstream reach and onset of pedogenesis on a stable landsurface, a long period of stability appears to have ensued in the catchment. This is suggested not only by the maturity of the buried soil at the downstream site but also by the soil pollen analysis described in Chapter 4.2. This analysis showed a marked contrast between the pollen assemblage found at the base of the organic layer of the upper terrace soils which was dominated by tree pollen including alder, and that found at the base of the organic layer of a middle terrace soil which was dominated by Ericales. The soil pollen evidence was shown to imply a relatively long time interval between the onset of pedogenesis for the soils which distinguish the upper terrace fragments and the gravel aggradation that produced the land surface which formed the parent materials for soils belonging to the Group 2 middle terrace soils. This pollen evidence is supported by the soil evidence discussed in Chapter 3.9 which pointed to marked differences in both soil morphology and chemical properties between the Group 1 and Group 2 soils.

The stratigraphic evidence at the downstream C^{14} site at Dovedale suggests that some time after onset of the phase of pedogenesis that produced the B horizon of the truncated soil there was a renewed phase of instability which was once again accompanied by gravel aggradation at the downstream end of Dovedale. The discriminant analysis carried out in Chapter 4.3 as well as the height range evidence discussed in Chapter 4.2 suggested that the middle terrace gravels upstream of the valley constriction and the Unit 4 gravels at the C^{14} site which bury the podzolic B horizon belong to the same phase of gravel deposition. The combination of the soil pollen evidence, the dating of the middle terrace surface soil stratigraphic unit and the basal date from the Bridestones Griff slack all indicated that this phase of catchment instability and gravel aggradation occurred about 1000bp - 900bp.

This renewed phase of gravel aggradation appears to have been a valley wide event resulting in the aggradation of the middle terrace gravels along the length of Dovedale with these gravels inundating the upper terrace surface at a point upvalley at the position of fragment 8 (Figure 4.2). Gravel aggradation must have also buried the bedrock outcrop at the valley constriction and

inundated the former land surface represented now by the buried soil. This more recent phase of valley floor instability contrasts with that which occurred at about 6200bp for this phase of aggradation must have resulted from a basin wide control which saw an increase in the sediment yield: streamflow ratio.

As with the earlier phase of valley floor instability, this more recent phase of valley floor gravel aggradation and the incision which followed it produced a varying spatial response along the valley floor of Dovedale Griff. Subsequent incision left two terrace levels in the upper reaches of Dovedale, the upper terrace and the middle terrace. However, below fragment 8 inundation of the upper terrace by the middle terrace gravels meant that only one terrace level would have been present. Downstream of the valley constriction downcutting through the Unit 4 gravels would once again have been controlled by the baselevel control of Staindale with incision proceeding upstream to once again expose the bedrock outcrop. This phase of gravel aggradation and incision result in the development of the overlapping stratigraphies shown in Figure 4.1.

Alluvial fan accumulation is often indicative of rapid sediment production during periods of environmental instability associated with phases of catchment wide disturbance (Ryder, 1971; Wells and Harvey, 1987). The alluvial fan at the tributary alluvial fan junction of Egg Griff and Dovedale Griff has a complex structure in which various sedimentation and incision episodes have created surfaces of differing age (Chapter 3). The properties of the soils on the fan surfaces indicate that they correlate closely with the three terrace surfaces in the main Dovedale valley (Chapter 3.8) thus indicating synchronous phases of aggradation and incision in the tributary and main valley. There is thus no evidence to indicate that aggradation was occurring in the main Dovedale valley when and because incision was occurring in the tributary valleys. Evidence for the operation of complex response in the main section of Dovedale above the valley constriction is thus not forthcoming.

A final phase of gravel aggradation occurred in the Dovedale catchment at about 225bp. The extensive preservation of the terrace fragments relating to the 900bp phase of valley floor aggradation suggests however, that the 225bp phase of valley floor instability was less vigorous than the preceding 900bp phase.

This explanation of the development of the terrace surfaces in Dovedale Griff implies that changes in the background environmental conditions occurred at least three times within the Dovedale catchment, these changes resulting in the formation of three alluvial surfaces on the valley floor of Dovedale griff.

5.3 Jugger Howe Beck

In Chapter 4 the oldest valley floor surface in the Jugger Howe Beck fill was suggested to have formed in the Loch Lomond or immediate post Loch Lomond period about 10000bp. This old land surface consists of two main landform elements, an extensive alluvial fan formed at the junction of Hollin Gill and Jugger Howe Beck, and a degraded upper bench which is found along the western margin of the valley floor. The properties of the soils developed on these old land surfaces indicate that they correlate closely in age (Chapter 4). The surface soils developed into these landform elements are extremely mature gleyed soils which show a consistent stratigraphic relationship to the fine-grained deposits making up the upper bench and the matrix rich deposits of the main fan unit. The mature gleyed soil was therefore identified as a distinctive surface soil stratigraphic unit. Freely drained brown podzolic soils are developed into the clast- supported cobbles and gravels at the eroded fan margin and were suggested to form a freely drained phase of this old surface soil stratigraphic unit. As these soils are freely drained, they could be compared with the brown podzolics developed in Dovedale. The Hollin Gill brown podzolics were shown to be at a more advanced stage of soil development, and therefore older, than the Dovedale Griff upper surface soils dated to about 6200bp. The Jugger Howe Beck soil stratigraphic unit and underlying deposit does not display evidence of stadial soil forming conditions in the form of discontinuous ground ice structures which implies that it probably was

not a stable land surface during the Loch Lomond Stadial. It was therefore suggested that the most likely date for valley filling to produce the sedimentary units which make up the upper bench and main fan unit was the Loch Lomond/immediate post Loch Lomond period, with stabilisation and onset of pedogenesis occurring shortly afterwards (Chapter 4).

The main fan unit of the Hollin Gill fan has a mean slope of 4°. Exposures through the trimmed margin at the north side of the fan and the erosional bluff at the eastern edge of the fan indicate that the fan is made up of at least two main facies types (Chapter 2). These are matrix-rich (silt and clay) deposits supporting angular clasts and blocks of bedrock and clast-supported sub-angular cobbles and gravels. These two contrasting facies types are indicative of different processes operative during the formation of the fan.

Alluvial fans may be the result of a range of depositional processes, from mud flows and debris flows to streamflows (Ryder, 1971; Wells and Harvey, 1987). In south central British Columbia paraglacial fan accumulation involved deposition by mud-flow (debris flow) and streamflow processes (Ryder, 1971). Recent studies of alluvial fans in upland Britain have demonstrated that fans may be the result of a combination of debris flow, transitional flow and fluvial processes. (Wells and Harvey, 1987; Brazier et al., 1988). One of the factors influencing the relative proportions of fluvial and mud-flow (debris flow) will be the composition of the available sediment.

The presence of the fine-grained matrix rich deposit with poorly sorted coarse angular clasts and slabs of rock in the Hollin Gill fan suggest that this is a mud/debris flow comparable to the debris flow deposits described from the Glen Etive debris cone in the western Grampians and attributed by Brazier et al. (1988) to debris flow activity in the immediate post Loch Lomond period. The clast supported cobbles and sub angular gravels are fluvial deposits comparable with the fluvial deposits described by Wells and Harvey (1987) from fans in the Howgill Fells.

The main source of sediment for the mud/debris flow deposits of the fan are the slopes of Hollin Gill. Destabilisation of slopes in the Loch Lomond and immediate post Loch Lomond period is likely to have taken place on both the steep slopes of the tributary valley catchment as well as in the main Jugger Howe Beck valley at a time when thawing of the sparsely vegetated frozen ground was taking place. The hillslope sediments would have been particularly susceptible to mass movement processes under these conditions. Such conditions would have contributed to widespread erosion of the Hollin Gill and Juggerhowe Beck hillslopes and as a corollary sedimentation in the valley floor. The fine grained deposits of the main unit of the Hollin Gill fan and the upper bench form the oldest valley fill deposit of the present alluvial fill in Jugger Howe Beck.

The most extensive fluvial surface in Jugger Howe Beck is that which aggraded about 225bp (Chapter 4) and is therefore considerably younger than the fill deposits of the upper bench and main fan unit. Landform elements contributing to the 225bp surface include the lower Hollin Gill inset fan unit and the low terrace deposits downstream of the Jugger Howe Beck and Hollin Gill confluence. The low terrace fragments are made up of a well defined complex of bars and infilled palaeochannels.

Unlike the terraces in Dovedale Griff, the low terrace fragments downstream of the bedrock constriction in Jugger Howe Beck possess quite well defined palaeochannels and bars. The channel pattern of the palaeochannels is shown on Figure 5.1. Although it is not possible to know if all the channels shown on Figure 5.1 were active at any one time, the channel pattern is indicative of a braided channel which probably migrated actively over the narrow valley floor.

A series of C^{14} dates was presented in Chapter 4 from a palaeochannel infill which forms a part of one of the bar and channel complexes at the downstream end of the study reach in Jugger Howe Beck. The availability of dates from both the bottom and top of the infill demonstrated rapid sedimentation of the floodplain with a date from the base of the deposit indicating that sedimentation began about 225bp. Although the limited range of dates obtained for the samples,

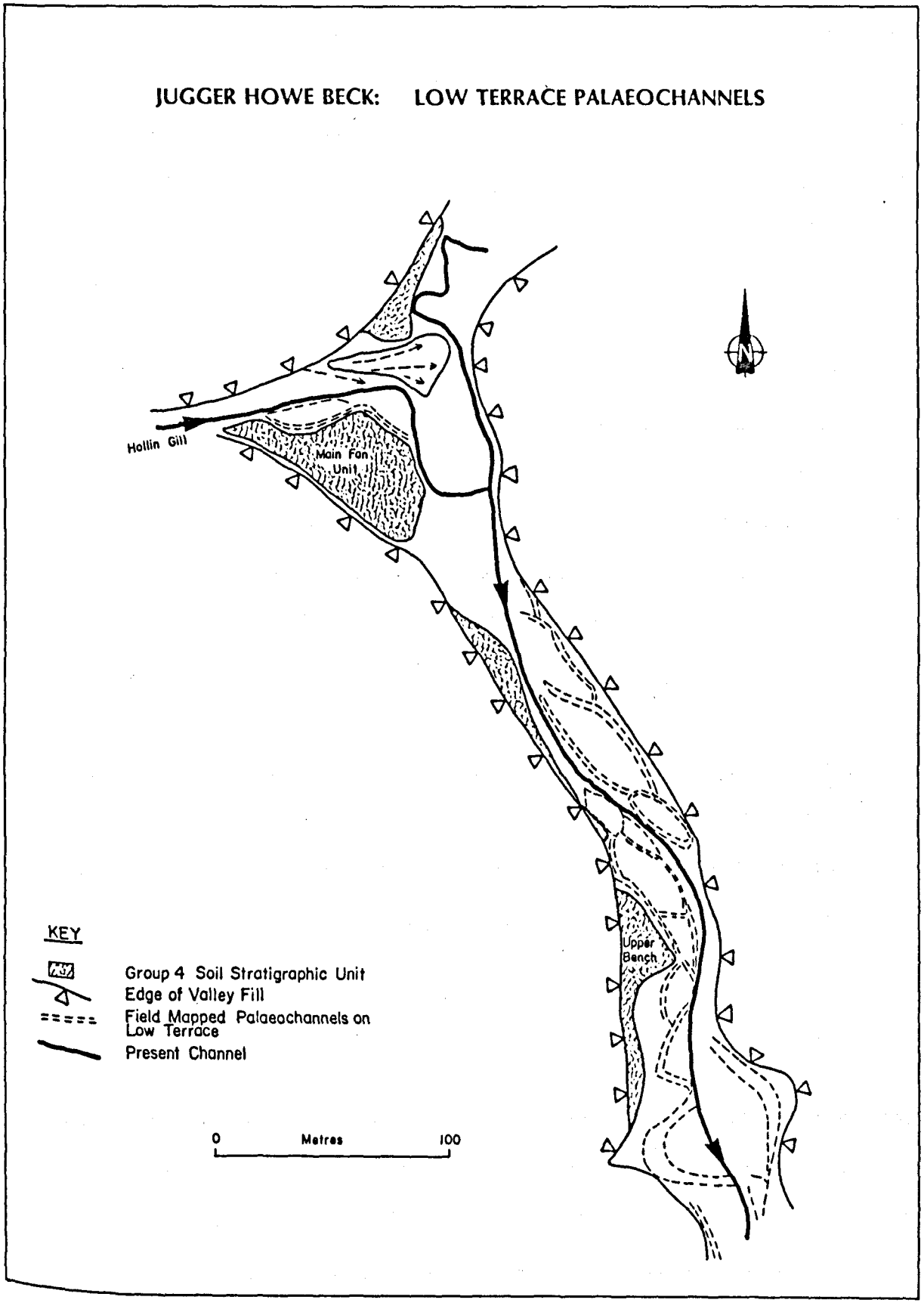

JUGGER HOWE BECK: LOW TERRACE PALAEOCHANNELS
Hollin Gill
Main Fan Unit
Upper Bench
N
KEY
Group 4 Soil Stratigraphic Unit
Edge of Valley Fill
Field Mapped Palaeochannels on Low Terrace
Present Channel
0
Metres
100

Figure 5.1

together with the relatively wide age ranges implied by these determinations, make interpretation of the dates in terms of periodicity of phases of deposition unrealistic, the dates taken together provide consistent evidence of a period of very rapid sedimentation around 260-200bp. Sediments exposed in cut banks of the low terrace surface both upstream and downstream of the C^{14} site display similar sequences of buried organic horizons and silty-sand deposits thus suggesting that the C^{14} site provides evidence of general floodplain accretion along the study reach, with floodplain accretion occurring within the age range encompassed by the C^{14} dates (Richards et al., 1987)

Examination of the landform elements in the northern study reach between Hollin Gill and Juggerhowe Beck shows that the inset lower fan is quite extensive and includes the surfaces on which soil pits 28 and 35 were dug as well as the landform elements immediately upstream of these sites (Figure 4.6). Exposures through the lower fan element on which soil pit 28 is situated reveal that these fan deposits are comprised only of matrix supported fluvial gravels. The slope of the fan element on which soil pit 35 is located is 2.2° from Hollin Gill to Juggerhowe Beck, and 2° from south to north. These fan units are shown on Figure 4.6.

As the properties of the soils on the lower fan unit of the Hollin Gill tributary fan and the low terrace deposits of the valley surface downstream of the confluence fall into one soil stratigraphic unit, these data imply that the Jugger Howe Beck catchment was responding as a whole to changes in sediment delivery from the hillslopes during a period of quite severe catchment disturbance at about 260-225bp.

The building of the lower Hollin Gill fan was probably responsible for the realignment of the channel of Jugger Howe Beck with deposition of the lower fan unit at the tributary/main valley junction blocking the channel pathway of the prior Juggerhowe Beck, pushing the channel of Jugger Howe Beck eastwards towards the valleyside slope against which it is now pinned. This process of channel realignment as a result of fan growth has been described by Small (1973) in the Val d'Herens in Switzerland. Here the main valley stream is described as being "hemmed in"

by the contemporaneous growth of tributary valley alluvial fans. Realignment of main channel routes as a result of alluvial fan building has also been described by Harvey (1987) for fans which developed in response to the high magnitude 1982 storm event in the Langdale valley, Howgill Fells.

Apart from the localised terrace unit at the C^{14} site, there is no further evidence in the Jugger Howe study reach of any additional landform elements characterised by surface soil profiles such as are found on the Unit 3 gravels at the C^{14} site. It seems unlikely, however, that the phase of gravel accumulation that produced the inset gravelly fill overlying the silty clay deposits at the C^{14} site did not extend downstream to produce a thin inset fill along the length of the study reach.

The phase of sedimentation which resulted in the accumulation of the lower inset fan, the channel alignment changes in Jugger Howe Beck, and the aggradation of the fill deposits downstream of the confluence of Hollin Gill and Jugger Howe Beck indicates a phase of catchment-wide instability and valley floor aggradation with large amounts of sediment being transported by the stream. The braided channel pattern displayed by the palaeochannels downstream of the confluence suggests that the former beck was probably migrating across much of the valley floor. It is therefore possible that a prior, 900bp surface could have been reworked by a relatively powerful 225bp Jugger Howe Beck. There is no evidence in the cut banks of the low terrace to indicate that the 900bp surface has been buried by the phase of aggradation that took place at around 225bp. The surviving 900bp terrace fragment would have been protected from erosion and reworking by the change in channel alignment produced as a result of the accumulation of the lower Hollin Gill fan.

Reworking and scour of a relatively thin gravel fill by the braided channel of the 225bp stream is feasible in the context of erosional and depositional processes of upland streams. Harvey (1986, 1987) has shown in the Howgill Fells that extreme flood events may not only reshape the channel pattern but also the valley floor. In 1982 an intense storm with a return period in excess of 100

years affected Langdale and Bowderdale in the Howgill Fells. This storm resulted in major floods in both catchments, destabilisation of hillslope gullies and a massive sediment input into the stream channels. This sediment input resulted in the development of numerous debris cones and alluvial fans at tributary junctions and completely buried the valley floor in a tributary valley and in upper Langdale with 1m of fresh gravel and boulders. Widespread channel changes also occurred as a result of avulsion, bend cutoff and tributary fan aggradation. In a study of Langden Brook in the Bowland Fells, Thompson (1987) showed that 17.4% of the valley floor was eroded and reworked as a result of two major floods which occurred within the space of five days.

Such rates of valley floor erosion have also been demonstrated in historical times in response to high magnitude floods (McEwan, 1986; Robertson-Rintoul, 1986b). In Glen Feshie reworking of extensive 3500bp terrace deposits occurred in response to high magnitude floods between 1869 and 1899. This reworking was responsible for the erosion of a total of 30% of the terrace area in one upstream reach and the creation of an extensive braided channel and bar complex which has been subsequently abandoned to form the most recent terrace surface. Although these rates of reworking and sedimentation are rapid they are comparable with rates of reworking monitored by Ferguson and Werritty (1983) for a braided reach of the River Feshie and with the high rates of historical valley alluviation for the Afon Ystwyth in mid-Wales (Lewin et al., 1983).

As in Dovedale Griff at least three phases of catchment-wide instability are indicated by the stratigraphic units making up the valley fill deposits in Jugger Howe Beck. The early phase of valley filling involved a combination of debris flow and fluvial processes that accompanied widespread hillslope erosion and valley floor sedimentation that accompanied the Loch Lomond Stadial and the immediate post Loch Lomond period. Limited evidence from the 900bp phase of aggradation suggests that a thin inset fill of gravelly deposits was laid down over the silty clay deposits of the very early Holocene surface in the late Holocene. The channel alignment changes of Jugger Howe Beck, the creation of an inset tributary valley fan and the development of the bars

and channels of the stream which caused aggradation of an inset fill in the main valley are all suggestive of a period of high sediment supply from fresh erosional areas and high discharges at about 260-225bp.

5.4 Conclusion

The terraced valley fills of Dovedale Griff and Jugger Howe Beck record the response of the valley floors to several phases of catchment-wide instability and valley floor sediment surface elevation changes. A sequence of Holocene sedimentary units and terraces has been established for each valley using the available evidence, although as suggested by the limited spatial extent of the 900bp surface in Jugger Howe Beck, the record of Holocene sedimentary units may be incomplete with phases of sedimentation having been removed by subsequent erosion.

Correlation of alluvial sequences between valleys is often inhibited because of a lack of datable material with which to correlate the sedimentary units making up the fill deposits (Butzer, 1980). A Holocene alluvial chronology for Dovedale Griff and Juggerhowe Beck based on stratigraphy, radiocarbon dates, and surface soil stratigraphy has revealed at least three phases of intensified valley floor alluviation and floodplain construction, each represented by an alluvial stratigraphic unit.

In Dovedale Griff the alluvial surfaces have been dated to about 6200bp, 900bp and about 225bp. The stratigraphic evidence described above revealed evidence of an early phase of valley floor instability which resulted in redistribution of sediment within the valley floor of Dovedale Griff. A late Holocene phase of catchment wide sediment delivery resulted in the development of contemporaneous fan and terrace units throughout the valley about 1000 - 900bp while a more minor phase of terracing occurred in historical times.

Comparison of the sediment record at the C^{14} site with the terraces upstream serves to emphasise the complexity of the spatial relationships between aggradation and incision in valley fill evolution, with overlapping stratigraphies developing downstream of the valley constriction and inset terraces above.

In Jugger Howe Beck the main alluvial surfaces have been dated to about 10000bp, 900bp and about 225bp with the stratigraphic evidence revealing a very early phase of widespread hillslope erosion, mass movement and valley floor sedimentation, a prolonged period of stability and pedogenesis and two later phases of gravel aggradation. In this valley the efficacy of erosional and depositional fluvial processes in a stream where there is a high potential for channel and floodplain change was well illustrated by the probable reworking and scouring of the 900bp gravelly infill by a relatively powerful braided stream about 225bp.

Chapter 6

Vegetation History and Archaeology of the North York Moors

6.1 Introduction

The sequence of landform development discussed in Chapters 3, 4 and 5 implies that significant changes in the environmental controls on sediment and stream discharge occurred in the Dovedale and Jugger Howe Beck catchments. Vegetation cover is a major control on sediment availability and stream discharge. Vegetation cover can undergo changes that occur both very rapidly, and also over large areas. Many workers (for example Brazier et al., 1988) have demonstrated how vegetation change can have direct influence on the development of valley floor landforms. Others have shown that vegetation change does not always initiate an immediate response in the landscape. Harvey et al., 1981 for example suggested that in some situations vegetation change acted, in effect, to move landforms closer to the threshold of instability, and that subsequent de-stabilising processes operated to take the landforms beyond that threshold.

In this Chapter therefore, the Holocene regional pollen record from the North York Moors is examined to establish the vegetation history of the region, because of its significance as an environmental control on landscape stability. The role that man has had in bringing about vegetation change on the North York Moors is also examined by reference to documented archaeological evidence.

This Chapter first assesses the existing pollen evidence from the North York Moors; this is achieved by examining the pollen record from Fen Bogs, the most thoroughly researched Holocene pollen site on the North York Moors. Secondly the Chapter reports the results of a palynological and stratigraphic investigation that was carried out on a site identified for this present study in the Dovedale catchment.

6.2 Holocene Vegetation Change In the North York Moors

The North York Moors region has been the subject of extensive palynological investigations which have been carried out in a wide variety of geomorphological situations. Palynological work was initiated by Elgee (1912) and Erdtman (1927, 1928) who examined the peat deposits which formed in mires or "slacks". These slacks are found in sinuous channels incised along the hillsides which were formed as a result of the action of sub-glacial melt-off (Gregory 1962). Later workers (Cundill 1971; Atherden 1976, 1977) extended this research into the channel mires, and subsequently blanket bogs (Simmons and Cundill 1974a) and bogs formed behind large land-sliped blocks (Simmons and Cundill 1974b) were also the subject of intensive pollen analytical research. As shown in Figure 6.1, the great majority of these investigations on the North York Moors have been carried out on the central and northern Moors to the north of the Tabular Hills.

These studies referenced above have established a generally accepted pattern of Holocene vegetation change in the North York Moors. A secure chronology for these vegetation changes has been established largely as a result of the investigation of a site at Fen Bogs, on the east-central Moors. Atherden (1976) established a radiocarbon calibrated pollen record for the Holocene from Fen Bogs. Atherden (1976) suggested that Fen Bogs would be the most suitable site on the North York Moors to provide a regional standard pollen diagram, and she suggested therefore that the Local Pollen Assemblage zones she devised for the Fen Bogs record could be used as a basis for constructing wider Regional Pollen Assemblage zones.

6.3 The Fen Bogs Pollen Record and North York Moors Archaeology

Fen Bogs is probably the most significant site on the North York Moors because of the length of its pollen record which extends back to the Zone V, the early Boreal period. In addition several C^{14} assays were performed on the upper part of the core which provided a very secure chronology for vegetation change for the middle and late Holocene.

POLLEN ANALYTICAL SITES IN THE NORTH YORK MOORS

TEESSIDE

CLEVELAND PLAIN

NORTH SEA

WHITBY

R. Esk

R. Esk

ROBIN HOOD'S BAY

VALE OF YORK

THIRSK

PICKERING

VALE OF PICKERING

Dalby Beck

R. Derwent

SCARBOROUGH

N

0 5Km

KEY

1	KILDALE HALL	4	TRANMIRE SLACK	7	MOSS SLACK	10	FEN BOGS	D_X	DOVEDALE
2	WEST HOWE MOSS	5	ST. HELENA LANDSLIP	8	GALE FIELD	11	MAY MOSS	J_X	JUGGER HOWE BECK
3	EWE CRAG SLACK	6	BLAKEY LANDSLIP	9	SIMON HOWE SLACK	12	STAR CARR	G_X	LAKE GORMIRE

Figure 6.1

The Fen Bogs site is equidistant from Dovedale, 10km. to the SSW, and from Jugger Howe Beck, 10km. to the ENE (see Figure 6.1). It is a 20ha. valley mire situated in the very large N-S trending meltwater channel of Newtondale. The site is at an altitude of 164m O.D. and contains peat deposits almost 12m. deep, the deepest which have been found in the North York Moors. The peat directly overlies Late Glacial solifluction clay.

The Fen Bogs pollen record (see Figure 8.1) reveals an early Flandrian landscape which was quite open, with arboreal (tree) pollen comprising <25% of the total pollen sum (TP). Betula was the predominant tree, with smaller amounts of Pinus, Quercus, and Ulmus. The shrubs provided approximately 37% TP, with significant amounts of Salix (6%) and Corylus/Myrica (35%). Ericales, Gramineae and Cyperaceae were all important contributors to the non-arboreal pollen, although the good representations of other ruderal (weed) taxa such as Rosaceae (8%) and other species suggest that there were many open habitats in the vicinity of the site. This level in the record is dated to Flandrian Chronozone Ib (West 1970), a period which corresponds to Pollen Zone V, and Blytt and Sernander's (1908) early Boreal period, which was a time of rapidly increasing warmth and dryness.

Evidence from the North York Moors region for the presence of man during this early stage of the Holocene is found at sites on the lowland perimeter of the North York Moors. The stratigraphy of cores taken from these sites provided evidence for the occurrence of fire in the form of charcoal bands associated with sand layers. Such sequences have been reported by Clark (1971) from Star Carr and by Jones (1971) from Kildale Hall, where these workers have attributed them to localised burning by early Mesolithic man. Star Carr is the site of an early Mesolithic lakeside hunting camp situated at the eastern end of the Vale of Pickering. Artifacts recovered from the occupation horizon, where the inwash and charcoal were identified, were radiocarbon dated to 9538 +/- 350 bp, and belonged to the Maglemosian culture. The Maglemosian culture has been classically associated with forest, marsh and Phragmites sp. swamps, and is named after the type-site in Denmark called Maglemose (meaning "big bog"). Pollen analysis from the Starr Carr site revealed that the Maglemosians occupied a swampy environment, typical of much of the

lower areas of the Vale of Pickering during the early Holocene. The Star Carr site produced many heavy flint axes that were used for tree felling. The site, which included a platform of axe-felled birch trees, provided the earliest example of artificially felled trees in the British Isles. The presence of charcoal at the occupation level also shows that the Maglemosians were already using fire to modify their immediate environment. The tree felling and burning activities were of insufficient intensity however to be reflected in the pollen record from the site.

Pollen Zone V in the Fen Bogs record is succeeded by a Zone VI, or the Boreal period. In Zone VI there was a rapid expansion of Pinus, which attained 45% TP, and substantial records for Ulmus and Quercus. Alnus starts to increase halfway through this zone, and there are also the first records of Tilia and Fraxinus. Corylus/Myrica show a significant rise in this zone, with values up to 40% TP. The Corylus/Myrica rise has been recognised throughout England and Wales as a marker for the boundary between Zone V and Zone VI pollen (Godwin 1975; Beckett, 1981). This Zone was one of extensive Pinus forest with in some areas Corylus/Myrica forming a canopy tree rather than occurring only as an understorey shrub. The range of herbs, including Gramineae, Pteridium sp. and Filipendula sp. and the presence of various Ericales indicate that there were many open habitats.

The Fen Bogs Zone VI pollen record displays considerable variability in the Pinus and Corylus/Myrica values, with short periods of lower values for the former coinciding with higher values for the latter. This pattern occurs occasionally in conjunction with particles of charcoal. It is possible that sporadic woodland burning by man at this time encouraged the growth of Corylus/Myrica, due to their ability to recover after burning has occurred. Simmons et al. (1975) consider that such temporary fluctuations in the pollen record from Ewe Crag Slack and West House Moss on the central Moors, coinciding with silt layers and charcoal is evidence of man induced burning. At West House Moss a radiocarbon date of 6650 +/- 290 bp was obtained from peat immediately overlying the charcoal and sandy inwash layer. Archaeological evidence for permanent habitation of man on the central Moors during this period is however very scarce (Radley 1970).

The opening of the next pollen zone, Zone VIIa, identified at Fen Bogs is marked by the rapid Alnus expansion and a major Pinus decline. Quercus and Alnus dominate the arboreal pollen, with notable amounts of the thermophilous Ulmus and Tilia. Betula and Pinus are reduced to minimal amounts and non-arboreal pollen are at a minimum of only 27% TP. Corylus/Myrica retain the high counts of the Boreal period, indicating that it occurred as a widespread understorey shrub. The paucity of herb species indicates that closed woodland dominated the Fen Bogs site, a conclusion supported by the many wood fragments in the core at this level.

The Alnus rise has been widely identified from sites throughout the British Isles (Rapson 1984, Godwin 1975), as marking the start of the Atlantic period, and is usually considered to have occurred at c. 7000 bp (Tinsley, 1975). There is however some lack of uniformity as to the precise date at which the Atlantic period begins. In the North York Moors, Jones et al. (1979) places the opening of the Atlantic period at 6650 bp. This latter date is for the Alnus rise in the North York Moors region. The Atlantic was the phase of the post glacial Climatic Optimum, when both temperature and precipitation were higher than at present. Deciduous woodland reached its maximum extent in the form of the Quercetum Mixtum, which was dominated by oak and thermophilous tree taxa, notably Ulmus and Tilia, reached their peak during this period.

It is notable that pollen analysis from sites at higher altitudes in the North York Moors, such as May Moss at 244m (Atherden 1979) indicate that even during this phase of maximum forest development, the highest parts of the North York Moors probably did not support a closed canopy forest. These isolated clearings probably served to attract man to them for the game which would exploit the more verdant grazing that could flourish beyond the shade of the forest canopy. The origin of these clearings has been the subject of considerable debate between exponents of a "natural" explanation, whereby the open habitats were remnants of montane vegetation which existed before Boreal climatic warming (Tallis 1964) and the majority who proposed anthropogenic intervention in the landscape by burning during Atlantic times (Dimbleby, 1962; Simmons, 1969; Jones, 1978; Jones et al. 1979).

The latter viewpoint would seem to be supported by a large body of archaeological evidence from the North York Moors. Large quantities of Late Mesolithic flint microliths have been found from widespread locations on the central Moors (Radley 1970). The microliths have included arrowheads, scrapers, and cutting edges and are of a form distinctive of the Mesolithic Sauveterrian culture, named after the type site of Sauveterre-la-LeMance in France (Radley 1970). These Sauveterrian microlith finds lack the heavy axes used for tree felling which are associated with the lowland Maglemosian culture. Their presence on the uplands of the central and northern Moors indicates that man was moving away from the lowlands, which had been the primary settlement areas since the beginning of the Holocene. The establishment of the Sauveterrian hunting culture during the Atlantic may well have resulted in woodland clearings taking on considerable importance to man's hunting methods. It has been suggested by several workers (Dimbleby, 1962; Simmons, 1969; Jones, 1978; Jones et al. 1979) that during the Atlantic period fire was being used to clear woodland. The purpose for burning therefore may well have been to create, or enlarge existing clearing to attract more game.

It was during the Atlantic period that many of the blanket and "slack" peats began to accumulate on the central Moors (Jones 1979), and it is from these sites that microlith finds have often been found within organo-mineral deposits containing charcoal. The stratigraphic levels at which the microliths are found often have pollen sequences which reveal the existence of several ruderal species. For example in the Ewe Crag Slack Site site on the central Moors, Jones (1978) identified silt layers with charcoal coinciding with pollen spectra which included increased records for ruderals such as Rumex sp., Artemisia and Melampyrum, and also Corylus/Myrica. Many microlith finds are considered to represent hunting camps (Radley, 1970), at which fire would have invariably been used. The coincidence of increased rainfall and anthropogenic activity during the Atlantic period, specifically the sporadic removal of trees and their replacement by temporary clearances of grass and scrub vegetation, may have led to the initiation of blanket bog growth across large areas of the higher parts of the North York Moors (Simmons 1975).

The end of the Atlantic period is marked by the Ulmus Decline, which is the next significant point in the pollen record from Fen Bogs. The Ulmus Decline marks the start of Zone VIIb, or the Sub-boreal period. At the Ulmus Decline however, Atherden (1976) divides the Fen Bogs pollen record into Local Pollen Assemblage zones (LPAZ). This was done to allow the local vegetation history surrounding individual sites to be analysed independently of the chronological and climatic implications involved with using the standard British Post Glacial pollen zones. A date of 4720 +/- 90 bp calibrated to 5650-5500 bp by reference to Stuiver and Suess (1966) and Suess (1967) was obtained for the Elm Decline from Fen Bogs. Ulmus records fall from 7% during the preceding Atlantic period to only 2% at the Decline. A less severe decline is also experienced by Quercus and Tilia, but Alnus did not appear to be affected. Corylus/Myrica show an increase, as do several ruderals, notably Plantago sp. and Rumex sp. These changes suggest that localised woodland clearings were being made, thereby permitting the expansion of shrubs and herbs beyond the shade cast by the woodland canopy.

The Ulmus Decline is a distinctive marker in the Holocene pollen record throughout the British Isles and one which is generally interpreted as indicating both the end of the Quercetum Mixtum, and of the Climatic Optimum. It also marks the beginning of a period of episodic reduction and subsequent limited regeneration of arboreal taxa, together with a general increase in records of heliophytic taxa and also those taxa with anthropogenic associations. After the Ulmus Decline the early and mid-Holocene levels of Ulmus pollen are reached only very rarely in England, although the mixed oak forest tree taxa do recover to a greater extent (Godwin 1975).

Archaeological evidence of man in the North York Moors at the Ulmus Decline is in the form of Neolithic burial mounds and scattered finds of flint arrowheads. The burial mounds are restricted to the Tabular Hills while the arrowheads have been found largely on the central Moors. Evans (1976) interprets this distribution of finds to be evidence that Neolithic man had settlements on the Tabular Hills, while the higher land of the central Moors was used as a hunting ground.

In the Fen Bogs pollen record, LPAZ "A" is succeeded by LPAZ "B", with the boundary between the two zones providing a radiocarbon date of 3400 +/- 90 bp. Atherden (1976) defined the opening of LPAZ "B" by the Tilia decline, a feature in the pollen record which, like the Ulmus Decline has also been associated with man's activities, and especially with the use of the leaves of Tilia for fodder, and the inner bark for bast, with its fibrous nature making it useful for matting and padding (Turner 1970). LPAZ "B" includes records for Plantago sp., Rumex sp.and Compositae sp. and other herbaceous taxa, indicative of the creation of a series of small temporary woodland clearances. A date of 2280 +/- 120 bp for the boundary between LPAZ "B" and LPAZ "C" indicates that LPAZ "B" extends over middle and late Bronze Age times.

The pollen record from LPAZ "B" indicates minor vegetation changes typical of those which have been reported from other sites on the central Moors (Simmons, 1969; Cundill, 1971; Jones, 1971, 1976 & 1978; and Simmons and Cundill, 1974a & 1974b) and which indicate no radical change in the species composition of the forest. These workers reported a marked decline in all tree pollen, with only Tilia showing a decline, and a consistent increase in heathland and ruderal species.

The Fen Bogs pollen record does not include any Cerealia during the Bronze Age, suggesting that cereal cultivation was not carried out on the central Moors. Atherden (1976) summarises the impact of Bronze Age man on the vegetation as being restricted to small localised clearances, with the clearances primarily being used for pastoral agriculture. She also concluded that during this period Calluna heath became established on the higher areas of the central Moors, where woodland had never completely covered the landscape during Holocene times. Dimbleby's (1962) examination of pollen in the buried soils beneath Bronze Age barrows at Burton Howes on the central Moors similarly reveals no Cerealia, and artifacts associated with arable cultivation such as grain storage pits, querns, and sickles are also absent from this site.

In addition to the Bronze Age barrows which he examined on the central Moors, Dimbleby (1962) also carried out soil pollen analysis from buried soils beneath Bronze Age barrows on the Tabular Hills. This work has provided the earliest direct pollen evidence of vegetation conditions

on the Tabular Hills. The barrows are also the oldest structures to have survived on the Tabular Hills. From his buried soil pollen analyses, Dimbleby (1962) concluded that similarly to the central Moors, clearances also occurred on the Tabular Hills. However his identification of pollen of Cerealia, and several arable weed species indicated a marked difference in landuse on the Tabular Hills to the pastoralism which was practised on the central Moors. Evans (1975) also reports finds of saddle querns from the Tabular Hills, which are used for grinding grain.

The Fen Bogs pollen record shows that towards the end of the Bronze Age there was a short period of woodland regeneration, although Atherden (1976) suggests that this process mainly occurred on the more calcareous outcrops in the Tabular Hills. Dimbleby (1962) considered that during the Bronze Age, deterioration of soil conditions particularly on the wetter and more exposed central Moors, had resulted from the woodland clearances and burning. Dimbleby (1962) identified podzolized soils overlying the Bronze Age barrows both on the central Moors and on the Tabular Hills, whereas the soils beneath the barrows had not undergone podzolisation. Soil deterioration resulting in the formation of well-developed podzols on the Tabular Hills by the end of the Bronze Age must have occurred, however, selectively on the less calcareous outcrops of Lower Calcareous Grit, as there is archaeological (Hayes 1983) and pollen evidence (Atherden 1976) that strongly infers Iron Age cereal cultivation occurred on the Tabular Hills, most probably on the more fertile rocks of the Lower Limestone.

In the Fen Bogs pollen record the last episode of Bronze Age woodland regeneration is followed by a period of massive woodland clearance. This is the most marked period of woodland clearance in the Holocene vegetation record for the North York Moors region, and Atherden (1976) uses it to define the start of LPAZ "C". The opening of this zone provided a radiocarbon date of 2280 +/- 120 bp. Arboreal pollen drop to a minimum of only 5% TP, while records for Gramineae dominate the non-arboreal pollen sum, and a wide variety of ruderal species are also present. Plantago sp., a classical indicator species of cleared and rough ground reaches 5% TP, while Cerealia are also recorded with a definite peak in the middle of the period. LPAZ "C" was a period therefore of massive clearance of trees, leaving areas of clear-felled ground which grasses

rapidly colonised. This clearance is also associated strongly with arable cultivation, with arable weed species being well represented. LPAZ "C" ends with a period of woodland regeneration, and a radiocarbon date of 1530 +/- 130 bp marks the end of the zone. The zone therefore spans the Iron Age and the period of Roman occupation of Britain.

Atherden (1976) presents interesting evidence from other sites on the central Moors concerning the most likely location of the arable farming activity during the Iron Age period. This evidence comes from two sites to the north of Fen Bogs, Gale Field and Moss Slack Goathland, and two sites, Simon Howe Moss and May Moss, much nearer to Fen Bogs (see Figure 6.1). Pollen evidence from the two more northerly sites showed that the woodland clearance was less severe there, and the incidence of arable weed pollen is considerably less than that from Fen Bogs. This led Atherden (1976) to suggest that the arable weed pollen was derived from some distance to the south, and most probably came from arable cultivation on the more calcareous parts of the Tabular Hills. Such an interpretation supports the contention expressed above that the central Moors had suffered much more severe soil degeneration as a result of Bronze Age disturbance than that experienced on parts of the Tabular Hills. The deteriorated soil conditions on the central Moors therefore prohibited arable cultivation on the central Moors during the Iron Age period. Arable cultivation on the higher central Moors was also made less likely by a possible deterioration in climate at this time. Atherden (1976) considers this a possibility, based on evidence from the Fen Bogs pollen record in which there is a marked increase in the number and abundance of aquatic species, suggesting increased wetness at the site. There is also evidence from the Somerset Levels (Godwin 1960) of Bronze Age wooden trackways having been submerged by flood-silts upon which Spagnum peat growth formed new raised bogs. Godwin (1960) reported such a stratigraphy from several localities on the Levels and radiocarbon dates from the peat above the trackways gave average dates ranging between 3280 - 2247 bp. The range of these dates suggests that the climatic deterioration was ongoing during the late Bronze Age and early Iron Age. A phase of peat regrowth at the Sub-Boreal / Sub-Atlantic transition has also been reported from the Pennines by Tallis and McGuire (1972). Such an increase in precipitation would have most likely exacerbated the process of soil deterioration throughout the

North York Moors, but the effects would have been most severe on the more exposed and wetter ground of the central Moors.

There is considerable archaeological evidence of man's activities during this clearance period which is of Iron Age / Romano-British Age. Much of the evidence of farming activities and habitation comes from the Tabular Hills. Probably the earliest evidence of Iron Age settlement, and the most widespread Iron Age archaeological features, are the large linear earthworks. These are thought to represent, in some cases, estate boundaries, possibly of Iron Age clans (Hayes 1983). Levisham Moor, 5.6km southwest of Fen Bogs, contains the most extensive area of Iron Age remains. It includes several small dykes which are thought to have been used for stock control purposes, and various huts and shelters. These latter features are thought to be later in date than the dykes, probably dating from 2100 - 2000bp, which was the start of the Romano-British period. The huts and shelters are thought to indicate greatly increased activity on the Moor, with permanent habitations being established. In terms of impact on vegetation, the most significant find was the iron smelting furnace. Atherden (1976) notes that the widespread woodland clearance of this period was probably a direct result of the greatly increased demand for charcoal that was essential for the new technology of smelting iron ores. The pollen evidence from across the North York Moors of widespread woodland destruction (Jones 1979) suggests that smelting may have occurred in many locations close to sources of iron ore. The advent of iron tools at this time also meant that trees could have been cleared more rapidly. Iron Age agriculture has also left an archaeological legacy of field systems, in which individual plots were marked by lynchets, or linear mounds. Excellent examples of these are found at Cold Cam, 4km southeast of Lake Gormire on the Hambleton Hills and also on Levisham Moor (Hayes 1983).

The Iron Age woodland clearance recorded in LPAZ "C" at Fen Bogs is succeeded by a phase dominated by the rise of Calluna. The opening of LPAZ "D" has been radiocarbon dated to 1530 +/- 130 bp, and it marks the start of the Dark Ages. The zone is characterised by the Calluna rise and a general regeneration of particular woodland taxa. This regeneration favoured the heliophytic species such as Betula, Fraxinus and Salix, and the shrubby species, especially

Corylus/Myrica, are also seen to flourish at this time. This pattern of vegetation recovery suggests that the woodland was not as dense as existed in LPAZ "B" (Bronze Age). Atherden (1976) considers that the higher land of the central and northern Moors did not experience woodland recovery in LPAZ "D", and that the expansion of Calluna at the start of the period marked the actual origin of the Callunetum which still exists today over large tracts of the North York Moors.

The limited woodland regeneration during the Dark Ages is truncated at a horizon dated to 1060 +/- 160 bp in the Fen Bogs pollen record. This clearance period, LPAZ "E" is not as severe as that experienced during LPAZ "C", but does include ruderal taxa associated with both pastoral and arable agriculture, and Cerelia pollen is also present. The upper boundary of this is dated to 390 +/- 100 bp, and is marked by a regeneration of heliophytic trees and shrubs. This LPAZ spans the Viking and Medieval periods. The Viking invasions along the east coast of England started in the mid-8th Century AD, and by 886 AD the Danelaw was established in northern and eastern England, which demarcated the region under Viking control. By 900 AD (c. 1050 BP) therefore, relatively peaceful colonisation of the North York Moors was probably occurring. Thurlow (1979) has indicated the wide range of place-name evidence of Viking settlement in the North York Moors. The most common habitative element is the suffix "-by", which means village. Danby, for example, in the Esk valley simply means "the village of the Danes" (the most numerous Viking settlers). Other habitative elements are "thorpe" meaning a secondary settlement or outlying farm, and "toft" which refers to an isolated dwelling house. Viking words for topographical and other natural features include "carr", meaning an area of marshy ground, "howe", a tumulus or mound, "rigg", a linear hill or ridge, "dale", a valley and "beck", a stream. Viking names are also found for areas of cleared woodland, "thwaite", while "sleight" refers to an area of level pasture land, and the term "holme", "holm" or "hulme" is used for water-meadow.

These etymological elements can be found in various combinations across the North York Moors. Common combinations are "by" and "dale" with a prefixes which have been derived from Viking personal names. Thus the town and village names of Whitby, Cold Kirby and Aislaby are derived from the Viking personal names "Hviti", "Kaerir" and "Aslakr" respectively (Thurlow 1979). Several

of the large valleys which penetrate the central Moors have the same derivation, such as Bilsdale ("Bildr"), Bransdale ("Brandr") and Rosedale ("Russi") (Thurlow 1979). Most medium size streams in the North York Moors are described by the word "beck", such as Jugger Howe Beck, and Staindale Beck, into which Dovedale Griff flows. At its confluence with the small tributary Rustifhead Slack, Staindale Beck becomes Dalby Beck. The name "Dalby" can be broken down into the components "dal" (from "dale") and "by". This name thus refers to "the settlement in the valley" (Thurlow 1979). Other Viking names found in Staindale are "Thwaite Head", located on the spur above the Staindale Beck - Rustifhead Slack confluence 2.5km southwest of Dovedale, suggesting an area cleared of woodland, and on the valley floor immediately upstream of this confluence is "Holm Woods", which possibly refers to Viking use of the land for water-meadow. The Vikings also used the Old Norse term "steinn" for stone (Thurlow 1979), and this has evolved place names with the prefix "Stain". It is possible that Staindale gained its name therefore from the nearby situation of the rocky outcrops of the Bridestones, only 400 metres distant in Dovedale, and similar but smaller scale tor like features on Adderstone Rigg, on the south side of Staindale.

Beginning in the early 12th Century (c. 700 BP), there is a well-documented period of significant agricultural activity in the North York Moors associated with the establishment of extensive monastic settlements. In the vicinity of the Fen Bogs site is the Goathland hermitage (NZ 838008), a priory at Grosmont (NZ 829052), and the well preserved Benedictine Abbey at Whitby whose lands extended to within 2km of the Fen Bogs site. A major component of the monastic economy was rearing of sheep, for which the upland areas of the Moors were used extensively as sheepwalks. Some woodland clearance of the vales which penetrate the central Moors also occurred for provision of lowland pasture and some arable agriculture. Later, in the 13th and 14th. Centuries, there are many references to both legitimate and illegal felling of oaks in the Royal Forest of Pickering, in the northern part of which Fen Bogs was located. Medieval charters dating mainly from the 13th Century relating to the parish of Levisham, 5km southwest of Fen Bogs, indicate that there were many grants made of wood for building as well as for fuel (Hayes 1983). There is also documentary evidence that iron smelting was an important component of Levisham's local economy during Medieval times (Hayes 1983). The demand for charcoal,

necessary for the smelting process, would have provided continued incentive for intensive woodland clearance throughout Medieval times. Whereas today much of Levisham Moor, to the north of Levisham village is covered with heather moorland and highly podzolised soils, Medieval charters make regular reference to areas of the present heather moorland being given over to arable agriculture. The effects of agriculture and woodland clearance combined to result in the Royal Forest of Pickering having been virtually denuded of woodland by the end of the Medieval period (Atherden 1976). Forming part of the eastern boundary of the Dovedale catchment is a linear ditch, considered by the Yorkshire Archaeological Society (Spratt pers. comm.) to have been constructed sometime in the late Saxon - early Medieval period. It is thought to have been used for stock control, or possibly as an aid in land ownership demarcation. It indicates that the Dovedale catchment experienced considerable anthopogenic activity in this period.

LPAZ "E" of the Viking-Medieval period is succeeded in the Fen Bogs at 390 +/- 100 bp by LPAZ "F". This was a zone of woodland regeneration limited to Betula and Corylus/Myrica. Records for Cerealia, arable weeds and disturbance indicators such as Plantago sp. increase however, indicating man's continued use of land for arable farming, which was most probably taking place in the valleys and on the better soils of the Tabular Hills. The limited woodland regeneration was thus considered by Atherden (1976) to have been only a relatively local phenomenon. There is also a consistent rise in the Calluna record, indicating the progressive expansion of the heather moorland on the higher ground surrounding the Fen Bogs site. Atherden (1976) associates this pattern of vegetation change with the Dissolution of the monasteries in the early 16th Century, when the large monastic estates were broken up and divided between farmers who undertook much reduced farming activities on the higher land of the central Moors. Farming during Tudor and Stewart times thus took place primarily in the valleys of the North York Moors with a tendency towards more intense arable cultivation. This supports Atherden's (1976) findings of increased weed indicators of arable agriculture. The spread of Calluna probably took place on the abandoned monastic sheepwalks on the central Moors, the northern Moors and the poorer soils of the Tabular Hills.

The last episode in the Fen Bogs pollen record is LPAZ "G", which Atherden (1976) identifies by the massive expansion of Calluna to values approaching 90% TP. The opening of this zone is assumed to date from c. 150 BP, by which time the heather moorland management for grouse shooting had begun. At the top of the pollen record Pinus increases, a result of the development of the coniferous plantations by the Forestry Commission in the first quarter of the 20th Century.

The evidence from the Fen Bogs pollen record and from other sites referenced above shows that man has had a varying impact on the vegetation history of the North York Moors throughout the Holocene. During the Boreal and Atlantic periods, man probably enlarged existing small clearings by burning as well as probably creating new clearings on the central Moors to aid in his hunting for game. After the Ulmus Decline at c.5000 bp, Neolithic barrows on the Tabular Hills provide the earliest evidence of scattered permanent settlements on the Moors. Neolithic farming resulted in temporary clearances being created, while flint arrowheads found on the central Moors suggest that those areas were hunting grounds. A much more extensive distribution of Bronze Age barrows on both the central and northern Moors, and the Tabular Hills, suggests that after c. 3800 bp, settlements were located over much of the North York Moors. Buried soil pollen evidence from beneath the barrows indicates that the Bronze Age woodland clearances on the central Moors were used for pastoral agriculture, whereas the clearances on the Tabular Hills were used for cereal cultivation. Calluna started to colonise small areas of the North York Moors which had been abandoned due to deterioration of the soil.

The Iron Age and Roman-British period at c.2000 bp was the period of most severe woodland removal from across the North York Moors. There was a heavy demand for charcoal from the new technology of iron smelting, and arable cultivation was also carried out on the Tabular Hills. Archaeological evidence suggests that the main centres of settlement were on the Tabular Hills. During the following period of woodland regeneration which began at c. 1500 bp Calluna underwent a further expansion on the poorer soils, while the woodland probably only re-colonised the Tabular Hills. The Viking and Medieval woodland clearances that started at c. 900 - 1000 bp affected not only the Tabular Hills and those areas of the central and northern Moors

where trees had survived, but also many valleys which penetrate the North York Moors. The uplands were used for sheep rearing by both the Vikings and more extensively by the various monastic orders which established priories and abbeys in the North York Moors in the 12th Century. Both the Vikings and monasteries were responsible for woodland clearances. The valleys were used for both winter pasture and arable agriculture by the monastic orders.

This extensive use of the uplands for sheepwalks ended with the Dissolution of the monasteries in the early 16th Century, and subsequent farming activities were mainly arable and concentrated in the valleys. Calluna expanded onto the disused sheepwalks, while limited and localised scrubby woodland recolonised steeper hillsides from where it was difficult to clear and the land was of little agricultural use because of slope and soil limitations. The last stage in the development of the contemporary vegetation of the North York Moors was the expansion of Calluna heather moorland at about 150 bp onto both the poorer areas of the Tabular Hills and much of the central Moor as a result of man's intervention for moorland management for grouse rearing. This was followed in the early 20th Century by the extensive programme of coniferous planting by the Forestry Commission in both areas on the central Moors and the Tabular Hills.

6.4 The Bridestones Griff Slack Site

6.4.1 Site Description

The site in the Dovedale catchment for which pollen analysis was carried out is situated at the head of Bridestones Griff, a small deeply incised valley on the east side of Dovedale Griff (see Figure 2.3). The site, named Bridestones Griff slack for the purpose of this study, is a flat rectangular area measuring approximately 75 metres west-east and 25 metres north-south. It is vegetated by grasses (Agrostis sp. - Festuca sp.) and sedge (Carex sp.), and isolated patches of Calluna. Several narrow, seasonally active channels traverse the surface of the slack. These terminate in a bluff at the western edge of the slack, a point which also marks the headwater of the Bridestones Griff stream. The northern and southern margins of the slack are marked by a marked break of slope and a rapid transition to the surrounding heather moorland. The break of slope is very gradual at the eastern end, but gradually increases towards the west where it comprises a 30° slope rising above the bluff.

Initial attempts were made with a Hiller corer to core through the surface of the slack. These attempts were unsuccessful due to the large quantities of sand subsequently found beneath the slack surface. Screw augering was attempted in order to establish the sub-surface boundary between the slack infill and the underlying solid geology. The sandy infill also made these attempts unsuccessful. Subsequent investigations into the material infilling the slack were therefore limited to the sediments exposed in the bluff at the western edge of the slack. The scarp face is comprised of a complex sequence of interstratified organic layers and inwash sand of variable thicknesses and composition. At the base of the profile is a buried soil A horizon which lies directly on the Lower Calcareous Grits. The other organic layers vary between apparently inwashed soil organic A- horizons, and in situ peat, in varying stages of humification, and comprised of both ericaceous and monocotolydenous vegetation. Both the sandy inwash and the organic layers vary in thickness from only 1 - 2 cm. to several tens of centimetres.

Radiocarbon Dating of the Site

Two radiocarbon dates were obtained from the base of the profile, and these are presented below in Table 6.1.

Table 6.1 **Bridestones Griff Bog Radiocarbon Dates**

Ref.	Material & Depth (m)	Age	Calibrated Age*	Approximated To:
Q-2471	Ao soil horizon (2.50 - 2.55)	1135+/-40 bp	970 - 1180 BP	1075 BP
Q-2472	Peat (2.18 - 2.20)	1320+/-40 bp	1180 - 1310 BP	1245 BP

* Calibration by dendrochronology using curves of Stuiver (1982); the range includes +/- 2 standard errors.

Sample Q-2471 taken from the buried soil organic horizon provides a date of c. 1075 BP. This suggests that infill of the slack began at approximately that time. The upper date, Q-2472, is older than the lower probably as a result of derived older carbon in the upper sample. The upper sample was taken from the top organic band in a composite organic-sandy unit. Subsequent examination of the stratigraphy of the unit showed the sampled organic material to be a peaty inwashed Ao soil horizon. The process of slack infilling would have involved the erosion and transport of catchment organic A horizons into the slack, and the effect of residence time of the soil carbon has resulted in an older date being derived from the inwashed soil organic material than from the in situ soil organic horizon in the base of the slack.

6.5 Selection of Sampling Profiles

It was necessary to have two sampling profiles, one for the radiocarbon sampling and one for the pollen analysis. The profile with the best exposure of organic material at its base was selected for sampling for C^{14} assay. The top of this profile was however degraded back from the vertical by almost 1 metre. This lack of verticality would have required large volumes of material to be cleared back to enable undisturbed sampling for the pollen analysis. This was considered

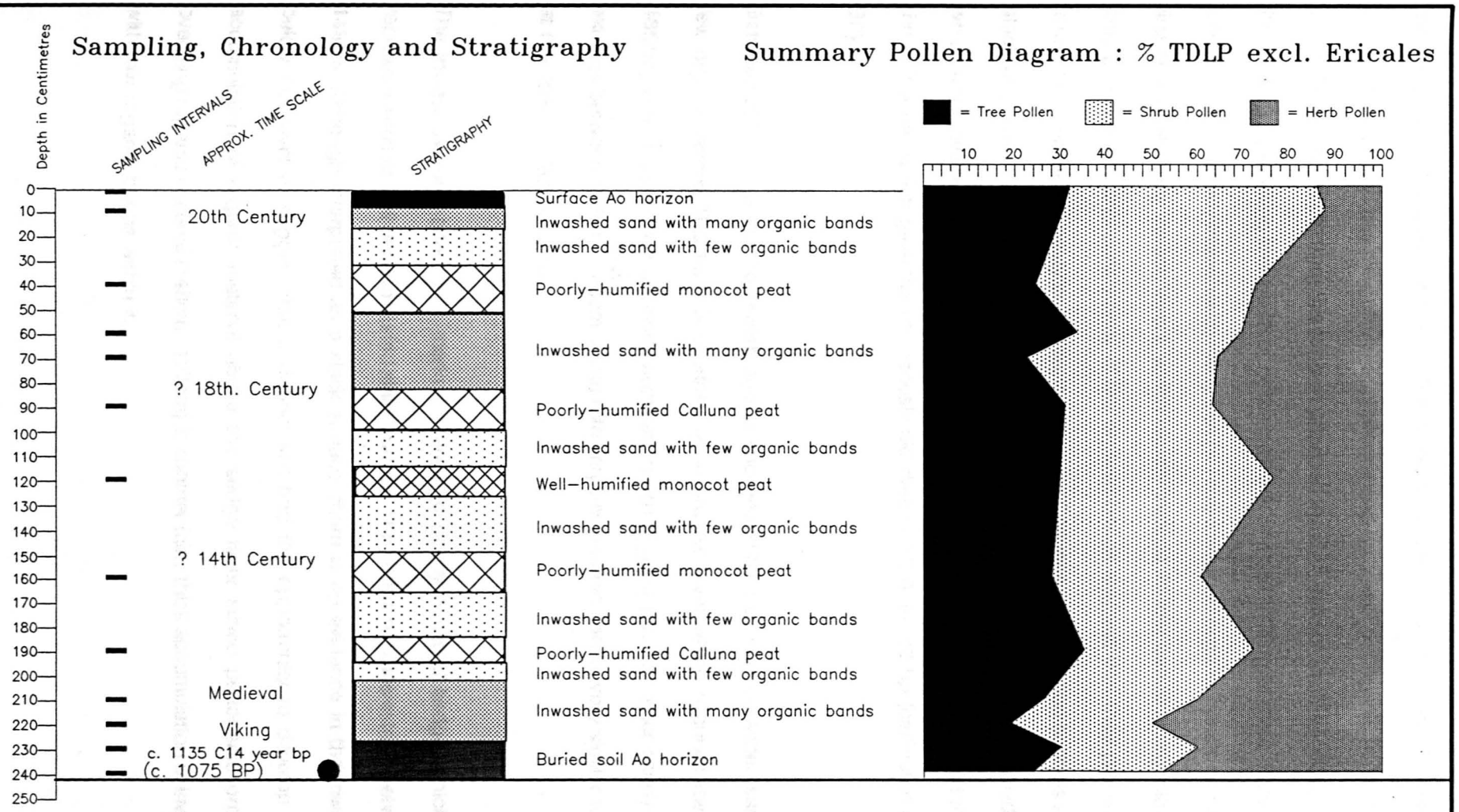
unacceptable, primarily as a consideration to the SSSI, Local Nature Reserve and National Trust status of the site, but also due to the practical problem of disposing of such a large amount of sandy peat. An alternative sampling profile 15cm to the left of the C^{14} profile was therefore selected which did not require such a large scale clearance of surface material.

Samples for pollen analysis were taken primarily from the more organic levels, within which the pollen was likely to be in the best state of preservation. It was considered that close sampling of the sandy inwash levels would produce samples in which there would be much lower pollen concentrations than in the organic material, and that the pollen in the inwash would have suffered damage during transport to the slack surface, thereby rendering them unidentifiable. Damaged pollen grains and low pollen concentrations were subsequently found in the samples that were taken from the inwash levels. The slack was sampled at 240cm, 230cm, 220cm, 210cm, 190cm, 160cm, 120cm, 90cm, 70cm, 60cm, 40cm, 10cm and surface Ao horizon. The sampled levels are shown in Figure 6.2.

The depth of the slack infill at the profile selected for sampling for pollen analysis is 240cm, but the uneven bedrock base of the slack results in the infill depth varying across the face of the slack exposure. The C^{14} profile consequently had a depth some 15 cms greater than the profile sampled for pollen analysis. This has resulted in the C^{14} levels being 15cm deeper than the same stratigraphic level in the pollen profile. For clarity therefore the levels from which the C^{14} dates were obtained are shown in Figure 6.2 alongside the stratigraphic units in the profile which were sampled for pollen analysis. This allows direct relation of the C^{14} dates to the pollen diagram.

6.6 Bridestones Slack Stratigraphy

Figure 6.2 shows the stratigraphy of the Bridestones Slack infill. The bedrock underlying the infill is comprised of large broken blocks of the Lower Calcareous Grit sandstone.



BRIDESTONES GRIFF SLACK POLLEN SITE

Figure 6.2

The basal horizon extends from 240cm - 225cm. The material is considered to be the buried mineral-organic A-horizon of a soil. The material is unlike subsequently deposited peat and inwashed sand, and has the general appearance and texture of a pedogenic horizon with a colour of 7.5 YR 2/0. A sample from this horizon provided the C^{14} date of 1135 +/- 40 bp (calibrated to 970-1180 BP), marking the initiation of the process of slack infilling at circa 1075 BP. Between 225cm - 203cm sandy inwash with many thin (<1cm) inwashed organic bands occurs. This is the first of several sandy inwash layers, which usually include thinner bands of organic material. The colour (10YR 2/1) and consistency of the organic bands suggest that they probably represent eroded Ao horizons of peaty soils developed under Callunetum vegetation such as surrounds the slack at present. The inwashed sand most likely originates in the deep bleached Ea horizons which also develop under these types of soils. The top 2cm of this layer provided the sample for the C^{14} assay which gave the erroneously old date of 1320 +/- 40 bp (calibrated to 1180-1310 BP).

Between 203cm - 194cm the inwash layer is succeeded by a band of inwashed sand which has few organic layers. This layer is overlain by an organic layer which occurs between 194cm - 185cm, and is comprised of poorly humified in situ Calluna peat. Another sandy inwash layer extends between 185cm and 165cm, again with very few organic bands, very similar to the material at the 225cm - 203cm level.

The inwash is succeeded by a marked change to poorly humified sedge, which appears to represent another well defined buried slack surface. The sedge remains extend between 165cm and 148cm. Although interpreted as a slack surface, there is no evidence in the inwashed sands below this level to suggest that a distinct soil had the opportunity to develop before rapid accumulation of organic material above the sedge layer stifled pedogenic processes. The overlying organic material (148cm - 127cm) is another fairly thick accumulation of inwashed sand, with few organic bands within it.

Between 127cm and 115cm is the thickest layer of well humified sedge peat in the profile. The layer probably represents a fairly long period of organic matter accumulation. It is homogeneous, with no sandy or organic inwash within it. This sedge peat is succeeded by a 16cm thick layer of inwashed sand with few organic bands. This extends from 115cm - 99cm. This is suceeded by 17cm of poorly humified Calluna peat, which is itself succeeded at the 82cm level by a 31cm thick band of inwashed sand with numerous organic bands of varying thicknesses. This is the thickest unit of inwashed material in the profile. It is succeeded by 20cm of poorly humified Calluna peat. The material is poorly humified, with many stems and roots remaining intact. No inwash material is visible in this peat layer. The Calluna layer extends between 51cm and 31cm. The Calluna layer is overlain by 14cm of sandy inwash. At the 17cm level, more organic bands are present in the sandy inwash. This more mixed sandy organic inwash layer extends up to 8cm where the base of the present day soil Ao horizon is reached.

6.7 Sample Preparation and Counting Methedology

Preparation of the pollen samples followed the standard methods of Faegri & Iversen (1964). This involved 10% KOH treatment, acetolysis dehydration with tertiary butyl alcohol followed by filtration through a 10 micron sieve in an ultrasonic bath. The acetolysis technique is detailed in Appendix 3. Samples were mounted in silicon oil and counting was carried out with a Nikon microscope at magnifications up to 300x.

A preliminary analysis had revealed that at several levels in the slack pollen record, Ericales counts overwhelmed all other taxa. This was probably associated with Ericales common occurrence both on the slack surface and on the slopes surrouinding the slack at various stages in the history of the slack infilling. The problem of local taxa over-representation has also been identified by Simmons and Cundill (1974a, 1974b) when examining blanket bogs and landslip bogs on the central Moors. They based their analysis on counting a minimum number of arboreal pollen grains, but excluded Alnus from the Total Tree Pollen sum due to its predominance in the vicinity of their sites. In the full analysis of the Bridestones Bog slack pollen record, the counts for

taxa are expressed relative to the Total Tree Pollen sum (TTP), and the effect of the Ericales overrepresentation is therefore removed. Counting continued until 100 arboreal pollen were recorded. This type of counting method, using the Total Tree Pollen sum is also considered to provide a better indication of regional changes in amount and type of woodland beyond the immediate vicinity of the pollen site under investigation (Godwin 1975).

6.8 The Pollen Diagrams

Figure 6.2 presents the different pollen types, (Tree Pollen, Shrub Pollen, and Herb Pollen) expressed as percentages of the Total Dry Land Pollen Sum (TDLP). The Total Dry Land Pollen Sum is obtained from the summation of all the dry land pollen taxa recorded from the site. The TDLP Sum excludes those taxa which are characteristically associated with wet habitats and therefore over-represented in mire and slack situations, and also lower plant taxa such as brackens (Pteridium sp.) and ferns (Filicales) which release spores rather than pollen. In this study, Ericales has also been excluded from the TDLP Sum because of its massive over-representation at the site and the consequent distortions that it would therefore give to the TDLP Sum. Figure 6.3 presents the full pollen diagram, with the taxa presented as percentages of the Total Tree Pollen sum; the Local Pollen Assemblage Zones derived from the diagram are discussed below.

6.9 Bridestones Griff slack Local Pollen Assemblage Zones

BG1 Alnus - Gramineae - Plantago zone

Depth: 240cm - 230cm

Description:

Tree pollen varies between 24% and 30% TDLP,

Shrub pollen varies between 24% and 30% TDLP

Herb pollen varies between 52% and 40% TDLP

Alnus is the dominant tree species accounting for a maximum of <55% of total tree pollen (TTP). There are lesser amounts of Betula (<30% TTP) and Quercus (<25% TTP). Values for Corylus/Myrica pollen only reach 100% - 110% TTP, and Ericales values of 103% TTP at the 240cm level are at their lowest for the whole diagram. Gramineae (150% - 115% TTP) is important in this zone, as is Plantago sp. (6% TTP), which is its greatest value for the whole diagram. There is a record for Cereal pollen at the base of the zone.

BG2 Gramineae - Ruderals zone

Depth: 230cm - 210cm

Description

Tree pollen varies between 30% < 27% TDLP,

Shrub pollen varies between 30% < 33% TDLP

Herb pollen varies between 40% < 50% TDLP

Herb values are at their greatest in this zone and there is a wide range of herb taxa represented, notably Plantago sp., Rumex sp., Urtica sp., Compositae liguliflorae and Compositae tubuliflorae. Gramineae reaches a peak for the whole diagram with a value of 195% TTP. Other taxa which peak in this zone are Cyperaceae and Filicales. Alnus is the most important tree species in the zone (<45% TTP). Corylus/Myrica values show a marked increase from the preceding zone, rising to 160% TTP. Ericales counts are very high, reaching a value of 1056% TTP.

BG3 Betula - Fraxinus - Carpinus - Ruderals zone

Depth: 210cm - 170cm

Description

Tree pollen varies between 27% < 35% TDLP,

Shrub pollen varies between 30% < 37% TDLP

Herb pollen varies between 27% < 39% TDLP

Tree pollen rises to account for 35% TDLP, its maximum representation in the pollen diagram. The rise is mainly due to the expansion of Betula, which reaches 47% TTP. Alnus and Quercus remain relatively suppressed in this zone, but there is a noticeable rise in Fraxinus (6% TTP) and also Carpinus (5% TTP). Corylus/Myrica undergo a reduction, to >105% TTP, as does Ericales, which is markedly reduced to 245% TTP. The herbs show a reduction in the diversity and counts of taxa recorded, with the exception of Rumex sp. which peaks in this zone with a value of 12% TTP. Counts for Gramineae are also reduced, >54% TTP. Cereal pollen is recorded at the base of the zone.

BG4 Alnus - Quercus - Ulmus - Tilia - Corylus/Myrica zone

Depth: 170cm - 90cm

Description

Tree pollen varies between 28% < 31% TDLP,

Shrub pollen varies between 32% < 36% TDLP

Herb pollen varies between 24% < 39% TDLP

Tree pollen shows a gradual increase through the zone, although it does not reach the levels attained in the preceding zone. Alnus (<48% TTP) and Quercus (<23% TTP) are the most important components of the tree pollen in this zone. Ulmus and Tilia show a recovery with values <4% TTP and <5% TTP respectively. All these tree taxa achieve their maximum values in the middle of the zone and all begin to decrease at the top of the zone. Fraxinus is at slightly reduced levels from those in BG3. This is the opposite to the pattern for the Betula record, which drops down to its minimum value of 18% TTP for the whole diagram in the middle of the zone, but shows a marked recovery towards the top of the zone.

The herb pollen fluctuates markedly, with Gramineae initially high (115% TTP) near the base of the zone, falling to 67% in the middle, and then recovering to 100% TTP at the top of the zone. The range of ruderals is limited with Rumex sp. and Plantago sp. consistently the most important

ruderal taxa recorded. The Corylus/Myrica shrub record behaves in an opposite manner to the Gramineae record, reaching a value of 160% TTP in the middle of the zone before undergoing a sharp reduction at the top of the zone. There is a record for Cereal pollen at the base of the zone. Ericales shows a progressive increase throughout the zone, rising from 278% TTP at the base to 418% TTP at the top of the zone.

BG5 Betula - Corylus/Myrica - Gramineae - Ruderals zone

Depth: 90cm - 65cm

Description

Tree pollen varies between 31% < 23% TDLP,

Shrub pollen varies between 32% < 42% TDLP

Herb pollen varies between 33% < 37% TDLP

This zone shows a second phase of tree reduction, with tree values dropping from 31% TDLP down to 23% TDLP. All the main tree taxa show reductions except Betula, which rises to 44% TTP in this zone. Ulmus is reduced to <1% TTP, Tilia to 2% TTP and records for Fraxinus decline to zero at the top of the zone. Alnus and Quercus show greater reductions, down to 34% TTP and 15% TTP respectively. Corylus/Myrica shrub pollen undergoes a steep rise in this zone from only 108% TTP up to 187% TTP. Gramineae also gradually increases through the zone to 108% TTP. The diversity of ruderals is increased in this zone, with Plantago sp. reaching a value of 4% TTP. There is a record of Cereal pollen towards the top of the zone. Ericales reaches another peak in this zone with counts up to 535% TTP.

BG6 Alnus - Carpinus - Conifers - Gramineae - Filicales zone

Depth: 65cm - 40cm

Description

Tree pollen varies between 24% < 34% TDLP,

Shrub pollen varies between 34% < 46% TDLP

Herb pollen varies between 27% < 33% TDLP1

Tree pollen recovers in this zone and rises to its second highest value for the diagram at 34% TDLP. Values decrease however towards the top of the zone. Pollen of coniferous trees becomes significant, and others such as Carpinus, Tilia and Ulmus show rises. The zone is marked by Corylus/Myrica shrub values showing a considerable increase through the zone from 107% TTP up to 195% TTP, its highest value in the diagram, at the boundary with the next zone, BG7. Gramineae values remain relatively constant through the zone, but there are fewer ruderals recorded than in BG5. Significant values for aquatics and Filicales suggest that the site was a relatively wetter habitat at this time.

BG7 Corylus/Myrica - Alnus - Quercus - Ulmus - Tilia

Depth: 40cm - 10cm

Description

Tree pollen varies between 24% < 31% TDLP

Shrub pollen varies between 33% < 56% TDLP

Herb pollen varies between 13% < 27% TDLP

This zone is characterised by the dominance of the Corylus/Myrica shrub record. Shrub pollen as a whole expands to 56% TDLP at the top of the zone. The Corylus/Myrica record attains a value of 195% TTP, its maximum for the diagram at the base of the zone, and it only drops slightly to 185% TTP at the close of zone. Tree pollen also increases, with the main increases seen in the records

for Alnus (<43% TTP), Ulmus (<6%) and Tilia (<5%). Betula remains at a constant level of 28% TTP, while Quercus has a value of 20% TTP at the base of the zone. There is a large decrease in Gramineae, from 80% TTP at the base of the zone to only 25% TTP at the top of the zone. Ruderals are mainly represented by records for Plantago sp. and Compositae liguliflorae, with Rumex sp. starting to increase towards the top of the zone.

Aquatics decrease down to very low levels again in this zone and Filicales records decline also. The Cyperaceae record also declines throughout the zone. There is no record for Cereal pollen in the zone. Ericales undergoes a large decline falling from 377% TTP to 170% TTP at the close of the zone.

BG8 Corylus/Myrica - Conifers - Alnus - Quercus - Ulmus - Tilia - Ruderals - Pteridium sp. zone

Depth: 10cm - Surface

Description

Tree pollen varies between 31% < 32% TDLP,

Shrub pollen varies between 56% < 54% TDLP

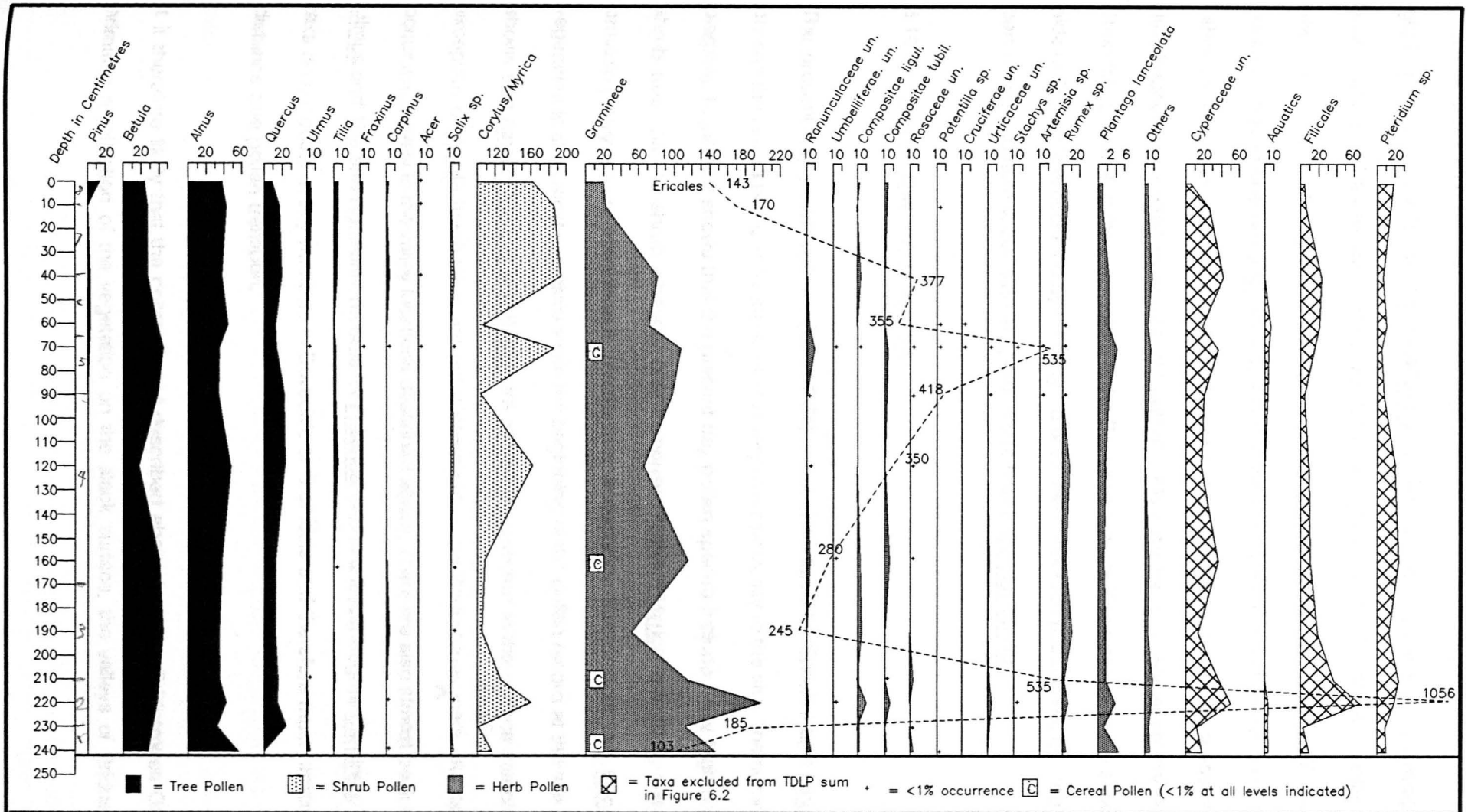
Herb pollen varies between 13% < 14% TDLP

The recovery of the tree pollen continues in this zone with coniferous pollen counts up to 16% TTP. Betula, Alnus and Quercus all show slight drops. Ulmus and Tilia maintain their levels from the preceding zone, while Fraxinus and Carpinus display small increases. The Gramineae record is at its lowest for the diagram, at only 20% TTP, but ruderals show an increase both in diversity and overall counts. Corylus/Myrica shrub type pollen, although still high, undergoes a reduction to 162% TTP. Pteridium sp. continues its rise from the preceding zone BG7, and reaches a value of 20% TTP at the surface sample.

6.10 Bridestones Slack Pollen Record Interpretation

The work of Cundill (1975, 1979) has demonstrated that the location of a site can provide an important control on the nature of the site's pollen record. Examining the contemporary pollen spectra from several sites on the North York Moors, Cundill (1979) has shown that the provenance for the pollen rain at a particular site is considerably influenced by the physiography of the area surrounding the site. Most relevant to this study are his findings for two sites, at North Gill (NZ726007) and Stony Ridge (NZ635025). Both these sites are situated in Calluna moorland at the heads of valleys in the central Moors area. Cundill (1979) reported that the sites provided records for tree pollen which he considers to have been derived from the small areas of woodland in the valleys below the sites. He concludes that a transfer mechanism for the tree pollen exists which involves wind currents being channelled along the valleys, thereby picking up the pollen and transporting it to the valley head sites. His more general finding that tree pollen is not transported over very long distances is qualified by the conclusion that local topographic factors can have major effects so that favourably situated sites can have elevated tree pollen records as a result of such focusing of pollen transport and deposition. Cundill (1975) reached similar conclusions during palynological research at Archer Moss in the Howgill Fells.

An examination of the surface pollen record at Bridestones Griff slack should provide the best indication of the extent to which the local topography influences the pollen deposited at the site. According to Cundill's (1975, 1979) findings, strong local topographic influence should be reflected by a good representation in the Bridestones Griff slack pollen record for pollen derived from the present day vegetation which occurs upwind, in Bridestones Griff, Dovedale Griff and Staindale. The Bridestones Griff slack site is located approximately 200m west (downwind)of a Forestry Commission conifer plantation. The slack surface is vegetated by grasses and sedges with some Calluna, and the slopes surrounding it support primarily Calluna with some bracken (Pteridium sp.). The site is located at the head of the deeply incised Bridestones Griff gully which is itself a tributary of Dovedale Griff. 600m from the mouth of Bridestones Griff, Dovedale Griff joins the much larger valley of Staindale.



% of Tree Pollen Sum excluding Ericales

POLLEN DIAGRAM FROM BRIDESTONES GRIFF SLACK

Figure 6.3

The floor of Bridestones Griff is densely vegetated by birch (Betula pubescens), with alder (Alnus glutinosa), and some hazel (Corylus/Myrica). Dovedale Griff is dominated by grassland on the valley floor with the westerly slope covered by oak (Quercus). On the eastern slope there are a few birch and rowan growing through a thick ground cover of bilberry (Ericales), grass (Gramineae)and bracken (Pteridium sp.) and there is a mixed stand of deciduous tree, firs and other conifers at its southern end. Staindale valley floor is also dominated by grassland, with the field boundaries marked by stands of hawthorn. Alder grows profusely along the banks of the Staindale stream and the lower 200m of the Dovedale stream. The majority of the southern valley side of Staindale is occupied by Forestry Commission coniferous plantations, although the lower part of the southern valley side supports some hazel (Corylus/Myrica).

6.10.1 Present Day Pollen Spectra

The present day pollen spectra (Zone BG8) are not dominated by Ericales and Pinus records, despite these taxa being well represented in very close proximity to the site. The summary pollen diagram, Figure 6.2 shows that the present day pollen spectra include very high counts of shrub taxa. As the shrub category only comprises Corylus/Myrica and Salix, with the latter providing only a very insignificant contribution, it suggests that present day Corylus/Myrica vegetation is at its most extensive since the beginning of the pollen record at the site. Figure 6.3 shows that Alnus, Quercus and Betula are all well represented in the surface sample. With the exception of Betula these trees are not widespread at the Bridestones Griff slack site itself, but do occur extensively in the valley locations described above. There are also almost peak records for Ulmus and Tilia and significant records for Fraxinus, and to a lesser degree Carpinus. These tree taxa do not occur in any numbers in Dovedale or Staindale and therefore must represent longer distance tree pollen transport.

It it therefore likely that the pollen record described above from the Bridestones Griff slack is primarily a reflection of the vegetation on the slack surface, the valleys of Bridestones and

Dovedale Griff and Staindale, and probably also the plateau top of the Tabular Hills to the south and southwest of the site.

6.10.2 Local Pollen Assemblage Zones

The scope of the interpretation of the main pollen diagram in Figure 6.3 is limited partly by the sampling interval, but primarily by the lack of any further C^{14} dated horizons above the base of the slack. The limited resolution obtainable from the pollen record does not allow direct comparison to be made between the Bridestones Griff slack record and the record from Fen Bogs. The interpretation therefore concentrates on identifying patterns of land use since the inititation of infill at c.1075BP, in the Dovedale catchment generally and the slopes surrounding the slack specifically.

The basal zone BG1 extends between 240cm and 230cm. A radiocarbon assay from the base of the zone provides a date of 1135 +/- 40 bp (c. 1075 BP). BG1 has a range of ruderals associated with a mixture of both pastoral and arable cultivation. A large amount of disturbed ground and rough grassland in the vicinity is suggested by the high counts for Plantago sp. Tree counts are not high, but increase towards the top of the zone. Alnus is the most important tree species, although its relative importance declines apparently in favour of Quercus. The main tree species recovering are Betula and Quercus, with smaller increases for Fraxinus.

The basal sample from 240cm shows Alnus to be the dominant tree. Alnus was possibly growing in the surface soil of the slack from which the above radiocarbon date was obtained. The low tree counts and high Gramineae and Plantago sp. counts suggest that woodland clearance immediately prior to the initiating of slack infilling was primarily for pasture and grazing. However there is also more limited evidence for cereal cultivation. The Ericales counts are the lowest for the diagram, and this, together with stratigraphy of the site, indicate that ericaceous taxa were not present on the slack surface, although they probably were growing in some areas of the catchment. The radiocarbon date from BG1 closely coincides with the beginning of a

major woodland clearance phase in the Fen Bogs pollen record. Atherden (1976) presents a radiocarbon date of 1060 +/- 160 bp for the start of that phase of clearance, and attributed it to Viking settlers introducing extensive sheep rearing on the North York Moors. This endorses the pastoral interpretation of the high Gramineae counts in the Bridestones Griff slack pollen record.

BG2 (230cm - 210cm) is marked by peak counts for Ericales. The stratigraphy at this level indicates that the very large count is probably mainly the result of the erosion of Ao horizons of soils supporting an ericaceous vegetation cover (see Figure 6.2). The organic inwash layers are intercalated with much larger volumes of inwash sand from the catchment soils' Ea horizons. The zone marks a change from a period of relatively stable catchment soils to a period marked by episodic inundation of the slack surface by the products of catchment soil erosion. A peak in the Cyperaceae and Filicales may also indicate that increased surface wetness in the catchment accompanied the initiation of soil erosion.

Gramineae reaches its peak counts in BG2, at a time when primary woodland trees such as Quercus, Ulmus and Tilia underwent reductions. The marked increase in the counts for ruderals including peak counts in Compositae undiff. also suggests that there was an abundance of weed habitats; the peak for Urtica sp. could represent the colonisation of nitrogen rich, possibly wet sites. Urtica sp. is often associated with stream banks and ponds where animals are watered, and where manure from the animals raised soil nitrogen levels (Schauer 1980). It is possible therefore that the expansion of grassland may be associated with a period of sheep or cattle rearing. Extensive open grassy areas would also encourage the high counts for Rumex sp. as most varieties of this species flourish where there is little competition from other species for light (Schauer 1980). The rise in Corylus/Myrica may also be indicative of the use of hazel for forage. Such agricultural activities may be related to the existence of a manor in Staindale. Reference to a manor being in the Dalby area is mentioned in the Domesday Book (Waites 1967). The exact location of the manor is not recorded, but the area that is presently referred to as Dalby includes the hilltop and valley side Forestry Commission plantations immediately south of Dovedale, and the valleys of Staindale and Thornton Dale. Place name evidence given above has shown that the

name Dalby suggests that the valley was settled by Viking farmers, and that they carried out woodland clearance and also used water-meadows on the valley floor. There are at least two possible locations for the manor in Thornton Dale: one is the site now occupied by Low Dalby village, 3.8km SSW of Dovedale; the other is the vicinity of High Dalby House, 2.6km SW of Dovedale. The Domesday Book records that the manor had 16 oxgangs of ploughland, which is equivalent to about 480 acres. This amount of land would have required perhaps ten or twenty villeins to work it (D. Sprat, pers. comm.). It is almost certain that a manor of this size also owned large expanses of rough grazing for sheep, which may well have extended into the Dovedale and Bridestones Griff catchment areas. The movement of large flocks of sheep in the vicinity of the Bridestones Griff slack would have led very rapidly to the break-up of the soil surface, exposing the highly erodible sandy Ea horizon, and leading to the initiation of slack infilling.

BG3 (210cm - 170cm) in the Bridestone Griff slack pollen record is marked by maximum tree pollen records, which reach a peak in the middle of the zone of 35% TDLP. The expansion of the trees appears to be at the expense of the herb taxa. The zone marks a period of limited woodland recovery, which may have taken place towards the end of the medieval period. The pollen evidence suggests that the areas of rough grassland were being colonised by Corylus/Myrica. The tree regeneration is marked in the records for Fraxinus and Carpinus, which rise to 6% TTP and 5% TTP respectively. Fraxinus and Carpinus have both been shown to be highly responsive to the clearance of competing trees, such as Quercus, Ulmus and Tilia. Given their close association with neutral and basic soils, and in the case of Carpinus, sheltered situations (Godwin 1975), it seems unlikely that these two species recolonised the exposed plateau tops in the catchment at this time. Their presence in the pollen record is therefore likely to represent relatively far-travelled pollen from the valley floors and the more calcareous soils on the south facing slopes of the Tabular Hills, to the south of the catchment. The increase in counts for Betula is however likely to represent this tree's growth in the immediate area of the Bridestones slack site, where it is found today.

The slack stratigraphy of mainly inwashed sand with an intervening layer of in situ ericaceous remains suggests considerable catchment erosion. This indicates that disturbance of the catchment soils surrounding the slack was continuing, although some tree regrowth was probably occurring at locations some distance upwind from the Dovedale catchment. The reduction in grassland and the general recovery of scrub (Corylus/Myrica) may be attributable to somewhat reduced agricultural activity in the valley floors of Dovedale and Staindale. A cause for such reduced agricultural activity may be the possible abandonment of the Dalby manor due to depopulation as a result of the effects of the Black Death in the 14th Century. High mortality during the bubonic plague reduced the intensity of landuse pressure throughout Europe and as a result many marginal areas were abandoned (Utterstrom 1955).

BG4 (170cm - 90cm) is distinguished from the underlying BG3 on the basis of a change of the relative importance of tree type in the pollen record. The most notable change is the reduction of Betula and the increase in Alnus and Quercus counts. The lower half of the zone's stratigraphy (170 - 125cm) includes poorly humified in situ ericaceous remains. This suggests that for a period heather growth on the slack occurred, at a time when there was little soil erosion from the slopes surrounding the slack. This may reflect the continued effect of the bubonic plague, with reduced agricultural activity c[au]sing the abandonment of the Dovedale catchment for agriculture. This suggests a tentative date in the late 14th Century for the BG3 - BG4 boundary.

Later, in the central part of BG4, renewed soil erosion buried this in situ ericaceous material. This disturbance may indicate another period of sheep rearing in the catchment, but the pollen evidence of increasing woodland cover outwith the catchment indicates that this period of catchment disturbance was not a result of renewed clearance for agricultural purposes in the valleys of Dovedale and Staindale.

The upper half of the stratigraphy of zone BG4 displays by contrast a band of well humified monocot peat. This suggests that it accumulated over a lengthy period, during which time there was minimal disturbance of the slopes in the slack catchment. This period of quiescence is

followed by another influx of sandy material, which is in turn overlain by a layer of very poorly humified Calluna plant remains. Humification is so little advanced that there are still leaves visible. Ballantyne and Brazier (1989) report similarly well-preserved plant remains from an organic horizon in a debris flow in Glen Feshie in the Cairngorm Mountains. The plant remains provided radiocarbon dates that ranged between 180 +/- 50 bp and 350 +/- 50 bp. It is possible therefore that the inwashed ericaceous material in Bridestones Griff slack has a similar age of perhaps 200 - 300 bp. A date of c.250 bp for this material in BG5 implies that the underlying zone BG4 represents deposition in the slack from c. 450 bp to 250 bp, a period of 200 years spanning the 16th and 17th Centuries.

BG5 (90cm - 65cm) is therefore tentatively interpreted as starting at approximately 250 bp. The rise of coniferous tree pollen in this zone is of some value for evaluating this possible date, as there was a period of ornamental tree planting which began in the latter half of the 18th Century throughout much of Yorkshire (Tuke 1800) and species of firs were amongst those planted. At the confluence of Dovedale and Staindale there is a considerable number of very mature ornamental firs on the south-facing valley side.It is possible that these may date from perhaps the early 19th Century. The inwashed sand and ericaceous material in the BG5 stratigraphy is accompanied by a rise in pollen of indicators of disturbance, such as the substantial rise in Plantago sp.

More intense disturbance of the catchment soils is suggested by the 30cm thick sandy inwash band that characterises much of the overlying zone, BG6. The very high counts for Ericales pollen at this level suggest that ericaceous (Calluna) heather moorland vegetation existed over much of the slack surface and on much of the slopes surrounding the slack during this period of disturbance. Although Atherden (1979) notes that Calluna heather moorland management for grouse shooting started in the early 19th Century in the North York Moors, the slack pollen record provides evidence that suggests that the encouragement of heather moorland had not resulted in the slopes surrounding the slack site being entirely covered in Calluna heath. This evidence is the presence in the 70cm sample of Stachys sp. and Artemisia sp., which are both

distinctive indicator weeds of arable fields and waste ground previously used for arable cultivation (Schauer 1980) and Cerealia pollen. It may have been that the impact of arable cultivation in the catchment was responsible for the thick inwashed sand layer in the slack stratigraphy. The proposal that arable cultivation was occurring in the catchment surrounding the slack sometime in the 19th Century is lent support by the 1856 edition of local Ordnance Survey maps which identify a limestone kiln and quarry to the east of the High Bridestones (D. Spratt, pers. comm.). The kiln and quarry are situated on a very small outlier of more calcareous rocks which provided the necessary raw materials for the limestone kiln. Lime burning was occurring in the Staindale area by the early 17th Century and by the early 19th Century lime was being used widely for fertiliser, implying that lime burning was by this time a large scale undertaking. Several lime kilns were in operation right up to the end of the 19th Century. There is also a small "lime-rich pasture" around the Bridestones kiln site, complete with field boundary. Arable agriculture may well have been possible in the catchment with large and regular additions of lime to acidic soils. The 1856 O.S. maps also identify at the confluence of Bridestones Griff with Dovedale Griff a small sheep fold. All that remains to the present day of the sheepfold is a heavily overgrown and barely recognisable base of four walls, approximately 2.5 metres square. This cartographic and pollen evidence suggest that there may have been a significant amount of agriculture on the plateau tops around Bridestones Griff slack as well as in the valley of Dovedale.

Rural population pressures in this part of Yorkshire, as is many other parts of England, reached a maximum in the 19th Century. It is possible that this would have provided incentives for previously unattractive land, such as the plateau tops around Bridestones slack, to be pressed into agricultural service where only a highly localised, but convenient, source of lime was present to bring the soil up to a cultivatable standard. The relatively low counts for Pteridium sp. at this time may also reflect such agricultural activities as bracken being cleared to provide better grazing for sheep.

The Bridestones Griff slack pollen record in zones BG6 (65 - 40cm.) and BG7 (40 - 10cm.) suggest a woodland recovery, with increases in the counts for Quercus, Ulmus, and Tilia.

Corylus/Myrica also show a dramatic rise. Within BG7 the stratigraphy changes from a poorly humified monocot remains to another layer of inwash sand with few organic bands. The monocot peat suggests a brief period of quiescence and the reduction in both the Gramineae counts and the record for arable weeds like Artemisia sp. and Stachys sp. suggests that the 19th Century farming activity in the catchment came to an end at this time. The massive rise in Corylus/Myrica may reflect a short lived colonisation of the "lime-rich pasture" referred to above when it fell into dis-use. There is however, no Corylus/Myrica growing on the plateau top around the Bridestones slack at present, possibly because the original artificially higher lime content in the soils has been exhausted.

The inwash sand overlying the monocot remains indicates another period of erosion when the slack surface was inundated with eroded bleached soil horizons. This possibly occured at the end of the 20th Century, and is succeeded by a period when more soil organic material was being washed on to the slack surface. This latter period of soil erosion may be associated with the development of coniferous plantations at the eastern margin of the slack. BG8 is characterised by the rise of the coniferous pollen, which at this level is dominated by Pinus. Forestry Commission planting began in the 1920's in the Dovedale area.

Present day soil erosion in the Bridestones Griff slack catchment appears to be of insufficient intensity to cause burial of the surface of the slack. The slack is at present crossed by channels in the peat which are approximately 60 cm deep near its bluff edge. Although it is evident from the many runnels in the track at the head of the slack that soil erosion is occurring at present, the channels must be capable of transporting the eroded material across the slack surface and into the Bridestones stream without channel infilling occurring.

6.11 Conclusion

6.11.1 The North York Moors Region

The documented pollen and archaeological evidence from the North York Moors region indicates that the Holocene has been a period of episodic vegetation change, with man at several phases providing a major determining factor as to the nature and scale of the vegetation change. Man's influence on Holocene vegetation appears to have been highly localised and largely peripheral to the North York Moors during Flandrian stage I (pre-7000 bp). During this period, the secular changes in postglacial climate were probably more important in determining the vegetation changes which occurred at the transitions between Zones IV, V, and VI.

During Flandrian stage II however, man's activities seem to have been much more widespread on the central Moors, and probably resulted in both the maintenance and creation of clearings in the otherwise closed woodland canopy of the postglacial deciduous climax vegetation. At this time, (7,000 - 5,000 bp), both the pollen and archaeological evidence suggest that clearances were temporary and probably formed an integral part of a Late Mesolithic hunter-gatherer type culture.

An important change in man's activities is suggested however at the transition to Flandrian stage III (c.5,000 bp). The pollen evidence for the Ulmus Decline, and the first occurrences of (Neolithic) burial mounds are thought to indicate a move towards more stable population which in addition to hunting on the central Moors, possibly engaged in pastoral farming (Jones 1979). The Ulmus Decline has been thought to be largely attributable to the tree's use at this time for fodder. After c.3,500 bp the advent of the Bronze Age culture was accompanied by a change to mixed agriculture, with cereal cultivation taking place on the Tabular Hills and pastoral farming being conducted on the central and northern Moors. A large number of Bronze Age artifacts and barrows have been found in both areas of the North York Moors. During this period, those areas of the central Moors with the poorest soils were capable of supporting only heathland vegetation. The development of Calluna heathland in the North York Moors began at this time.

The establishment of the Iron Age culture, starting at c. 2500 bp and reflected in the large and extensive linear earthworks on the Tabular Hills was instrumental in causing severe deforestation which as the pollen evidence has shown, occurred throughout the North York Moors region. Woodland clearance accompanied the expansion of both pastoral, and especially on the Tabular Hills, arable agriculture. Probably the major incentive for woodland clearance was the provision of charcoal for iron smelting. Later during this period, Roman occupation and settlement probably provided additional stimulus for both iron production and both arable and pastoral agriculture.

At the end of the Roman period (c. 1500bp) woodland regeneration occurred, probably mainly on the Tabular Hills where the least degraded soils occupied the more calcareous outcrops. Archaeological evidence on the North York Moors from this period, the Dark Ages, is very limited. Pollen evidence indicates that a mixed agricultural economy existed, although the intensity of agricultural land-use was likely to have been reduced relative to that experienced during Roman times.

Another period of woodland clearance marked the invasion and settlment of the North York Moors area by the Danish Vikings, beginning at c. 1060 bp. The Vikings introduced sheep farming to the area, but the mixture of arable and pastoral weeds indicates that they also probably engaged in arable agriculture in less exposed valley locations within the North York Moors. Many place names in such valley situations have Viking origins, and these have provided evidence of Viking settlements and agricultural enterprises in these locations.

The expansion of monastic lands in the 12th. and 13th. Centuries brought much of the North York Moors under monastic control. Sheep farming was an important component of the monastic orders' economies, and much of the poorer land was given over to sheep walks, which consequently covered very large areas of the North York Moors. The partial removal of woodland from the valleys penetrating the central Moors also occurred to provide more land for the growing of crops. After the Dissolution of the Monasteries in the early 16th Century, the large estates were broken up, and many of the large sheep walks were abandoned, and subsequently became

colonised by Calluna heather, which by this time covered much of the central Moors. Further woodland removal proceeded in the valleys as population expanded in the 18th and 19th Centuries, although a degree of ornamental tree planting began in the 18th Century.

The next major change in vegetation was the expansion and management of the Calluna heather moorland for grouse shooting purposes in the early 19th Century. This affected much of the central Moors, but also the poorer soil areas on the Tabular Hills. The most recent vegetation change that the North York Moors have experienced was the establishment by the Forestry Commission of commercial coniferous plantations in the middle of the 20th Century. Coniferous planting has been concentrated in the southeast of the North York Moors on both the Tabular Hills and the central Moors.

6.11.2 Bridestones Griff Slack and the Dovedale Catchment

The pollen and archaeological evidence from the Bridestones Griff slack site and the Dovedale catchment allows a more detailed examination to be made of vegetation change in the catchment and of the role of man in contributing to such changes since the slack started to infill at c. 1075 BP. The timing of the initiation of slack infill, the pollen evidence of tree felling and the place name evidence from close to the site together suggest that the influx of Viking farming practices was possibly responsible for the initiation of slack infilling. The establishment of a manor less than 3km from the Dovedale catchment in the 11th Century probably maintained the agricultural pressure on the catchment, possibly until the time of the Black Death in the 14th Century, when depopulation led to the abandonment of large areas of marginal agricultural land.

A gradual recovery of woodland in the Dovedale and Staindale valleys appears to have taken place during the 16th and 17th centuries. Archaeological evidence from the Dovedale catchment for 19th Century agriculture and evidence from the Bridestones Griff slack pollen record suggest that there was a brief period of both arable and pastoral farming in the catchment. The use of such marginal land for arable agriculture may have been a consequence of high population pressures

in the 19th Century. It is not clear when such landuse ceased in the catchment, but the poor state of preservation of the 19th Century archaeological sites and the complete disappearance from the present day vegetation of plants associated with arable cultivation suggest that the area was abandoned probably by the beginning of the 20th. Century.

After this last period of agriculture had ceased, the Calluna moorland vegetation spread throughout the area surrounding the slack site, and the slack surface itself gained its present cover of grasses and sedges. Finally the pollen record reflects the spread of the 20th. Century coniferous afforestation which has taken place to the south of the slack on the southern side of Staindale and the plateau tops above the valley, and also immediately to the east of the slack itself.

Chapter 7

Holocene Sediments and Palaeomagnetic Stratigraphy from Lake Gormire

7.1 Introduction

There are several significant obstacles to comprehensive reconstruction of alluvial chronologies in gravel valley fills. In such relatively high energy environments there is a general lack of preservation of dateable organic or cultural material. The fundamentally temporary nature of the sediment sinks that river terraces represent provides difficulties for correlating the alluvial record with the continuum of environmental change. Terrace sediments, representing sediment stores formed during periods of alluviation and partially isolated from subsequent stream incision, can undergo erosion by the realignment of meandering channels or the lateral migration of braided channels. Such processes are common in the relatively narrow valley floors of upland catchments, and subsequent periods of intensive channel change can effectively rework the sediments forming the terraces and floodplain (Lewin 1981). Periods of more extreme fluvial geomorphological response can be caused by severe environmental changes within the catchment, as a result of climatic changes, isolated high magnitude meteorological events, tectonic activity or major environmental disturbance by man. The consequence of such periodic reworking of fluvial terrace sediments in this way is that the full record of the history of upland valley alluviation is rarely completely preserved in extant alluvial landforms.

Much more permanent sediment sinks for the products of catchment erosion are those formed by the accumulation of lake sediments (Oldfield, 1977). Lakes which provide the most complete sediment traps are those which have no surface water exit, but which, in temperate climates drain through the underlying strata, or, in hot arid areas, undergo evaporation. In contrast to the processes involved in the formation of fluvial landforms, the process of lake sediment accumulation does not involve significant disturbance of material deposited at an earlier time. In

this way, an intense period of catchment disturbance which results in the transport of large quantities of sediment into the lake will not cause erosion of the underlying sediment (Holmes 1967). Exceptions to such highly conservative lake floor environments occur in steep sided lake basins, typically formed tectonically or directly by the action of glacier ice. In these situations lake sediments can undergo slumping, which can cause hiati in the accumulative lake sediment record. The identification of such discontinuities in the lake sediment record can be achieved by the establishment of an externally calibrated chronology of lake sediment deposition. In this study the palaeomagnetic properties of the Lake Gormire sediments are used to provide such a chronology, and later in this Chapter it will be demonstrated that the analysis of these properties reveals there to be no hiati in the Lake Gormire sediment record.

It has been widely recognised that cores taken through lake sediments can provide information on, and permit some degree of correlation between, palaeoenvironmental conditions and variation in the catchment sediment flux to the lake catchment (Mackereth, 1966; Pennington & Lishman, 1971; Oldfield, 1977). Oldfield (1977) developed the concept of the lake-catchment ecosystem in which lakes are regarded as an integral part of a drainage basin because the amount and nature of the sediments that accumulate in the lake are not only a function of internal lake processes but also of the hydrological, pedological, vegetational and anthropogenic processes that operate in the lake catchment.

This chapter presents the results of physical, chemical and palynological analyses of sediment samples from a core from Lake Gormire on the western margin of the North York Moors (see Figures 2.1 and 2.9). These analyses indicate the nature and degree of environmental change in the lake's catchment during the Holocene. The chronology of environmental change is established by analysis of the palaeomagnetic properties of the Gormire sediments and the development of a magneto-stratigraphy. With a chronology of lake sedimentation thus established, the environmental changes can also be related to the archaeological and historical evidence of man's activities in the vicinity of the catchment, and also to environmental changes across the North York Moors generally which are identified by Atherden (1976) in the

radiocarbon-dated regional pollen record from the Fen Bogs site in the central Moors, 35km ENE from Lake Gormire (see Figure 6.1).

7.1.1 Palaeolimnological Techniques

Two primary lines of research are applied in palaeolimnological studies. The most widely used is that dealing with the remains of micro- and macro-organisms, such as diatoms (Battarbee 1978; Bradbury, 1975; Elner & Happey-Wood 1980; and Evans & Walker 1977), the invertebrate coleoptera and ostracod faunas (Benson & MacDonald 1963; Delorme 1968; Coope 1977; Coope & Brophy, 1972), plant macro-remains (Birks 1973; Watts & Bright, 1968) and pollen (Davis 1969; Godwin 1975; Pennington 1973, 1977). Of these various subjects of study, pollen analysis is probably the most important and extensively used, particularly when catchment processes are of interest. The pollen record preserved in lake sediments can reveal the pattern of ecological change since the formation of the lake, not only within the lake catchment but also, where the physiography of the lake and its hinterland is suitable, throughout the region surrounding the lake. The identification of sub-fossil pollen in lake sediments, and to a lesser extent diatoms, has been a primary contributor to the elucidation of the history of vegetation and environmental change during the postglacial in Britain (Godwin 1975, Pennington 1977, Simmons and Cundill 1974).

The second approach in palaeolimnological studies centres on the physical and chemical characteristics of the lake sediments. This includes particle-size analysis which can reveal variations in sediment transport conditions into the lake (Pennington, 1947; Holmes 1967), and the identification of the magnetic properties of the sediments for the purposes of dating the sedimentary record (Mackereth, 1971; Thompson, 1977) and assessing the spatial variability of catchment sources for material transported into the lake sediments (Oldfield et al. 1978, Thompson et al. 1980, Hirons and Thompson 1986).

Particle size analysis of lake cores is a primary method of characterising the history of sediment accumulation into the lake. The lithostratigraphy of lake sediments provides an initial impression of the geomorphic processes operating in the lake catchment and resulting in the sediment flux to the lake. This linkage between lake catchment processes and lake lithostratigraphy is readily seen in studies wherein Late-Glacial inorganic clays deposited by periglacial processes are succeeded by Holocene organic muds, the result of reduced minerogenic input during periods of vegetated and stable catchment slopes. The Gormire sediments are typical of this, with grey clay being overlain by brown organic muds, the transition between the two litho-stratigraphic units coming at the 10,000 bp Late-Glacial - Holocene boundary (Blackham et al., 1981). Coarsening of sediment flux into lakes has been widely identified (Edwards and Rowntree, 1980; Rapson, 1984) as providing an indication of intense periods of catchment erosion. In this study the primary purpose of carrying out particle-size analysis was therefore to identify any phases of coarsening of the sediment flux into Lake Gormire. These phases of coarser sediment deposition can then be evaluated with respect to periods of catchment vegetation disturbance suggested by the pollen analysis carried out both for this study and by Blackham et al. (1981), and by the chemical stratigraphy presented later in this chapter.

In addition to this allogenic fraction however, the lithostratigraphy of lake sediments is also influenced by the endogenic and autogenic fractions (Jones and Bowser, 1978). The endogenic fraction is derived from those processes that operate within the water column, and primarily involve the assimilation of silica and other nutrients by diatoms and similar organisms. The autogenic fraction consists of the products of processes operating within the lake sediments, such as chemical diffusion, decomposition and mineralization of organic matter and the release of various nutrients and other compounds into the water column. The actual contribution that these latter two fractions make to the ultimate composition of the lake sediment has yet to be fully evaluated, as details of the interactions between and within the chemical cycles of the many elements concerned are themselves poorly understood at present (Petts and Foster, 1985). Consequently, in interpreting the findings of particle size analyses, the great majority of studies

have concentrated on the changing contribution that the allogenic input has had on the lithostratigraphy of lake sediments.

7.1.2 Erosion Indicators

Of particular value to the investigation of linkages between the nature of lake sediments and changing catchment environmental conditions analysis was the pioneer work of Mackereth (1965, 1966) in his studies in the English Lake District. He demonstrated that analysis of the chemistry of lake sediments can reveal linkages between changing rates and patterns of deposition in lakes and episodes of stability and instability in the lake catchment. Mackereth's central thesis was that the total chemistry of a given sample of lake sediment was a function of the ratio of the erosion of unweathered particulate material from lake catchment soils to that which was removed in solution by leaching, or change in the redox potential, within the catchment soils. Lake sediments which were identified as having large quantities of potassium (K), sodium (Na), and magnesium (Mg), termed "erosion indicators" by Mackereth (1966), were considered to represent periods of significant soil erosion in the catchment. These higher values for K, Na and Mg were due to intense soil erosion which removed material from deeper down the lake catchment soil profiles, where the minerogenic material had been subject to less leaching of these cations, and the subsequent deposition of this cation rich material into the lake sediments. During more stable periods, influxes of particulate matter to the the lake sediments would be limited to that derived from the more highly leached surface soil horizons, thereby giving lower concentrations of these cations in the lake sediments during such periods. K, Na and Mg all have a relatively low potential for combining with organic material, (Koljonen and Carlson 1975) and once in a soluble state they are not readily precipitated out by either inorganic or organic processes operating in lake waters or sediments.

During periods of stability, runoff containing dissolved nutrients, primarily calcium (Ca) and phosphorous (P), released by catchment soil-forming processes reaches the lake. This gradually increases its trophic status, often causing increased algal productivity, and the resultant organic

detritus provides the major component of sediment accumulation in the lake during these stable periods (Engstrom and Wright, 1984). Calcium readily combines with organic matter, usually by neutralizing fulvic acids, and precipitating them in the form of a highly polymerized humus material (Koljonen and Carlson 1975). Calcium's affinity for organic material often causes it to be found in greater concentrations in organic rather than minerogenic sediments. Consequently it does not have such a general applicability as K, Mg and Na for indicating periods of lake catchment sub-soil erosion.

7.1.3 Previous Holocene Palaeolimnological Studies

The work of Mackereth (1965, 1966) on linkages between lake sediment chemistry and lake catchment environmental conditions has led to the widespread application of his techniques in a number of palaeolimnological studies. In Britain, Pennington and various co-workers at the Freshwater Biological Association, Windermere, have concentrated on the Holocene sediment chemistry records of lakes in the English Lake District (Pennington & Lishman, 1971; Pennington, 1974; Pennington, 1976; Pennington et al. 1977) and Scotland (Pennington et al. 1972). Similar studies have also been carried out on Scandinavian Holocene lake sediments by Koljonen and Carlson (1975) and Huttunen and Tolonen (1977), and in North America (Liken and Davis 1975; Sasseville and Norton 1975; Burden and Norris, 1985).

In an examination of several high level lochs in Scotland, Pennington (1981) found that Late Glacial interstadial deposits from 13,000 - 11,000 bp showed decreased levels of K and Na which she attributed to the improved climatic conditions at the time permitting the development of substantial vegetation cover over stabilised soils. The glacial readvance of the subsequent Younger Dryas (Loch Lomond) stadial resulted in intense periglacial conditions and solifluction of devegetated soils, which was interpreted from increases in K and Na and a decrease in organic matter content of the core sediments. At the start of the Holocene, K and Na levels underwent a substantial reduction, and remained at low levels until c.5,000 bp when climatic changes and anthropogenic intervention in the landscape are deduced from increased levels of K and Na. The

organic matter content of the cores show a corresponding pattern of high values in the early Holocene followed by significant reduction at c.5,000 bp. Pollen evidence showed that the vegetational history was closely associated with the interpretation of episodic catchment soil erosion which was based on the patterns evident in the record for K and Na.

In England, one of the most heavily researched sites is Blelham Tarn in the English Lake District. The findings of the research on the Tarn provide a good example of how geochemical changes in the lake sediment record can be associated with distinctive lithological and palynological responses to changing catchment environmental conditions through the Holocene (Pennington et al. 1977). In a 6.0m core taken from the Tarn, representing 10,000 years of sediment accumulation, the first indication of increased potassium deposition was identified at the 5,000bp level. However, pollen analysis from the 5,000bp level showed no local vegetation disturbance in the catchment. This led Pennington et al. (1977) to conclude that the increased erosion of K-rich minerals into the Tarn was the result of climatic deterioration, with increased rainfall causing deeper soil erosion, rather than the result of anthropogenic disturbance of catchment vegetation. At an horizon dated to 2200bp, K values are again higher, and at this horizon there is evidence of woodland clearance in the Tarn's catchment. The most severe period of catchment disturbance occurred, however, at c. 900bp. The mean rate of sediment accumulation was doubled at this time, and values for potassium were also much increased. Organic geochemical analysis showed that the organic fractions in sediments of this age were derived from the organic horizons of soils which had developed under deciduous mixed woodland. Pollen evidence showed a steep decline in arboreal pollen and a rise in Gramineae and other herbaceous taxa. These lines of evidence strongly indicated that a phase of woodland clearance occurred at this time, and the consequent disturbance of the catchment soil resulted in extensive soil erosion into the lake. A third horizon, dated to c.400bp, also demonstrated increased potassium levels. This was again associated with an increase in sediment accumulation rates in the lake, and a marked decline in the organic component of the sediment flux. Pollen analysis at this level revealing cereals, flax and hemp indicated the beginning of a phase of local arable farming, and counts of Quercus pollen were as low as are presently found in almost completely deforested parts of the area.

In Northern Ireland Hirons and Thompson (1986) examined lake sediments which had been accumulating since the late glacial in lakes formed within inter-drumlin hollows. Their cores were taken from two such lakes, Killymaddy Lough and Weir's Lough. Pollen analysis from the base of the Killymaddy Lough core revealed an interstadial Juniperus - Empetrum spectra, which has been dated to approximately 12,000 - 12,400bp. Adopting Mackereth's (1966) total elemental digestion method, the sediments from the basal interstadial level of Killymaddy Lough revealed a low K content. The subsequent Nahanagan stadial, which ended at 10,200bp was marked by a ten-fold increase in the K content of the mineral fraction. At the start of the Holocene period the K content is reduced to values similar to the preceding interstadial. This pattern of K values at the Late Glacial - Holocene transition is very similar to the findings of Pennington (1977, 1981) from Scotland and the English Lake District. However, the Killymaddy Lough sediments do not show a further significant increase in K values until 1170 A.D. (Hirons and Thompson, 1986), despite there being pollen evidence for vegetation changes and agriculture in the catchment during Neolithic, Bronze Age and Iron Age times. The pollen evidence of intensive farming at 1170 A.D. which includes cereal cultivation, suggested that it was this anthropogenic activity which caused the erosion of unweathered sub-soil horizons and the transportation of K-rich minerogenic sediments into the Lough at that time.

A study of Holocene lake sediment by Sasseville and Norton (1975) in Maine similarly indicates variability of response to vegetation change and disturbance from one lake catchment to another. Sasseville and Norton (1975) found differences between three lakes that were all located within 100 miles of each other. The advent of European colonisation of Maine is very clearly indicated by the pollen evidence from all three lakes, which supports historical evidence of clearances being made for farming and widespread logging activities. While two of the lakes show major increases in the erosion indicators K, Na and Mg at the level of initial cultural disturbance, the third lake reveals no such change in these elements at the time of these clearances. Such a contrasting response from lakes which had experienced the same type of catchment disturbance suggests that physical characteristics of the lake catchments exert a major control on the

processes of sediment transport into the lakes, and ultimately the nature of the sediment deposited in the lake.

Most workers in North America who have studied Holocene lake sediments have concentrated on the anthropogenic impacts of European colonisation over the last 300 years (Liken and Davis, 1975; Davis, 1976; Brugam, 1978; Burden & Norris, 1985). Engstrom's 1983 study of Lake Hope Simpson and Moraine Lake in Labrador, Canada however also provided evidence of the impacts of climatic change. He found that the first 2,000 years of the Holocene period had maximum levels of K and Mg, derived from inorganic tundra soils. At 7,500bp climatic amelioration permitted the rapid expansion of spruce-fir forests into the lake catchments which stabilised the catchments' soils and increased their organic content, thereby leading to reduced levels of minerogenic sedimentation and lower K and Mg values. These low levels for K and Mg were maintained until 4,000bp when climatic deterioration initiated a change to a more open lichen woodland. This allowed greater soil erosion to occur and K and Mg values to increase in the lake sediments.

These studies show that in the absence of man, climatic change, and its influence on vegetation, can provide a major impact on the nature of lake sediments (Pennington 1977; Engstrom 1983). They also demonstrate that Holocene lake catchment vegetation disturbances sufficient to be reflected in the lake sediment pollen record do not necessarily result in significant erosion of catchment soils. Thus whilst Pennington (1977, 1981) reported geochemical evidence of eroded sub-soils from Neolithic, Bronze Age, and Iron Age levels from some lakes in the Scottish Highland and the English Lake District, Hirons and Thompson (1984), working in Northern Ireland only reported the deposition of deteriorated pollen grains at these cultural levels. The latter workers reported no increase in K, Mg or Na at these levels, which suggested that soil erosion only extended to the superficial disturbance of surface (A) horizons, where deteriorated pollen grains would be concentrated. It is likely that regional variations in climate, topography, soils and intensity of land use, as variations in the sediment delivery ratios of streams feeding the lakes have been responsible for these differences in lake sediment histories. As Lake Gormire does not

have a stream inflow, it is isolated from the effects of the variable efficiency with which fluvial systems can transport sediment. The Gormire sediments are therefore not susceptible to fluvial responses to extreme meteorological events which can result in the transport of stored sediments from the channel bed and banks into a lake basin. The sediment record in small lakes with a number of feeder streams may be more a function of variations in the fluvial system than a function of catchment wide changes in boundary conditions. Thus given the absence of a stream inflow, the Lake Gormire sediments should reflect more directly variation in slope hydrological processes, which are in turn more closely controlled by vegetation change.

In lake catchments both with and without feeder streams, it is possible that in areas of low relief, with pre-existing dense vegetation and low total and low intensity rainfall, only the most severe catchment disturbances are reflected in soil erosion and minerogenic inwash into the lake sediments. Conversely, lakes with high relief catchments, sparse vegetation and high rainfall are much more likely to suffer catchment soil erosion and minerogenic inwash in response to less severe catchment disturbance, or even to climatic deterioration. Although responses to similar soil-erosion stimuli can thus vary between lake catchments, it has been shown that Holocene lake studies can provide a good guide to the pattern of Holocene landscape stability and instability in individual lake catchments. It is also possible to obtain from the evidence in the lake sediments some indication of patterns of Holocene landscape stability and instability on a wider, regional scale. This can best be achieved when the lake in question is situated within the region of interest, and when the lake is so located that it has present day climatic, pedological and vegetation conditions which are representative of at least some areas of the surrounding region.

7.1.4 Palaeomagnetic Dating of Lake Sediments

The establishment of linkages between changing lake catchment conditions and the nature of lake sediments has become more secure as a wider range of palaeolimnological techniques has become available. Constructing a timescale of catchment changes from the evidence in the lake sediments is central to a greater understanding of the nature of these lake-catchment

linkages. One of the most important advances that has been made towards providing accurate chronologies of lake sediment accumulation has come from the field of palaeomagnetism. The term palaeomagnetism, when used in the context of Holocene lake studies invariably refers to the identification of the Natural Remanent Magnetism (NRM) within the lake sediments (Thompson and Oldfield 1986). NRM is the fossil magnetism attained by the sediments at the time of their deposition. NRM is comprised of three components: declination, inclination and intensity. Declination and inclination together describe the plane of the dip which particles display, and intensity is primarily a function of the number of individual particles which are aligned in this orientation, and secondarily a function of the strength of the magnetising field. In most lake sediments, this natural magnetic remanence is caused by Detrital Remanent Magnetisation, so called because the magnetic remanence is imprinted in the sediment during the deposition of allogenic magnetic particles. The formation of NRM in lake sediments is therefore a function of the combined influences of the status of the Earth's magnetic field at the lake's location, and the magnetic properties of the deposited particles at the moment of deposition.

The alignment of the Earth's magnetic field can be described at any point on the Earth's surface by reference to the two variables inclination and declination. Inclination is the angle of dip below or above the horizontal plane which would be assumed by a compass needle with freedom of vertical movement. Declination is the angle between true geographical north and the horizontal component of the magnetic field.

Particles which are most readily influenced by the earths magnetic field are those which include a variety of iron compounds. As these particles are deposited, the magnetic fields created at the atomic scale by electron spins within the iron compounds are aligned with the field lines of the Earth's magnetic field. This imparts a distinctive magnetic signature to the sediments deposited at that time. As the Earth's magnetic field displays gradual, or secular variations in declination and inclination, so lake sediments deposited over a given period acquire a similarly varying magnetic signature, which reflect those secular changes in the Earth's magnetic field occurring over the period that the lake sediments were accumulating.

Mackereth's (1971) studies in the English Lake District were largely instrumental in the exploitation of these secular variations of magnetic declination and inclination, observed in lake sediments, for dating purposes. In his work on Lake Windermere, Mackereth (1971) demonstrated that records of palaeomagnetic declination variation were held by the lake sediments, and that the youngest sediments revealed declination patterns which were highly comparable to declination variations recorded in London during historical times. Thompson and Turner (1979) conducted a detailed sampling programme from Loch Lomond and Lake Windermere with the aim of securing a palaeomagnetic chronology of lake sedimentation over the Holocene period. The Windermere and Lomond palaeomagnetic records were matched at the top of the cores, and also at the level of the Ulmus decline in the pollen record. Calibration was achieved with thirty radiocarbon age determinations and palynological age controls from five British lakes and also comparison with distinctive patterns of variation in the declination and inclination records from these lakes. Dating of distinctive palaeomagnetic features was also achieved by reference to archeaomagnetic results and observatory records. One of the most distinctive features is the westerly excursion of declination recorded by observatories in western Europe in A.D. 1815, and for which Thompson and Turner (1979) report a Pb^{210} date of 150BP. Thompson and Turner (1979) thus achieved a "master curve" of palaeomagnetic declination and inclination records within which the majority of distinctive palaeomagnetic "turning points" between 1000BP and 10,000BP were dated by radiocarbon assays calibrated by reference to Clark (1975). Comparing their results with palaeomagnetic records from Finland (Stober and Thompson, 1977), Switzerland (Thompson and Kelts, 1974) and Greece (Creer et al., 1977) and historic records (Barraclough, 1974), Thompson and Turner (1979) considered that their master curve would be applicable over the whole area of Western Europe for the last 10,000 calendar years.

In an earlier study, Thompson (1973) examined the sediments in Lough Neagh, Northern Ireland, and found that both within- and between-lake correlations could be made of palaeomagnetic declination and inclination records. Further research by Battarbee (1978) on diatoms and by O'Sullivan (1973) on the pollen record from Lough Neagh confirmed that the palaeomagnetic

record contained within the sediments provided a reliable dating method. The value of using palaeomagnetic techniques for establishing a lake sediment chronology was thus clear in the Lough Neagh case, where traditional C^{14} dating produced age inversions at certain levels in the lake stratigraphy where influxes of old carbon from catchment soil erosion had occurred. Edwards and Thompson (1984), in a study of Lough Catherine, Northern Ireland also found that the up-core sequence of progressively declining C^{14} dates was reversed, with too-old dates being obtained compared with the underlying dated samples. The earliest of these erroneous dates was 4895 +/- 110 bp. They suggested that the date may be associated with soil erosion induced by early Neolithic farming in the area. Other erroneously old dates were obtained from samples taken from above levels dated to 2105 +/- 95 bp and 1145 +/- 70 bp, although Edwards and Thompson (1984) did not publish these. Again, agriculturally-induced soil erosion is considered to have caused these dating anomalies, especially as cereal pollen was found consistently in the core from about 1650bp onwards. Analysis of the palaeomagnetic data and comparison with the pollen record and valid C^{14} dates demonstrated the greater reliability inherent in the palaeomagnetic dating method relative to C^{14} dating in this environment.

Edwards and Thompson (1984) were able to identify their erroneous C^{14} dates not only because they carried out parallel palaeomagnetic and palynological analyses, but also because they had obtained a sufficient number (23 in total) of C^{14} dates down through their cores to reveal the existence of the anomalously old carbon. Identification of old carbon in this way is also advantageous in confirming phases of widespread erosion of the A horizon of catchment soils, which other lines of evidence, such as pollen, organic matter fractionation and chemical analysis may have indicated. Nelmes (1983) undertook a detailed diatom study in Rostherne Mere, England for which he obtained nine C^{14} dates from the lake sediment in order to provide estimates of sediment and diatom accumulation rates. Unfortunately, most of these dates proved to be either erroneously old or erroneously young, and were certainly unsuitable to providing reliable data on accumulation rates. Palaeomagnetic investigation however revealed that the declination and inclination records could be closely matched to the master curve for Western

Europe, and therefore a chronology of sediment deposition and estimates of accumulation rates in the lake were made possible.

The above techniques cannot be directly applied in the Dovedale and Jugger Howe Beck catchments as neither contains a lake. Lake Gormire, situated at the western edge of the North York Moors is the nearest natural lake to the two catchments. As the lake is 38 km W. of Dovedale and 45 km. WSW. of Jugger Howe Beck an analysis of its sediments will obviously not provide information on the individual environmental histories of the Dovedale and Jugger Howe Beck catchments. The relatively short distance of Lake Gormire from the study catchments does, however, enhance the value of analysing its sediments with a view to assessing the degree to which the environmental changes which gave rise to the distinct alluvial landforms in the two study catchments took place on a wider regional scale across the North York Moors. As described in Chapter 2, the lake also experiences a very similar climate, and it is located in the same geological province of Jurassic sedimentary rocks which underlie the whole of the North York Moors region.

7.2 Lake Gormire Sediment Analysis

7.2.1 The Pollen Record

One other study has been carried out on Lake Gormire, by Blackham et al. (1981); this was primarily concerned with the palynological record in the lake sediments. Coring was carried out towards the middle of the lake, and the main core, "A", was 9.5m in length. Basement rock was not reached at the bottom of the core. The lower 3.5m of this core was through stiff grey clay, which was succeeded by approximately 3.75m of brown lake mud. Above 2.0m core recovery was impeded at some points, making the core incomplete above this level.

Pollen analysis carried out on the 9.5 m. deep core "A" provided evidence that sediment and pollen accumulation had been ongoing through the Holocene since Late Glacial times. The

Lake Gormire Pollen Diagram: after Blackham et al. (1981)

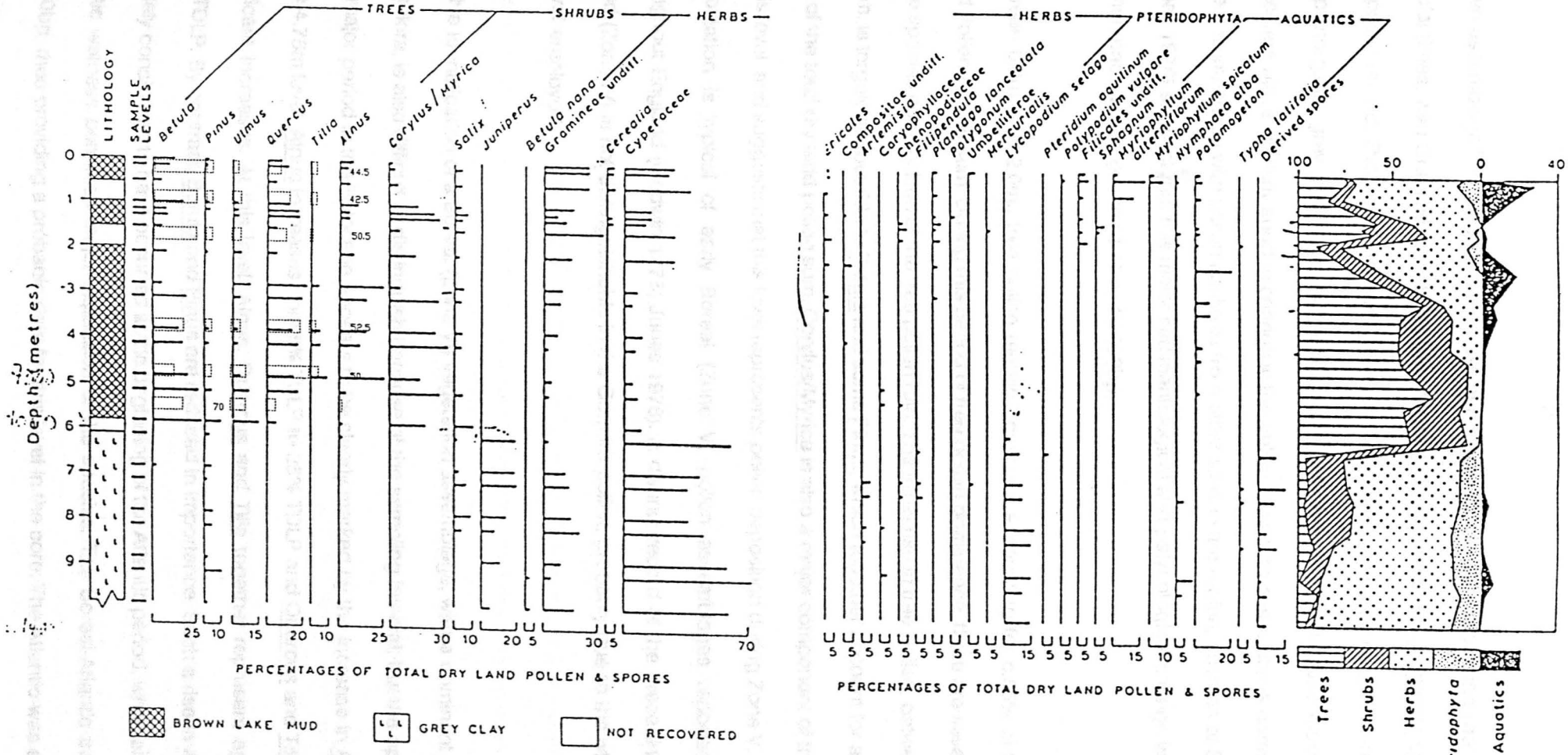


Figure 7.0

: approximate positions on Blackham et al.'s pollen diagram of pollen spectra identified in this thesis

pollen assemblage identified from the base of the core is characteristic of the vegetation of Late Glacial times, with Gramineae and Cyperaceae, and Betula nana and Juniperus sp. dominating the pollen record. This first zone in the pollen record extends through the full extent of the 3.5m. deep inorganic grey clay layer. An abrupt change to brown, organic lake muds at 6.0m. is coincident with a similarly sudden change in the pollen record, to one which is dominated by tree pollen. Comparison with pollen analyses from other sites in the region, such as at Seamer Carrs (Jones 1976) suggest that this major sedimentological and palynological change was a regional phenomenon which occurred at c. 10,000bp.

Between 6.0m. and 2.0m., tree pollen remain dominant, accounting for c.55% of the Total Dry Land Pollen (TDLP) sum. During this period of tree pollen dominance, there are several variations in the species composition of the tree pollen rain. The initial rise in tree pollen, between 6.0m and 5.25m. is largely attributable to Betula and some Pinus, which together account for approximately 35% of the total dry land pollen sum. Corylus/Myrica is also a major component of the pollen rain at this level, and suggests that this level represents pollen deposition during Zone V. This species combination is typical of early Boreal (Zone V) pollen assemblages reported from sites throughout England (Godwin 1975; Jones 1976). A distinct record of the preceding pre-Boreal period (Zone IV) is not distinguishable in the Gormire pollen, probably due to the wide sampling interval employed.

Positive identification of a Boreal (Zone VI) vegetation assemblage, with a dominant Corylus and Pinus flora, is also difficult to distinguish because of the sampling interval, but the opening of the next major period in the Holocene appears to be clearly marked by the increase in Alnus counts at the 4.75m level. Alnus increases from 5% TDLP to 25% TDLP and Quercus and Tilia also show significant increases. At this level, Alnus, Quercus and Tilia together represent approximately 50% TDLP. By contrast, Betula and Pinus are reduced in importance. Such a rise in Alnus counts is widely considered to have occurred at the beginning of the Atlantic period, when an increase in climatic wetness permitted major expansion of the species. The Boreal-Atlantic transition was c.7000bp, thus providing a probable date for this level in the core. The Atlantic was also the time

of the postglacial Climatic Optimum, when the deciduous forest cover was at its most extensive in England. This corresponds well with the high tree pollen counts of approximately 70% TDLP recorded between 4.75m and 4.0m.

The end of the Atlantic period, at c.5000bp is marked in pollen diagrams throughout much of England by the Ulmus decline. In the Gormire core, this feature appears to occur at the 4.0m level, where Ulmus counts drop from 10% TDLP to 5% TDLP, and tree pollen generally drops from 70% TDLP to approximately 60% TDLP. The Ulmus decline is succeeded by woodland regeneration at 3.0m. The regeneration appears short-lived however, as at the 2.0m level there is evidence of severe deforestation affecting the vicinity of the Gormire catchment. Tree pollen drops to only 10% TDLP, a value consistent with an almost totally deforested landscape around the lake. Evidence from across the North York Moors, presented in Chapter 6, shows that the Iron Age / Roman Period at c.2000bp was a period of massive tree clearance, to fuel iron smelting and to clear land with better soils for agriculture. The Gormire pollen record at 2.0m may therefore represent this deforestation at c.2000bp. There are records for Plantago lanceolata, a classic indicator of disturbed ground conditions, and also a big increase in counts of Potamogeton sp., a water lilly, which may represent the sudden influx of nutrients into the lake as soil erosion occurred in the lake catchment. It is also notable that immediately following this massive deforestation the first records of Cerealia pollen are made, directly indicative of arable agriculture taking place in or near to the Gormire catchment. Above the 2.0m level, Gramineae increases to 20% - 30% TDLP, compared to only 5% - 10% TDLP recorded between 6.0 - 2.75m. This is further evidence of expansion of an open, sparsely wooded landscape at c.2000bp.

At the 1.0m level the pollen record shows that considerable tree regeneration occurred, with tree pollen reaching 35% TDLP. This does not however reflect woodland recovery to pre-Iron/Roman Age levels. Such regeneration is well documented from pollen records across the North York Moors, and is considered to have taken place during Saxon times (the Dark Ages). This phase of regeneration is followed by another period of tree clearance at the 0.5m level. Tree pollen falls to only 11% TDLP at this level. This period probably represents vegetation disturbances between

approximately 1200bp - 900bp caused primarily by the Viking invasions and settlement and possibly also by the first effects of the expansion of monastic sheep farming activities in early Medieval times. Both the Vikings and the monasteries introduced large sheep populations during this period, and to increase the amount of grazing that was available, probably undertook considerable woodland clearance. The influence of the monasteries was also felt in the valleys under their ownership, as the valley floors were often cleared of woodland to permit agriculture to be practised to support the relatively large and concentrated monastic populations. After this period of tree clearance, the Gormire pollen record shows a sharp tree pollen recovery up to the top of the core and present day conditions, with tree pollen accounting for 17% TDLP.

The pollen record from Gormire therefore provides a very similar representation of vegetation change during the Holocene to that gained from other sites in the region and throughout England generally. A Late Glacial open park tundra vegetation with dwarf birch and juniper is succeeded at c.10000bp by the pioneer Silver Birch and Scots Pine during pre-Boreal times. Although a distinctly Boreal pollen record is difficult to distinguish, the Gormire pollen record provides clear evidence of the opening of the Atlantic period and the peak tree pollen counts which resulted from the expansion of the Quercetum Mixtum during this period of the postglacial Climatic Optimum. Following the Elm Decline at c.5000bp tree pollen was never again dominant, and the late Flandrian vegetation went through periods of tree clearance and subsequent limited regeneration, with the most severe deforestation occurring during the Iron/Roman Age (c.2000bp) and followed by a further period of deforestation during Viking and early Medieval times (c.1200bp - 900bp).

Blackham et al.'s (1981) work therefore clearly demonstrated that sediment accumulation had been ongoing in Lake Gormire throughout the Holocene. It was thus considered that the lake sediments may also reveal geochemical indicators of catchment disturbance, and that such indicators would be identified in the sedimentary record at similar levels to the indications of vegetation disturbance revealed in the pollen record. The degree of correspondence between pollen and geochemical evidence for catchment erosion should enable an assessment to be

made of the degree to which regional vegetation changes, identified not only in the Gormire record, but also from other pollen sites in the region, may have resulted in erosion in the Gormire catchment.

In an attempt to provide a more secure chronology of lake sediment deposition and to confirm the proposed dating control derived from Blackham et al.'s (1981) pollen analysis, the palaeomagnetic properties of the Gormire lake sediments were investigated. Because of the potential sources of error associated with C^{14} dating of lake sediments mentioned above, palaeomagnetism was considered the more appropriate dating method. Blackham et al. (1981) also considered the probable influx of old carbon into the lake due to soil erosion to be a major obstacle to C^{14} dating. In the absence of closely-spaced C^{14} assays, one could not be confident that, out of only two or three widely-spaced C^{14} dates, one was not erroneously aged. Thus only an intensive C^{14} dating programme at close intervals down a core would reveal at what levels old carbon was giving erroneously old C^{14} dates. Unfortunately, the cost of such an intensive sampling programme was prohibitive in this study; an advantage of palaeomagnetic dating, in addition to its freedom from the effects of date inversion, is therefore its relatively low cost.

7.2.2 Coring of the lake sediments

Blackham et al. (1981) obtained two cores from the centre of the lake, where the water depth is approximately 6.0m. In the absence of data on depth to bedrock beneath the lake sediments, Blackham et al. (1981) assumed that the centre of the lake would provide the thickest accumulation of sediment. In the course of obtaining sediment cores for the present study, coring attempts were also concentrated in the central part of the lake.

Coring was carried out with a Mackereth 3.0m pneumatic coring device, developed by Mackereth (1958). This design of corer is considered to be the ideal instrument for sampling lake sediments for subsequent palaeomagnetic analyses, as it takes a continuous core which can be extruded with minimal disturbance to the sediment to then allow sub-sampling of the core sediments for

analysis using a variety of magnetic sensory equipment (Thompson and Oldfield 1986). Coring took place from a 9.0m^2 raft that was re-constructed for each visit to the lake during the coring programme. A raft of at least the above size is essential when using a Mackereth 3.0m corer because of the corer's physical size (approximately 4.25m long) and weight (c. 150lbs.). The raft also has to accommodate at least one compressed air cylinder to operate the corer, lengths of compressed air hose, and storage tubes for recovered cores (see Plate 2.11). A minimum of two people is required to carry out the coring. A raft provides a much more stable launching and retrieving platform for the Mackereth corer than a boat, and the risk of capsizing is much reduced.

Detailed descriptions of the design and method of operation of the 3.0m Mackereth corer are given in Mackereth (1958). It is however relevant to an understanding of the condition of a recovered sediment core to outline the general design and operation of the Mackereth corer. The corer consists of a 3.0m plastic tube with an aluminium fixture at the top which houses air inlets to which hoses from the compressed air cylinder are attached. At the base of the 3.0m tube is a 0.75m diameter metal drum, 1.25m long and open-ended at its base. Inside the drum's upper surface, the end of second tube can be seen, located within the outer tube. The top of this second, inner tube is sealed off and attached to a piston. During operation of the corer, the drum is designed to penetrate the bottom sediments completely, leaving its top side flush with the sediment-water interface. Compressed air is then forced into a chamber above the piston at the top of the 3.0m tube. This forces the piston, and therefore the inner tube, into the sediment. When the piston has been depressed to its fullest extent, and therefore the inner tube is completely within the sediment, compressed air is forced into the drum. This starts to displace the bottom sediments, permitting sufficient air to enter the increasing space within the drum to eventually create sufficient buoyancy for the whole corer to extract itself from the lake bed. When it reaches the surface, the corer is travelling with considerable speed, and often even the base of the drum is propelled above the water surface. Plate 7.1 shows the corer returning to the lake surface after extracting a sediment core. Once at the water surface the corer falls on its side, and is brought alongside the raft by means of nylon rope attached to a handle at its top. These rather



PLATE 7.1

violent motions associated with core retrieval, and the unavoidable tipping over of the corer at the surface, inevitably mean that sediments that are of a liquid nature will not retain their original structure within the core tube.

One solution to the problem of obtaining undisturbed samples of very liquid sediments from lakes was the development by Mackereth (1969) of a smaller pneumatic coring device. This has a much smaller buoyancy drum and takes a 1.0m. long core. Its design permits much slower ascents to the lake water surface, and it remains vertical once at the surface. This device does not therefore significantly disturb the stratigraphy of highly liquid lake sediments. If this smaller corer is used during sampling of lake sediments which are thicker than 1.0m. another longer core is required to sample the remaining depth of lake sediment. Cross-correlation of the two cores' stratigraphies is then required to obtain a complete stratigraphic record of the sampled sediments. In view of the evidence from Blackham et al.'s (1981) study that the sediment thickness considerably exceeds 1.0m, this additional complication suggests that a 3.0m Mackereth corer would be much preferable.

In other studies where the upper lake sediments are very fluid, a freeze coring technique, introduced by Shapiro (1958), and developed by Wright (1969) and Huttunen and Merilainen (1978), has been employed to preserve the stratigraphy. Frozen core techniques have been used extensively by Scandinavian investigators for retrieving samples of relatively undisturbed samples of varve sequences from glaciolacustrine environments (Saarnisto et al., 1977; Huttunen and Merilainen, 1978). This technique however is not particularly suited to sampling sediments when it is subsequently intended to analyse the palaeomagnetic properties of the sediments. This is because the freezing process distorts the alignment of layering in the sediments, thus destroying the original Natural Magnetic Remanence of the sediments. The sediments cannot then be reliably used for palaeomagnetic dating purposes (Thompson and Oldfield 1986).

Several attempts were made to recover cores from the centre of the lake. Unfortunately, core recovery met with limited success, and only one complete core was recovered, after the coring location had moved nearer to the southeast corner of the lake. Each time the Mackereth corer was deployed unsuccessfully, it was necessary to move the raft so that the next attempted core would not be taken through sediments that had been disturbed by the previous attempt. Similarly to keep disturbance of the lake sediments to a minimum, the raft was not anchored in one place, but was tethered to a nylon rope that had previously been taken across the lake by rubber dinghy and attached to trees at both ends. This not only avoided having to anchor the raft to the lake bottom, but also allowed the raft to be rapidly and easily moved along a transect by the persons on the raft. The disadvantage of this anchoring and relocating method was that after many unsuccessful coring attempts had been made, the coring position had of necessity moved further away from the original central starting point, and nearer the edge of the lake. Only one core was obtained, on which all later analyses were carried out. Subsequent to the completion of the coring programme, a sub-aqua dive revealed that the lake bottom supported a heavy weed growth; this was the most likely cause for the corer not readily penetrating the lake bottom sediments.

7.2.3 The Gormire Lake Sediment Core

The top 10cm of the successful core was in a highly liquid state, and due to the vigorous nature of the coring process, this section of the core was highly disturbed and consequently of no use for subsequent analyses. The core taken for this study penetrated to a depth of 2.20 metres. Further penetration to the full 3.0m extent of the coring device was inhibited by a very tenacious grey clay. Only 10cm of this clay material was recovered in the core. At the time of sampling the clay was considered to be part of the same stratigraphic unit as was identified by Blackham et al. (1981) at 9.0 - 6.0m in their core from the middle of the lake. As discussed above, Blackham et al. (1981) interpreted the boundary between the underlying lacustrine clays and the brown lake muds as marking the Late Glacial/Holocene transition at c.10000bp. Subsequent analysis of the

core sediments, which is presented below, confirmed this initial assessment. The depth discrepancy of the grey clay/lake mud interface between Blackham et al.'s (1981) core and the core taken for this study would therefore be the result of the lake basin floor, beneath the Holocene sediments, shelving up from its deepest point in the middle of the basin towards its southern margin. The depth of infill of the lake basin would therefore be greatest in the centre of the lake, with sediment accumulation gradually decreasing towards the south. The core that was recovered for the present study was therefore considered to provide a complete record of Holocene lake sediment accumulation in Lake Gormire.

7.3 Palaeomagnetic Record of Gormire Sediments

Palaeomagnetic analysis of the Gormire sediments was carried out in the Geophysics Department of the University of Edinburgh, under the guidance of Dr. R. Thompson. The declination, inclination and magnetic intensity measurements used in palaeomagnetic analyses on lake sediments were made using a spinning fluxgate magnetometer. This instrument has several advantages for carrying out relatively rapid assessment of the palaeomagentic properties of lake sediments. The most significant of these are firstly that it is capable of detecting the very weak magnetic fields that are often found in lake sediments due to their high water and organic contents; and secondly, its speed of operation allows up to ten samples to be processed in one hour. Detailed information on the physics and mechanics of the spinning fluxgate magnetometer are given in the excellent account by Thompson and Oldfield (1986), who note that the qualities of the fluxgate magnetometers have resulted in its being used for the majority of palaeomagnetic research on lake sediments in the British Isles.

The spinning fluxgate magnetometer operates on small sub-samples of sediments which are contained in 10ml plastic cubes. Each cube is prepared by first having a small hole (c.0.5mm diameter) drilled into the end opposite the open side to allow air to escape as the cube is pressed into the core when the sample is taken. An arrow is then indelibly marked on the side of the cube into which the hole has been drilled. When taking the sub-samples, it is essential that for every sub-sample, the arrow points to the top of the core. This provides a uniform reference direction for all the sub-samples when they are placed in the spinning fluxgate magnetometer and aligned with an index mark in the magnetometer's sample holder. Before taking the sub-samples, each cube is marked with the depth down the core from which a sub-sample is to be taken.

The spinning fluxgate magnetometer measures declination, inclination and intensity in six steps. These steps are marked by the sample cubes being moved into six different orientations, to enable six components of the palaeomagentic properties to be measured. After each change in position, the magnetometer spins for approximately 30 secs., which is generally sufficient time for

a stable reading to be obtained. The readings are automatically entered into a computer programme in real-time, which gives final output of declination, inclination and intensity at the end of each reading cycle.

Forty-two 10ml sub-samples were taken from the core. Above the 37.5cm level, the sediment was in places too liquid for sampling. Any attempt to extract a sample from these particular points would result in the collapse of the surrounding sediments. Consequently, samples were only taken where the sample was sufficiently stiff. These samples were at 10cm, 15cm, 21cm and 30cm. Below 37.5cm the sediment permitted samples to be taken at 5cm intervals. 2.0cm below the 62.5cm sample there was a break in the core, which had occurred during extrusion of the core into the storage tube. The 62.5cm sample and the 66.5cm sample were therefore taken, respectively, 2cm above and below the break to avoid any degradation of the palaeomagnetic properties that may have resulted from the fracturing of the core at this point. Between 66.5cm and 151.5cm, the 5cm sampling interval was maintained. Below 151.5cm, the sediment was sufficiently firm to sustain sampling at a smaller interval of 4cm. The increased compaction that generally takes place in greater thicknesses of lake sediments as accumulation continues warrants as close a sampling interval as can be achieved.

By far the most distinct trends were identifiable in the declination data and, as advised by Dr. Thompson, all subsequent analysis was carried on the declination data. The declination data curve is shown in Figure 7.1. Selection of the declination data for detailed analysis is a common practice in studies of British Holocene lake sediments (Clark and Thompson, 1978; Mackereth, 1971; Thompson and Morton, 1979), and intensity data have been found to be unreliable for dating purposes (Thompson and Oldfield 1986).

The inherent scatter of palaeomagentic directions in Holocene lake sediments makes it necessary to carry out averaging, or smoothing, techniques to obtain a reliable estimate of the ancient geomagnetic field directions (Clark and Thompson, 1978). The data used to construct the declination curve in Figure 7.1 have been smoothed using an approximating cubic-spline

Lake Gormire : Palaeomagnetic Data

Relative Declination Curve

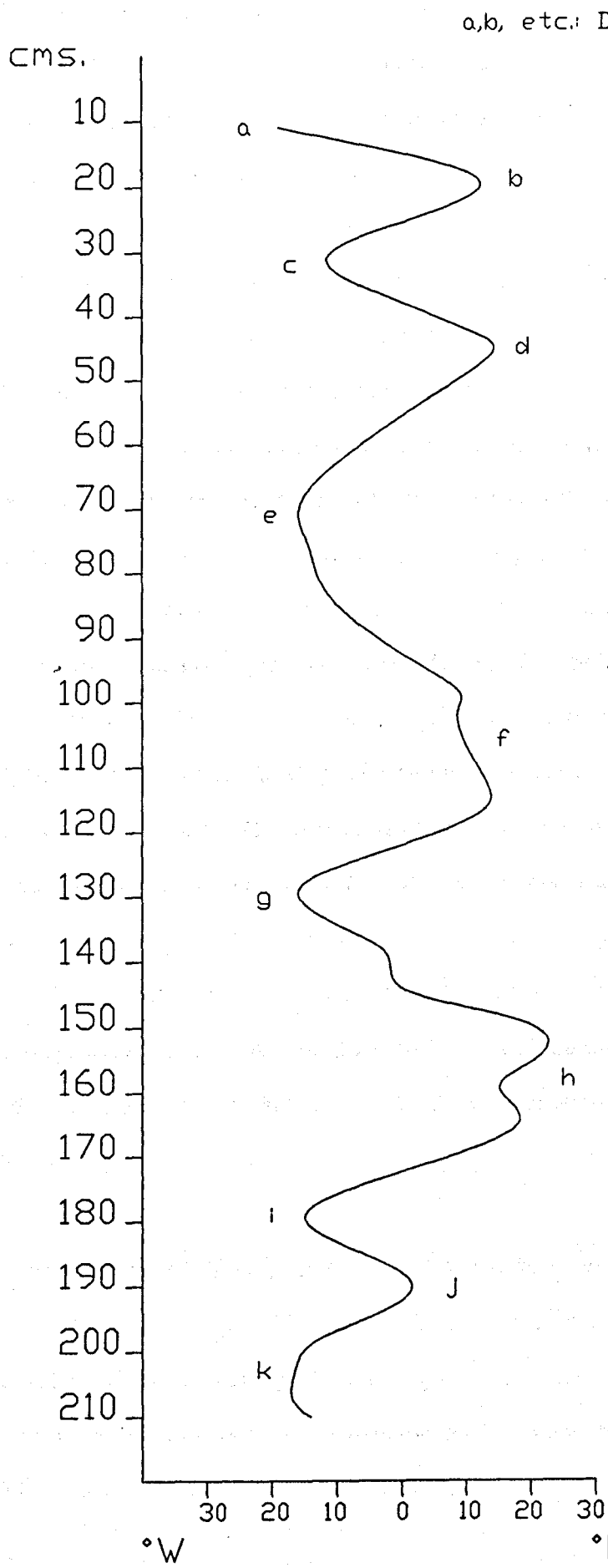


Figure 7.1

(Reinsch, 1971) which is one of the mathematical procedures recommended by Clark and Thompson (1978) for averaging palaeomagnetic data. A means of fitting cubic-splines is provided in the "Autosketch" programme for IBM-PC compatible personal computers, and an implementation of this programme was used to provide the declination curve in Figure 7.1. The programme allows the user to select the number of spline pieces making up the data. If a large number of spline pieces is selected, the curve will come closer to passing through all the original data points. The optimal number of spline pieces will produce a curve that most accurately discriminates between the underlying trend of the data and those data points that are outliers. Clark and Thompson (1978) adopted a complex mathematical procedure, termed cross-validation analysis which indicates the correct degree of smoothing (i.e. the optimal number of spline pieces) required for a particular data set and also allows the subsequent derivation of confidence and prediction limits. In the absence of a computer programme for carrying out cross-validation analysis, a rule of thumb was applied when deciding the appropriate degree of smoothing, (number of spline pieces) to be applied to the Gormire declination data. This involved identifying the major points of inflexion in the data, and the legs of data defined by the points of inflexion. Only those inflexions bounding legs of data which varied over a range greater than 10° were included. Creer and Kopper (1974) used a value of 3° as a limit on the identification of meaningful inclination variations on Lake Windermere sediments at some depths, whereas Thompson (1975) considered that a more stringent 6° was appropriate. Where the number of data points is limited, and therefore the reliability of interpretation is reduced, much higher limits have been employed. A notable example of this is the 20° limit of interpretability which Thompson (1976) placed on inclination data from Blekinge, Southern Sweden, due to the paucity of data from the site.

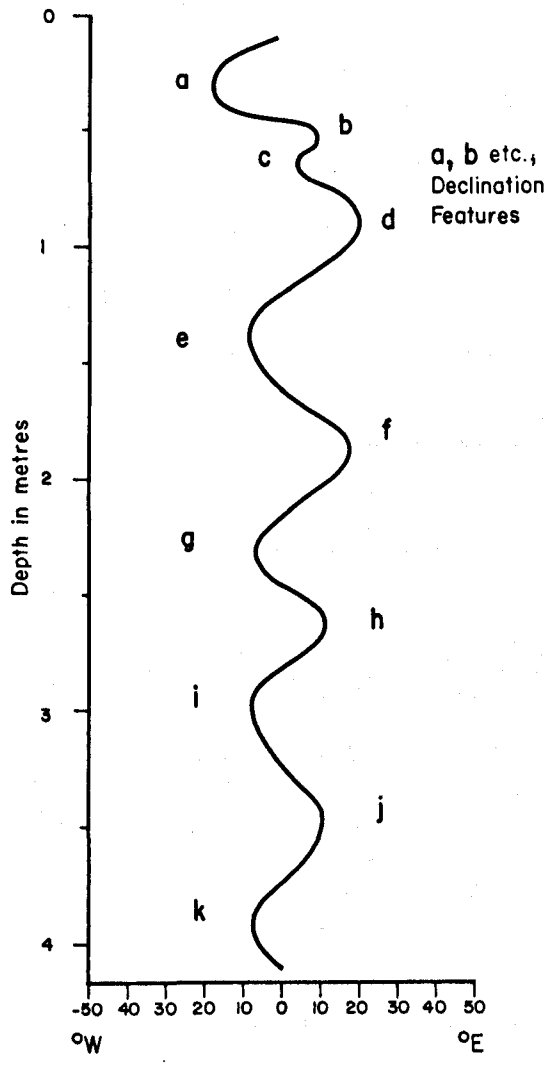
Based on these observations of Thompson (1975, 1976), and the relatively sparse sampling from Lake Gormire, a 10° limit was adop ted for the Gormire declination data. Applying this criterion in practice means, for example, that in Fig 7.1 the change in declination between 140 cms and 145 cms of 3° is not a significant leg of data, whereas the declination change between 145cms and 150 cms of 30° does constitute a significant leg of the data set, and can therefore be included for

purposes of deciding the number of spline pieces required. Whilst this method may underestimate the number of spline pieces that are appropriate to the declination data set, it does not risk overestimating the number required. This technique thus indicated that an 18 piece spline was applicable to the Gormire declination data set.

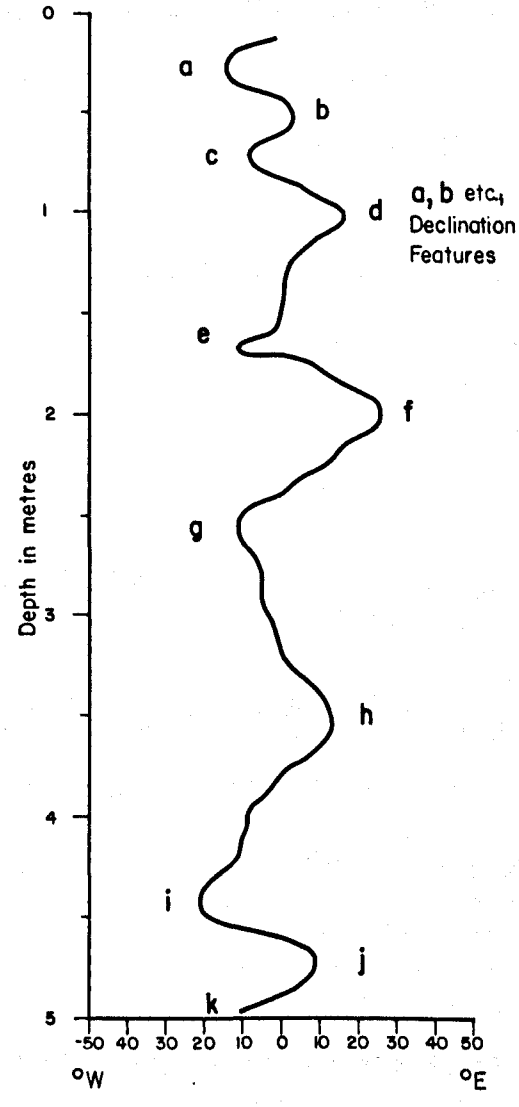
Figure 7.1 also shows the Gormire declination data annotated with the magnetic features a - k. These magnetic features, marking distinctive swings of declination between west and east, were first identified in Mackereth's (1971) original declination data from Lake Windermere, and dated by Thompson and Turner (1979) during their determination of the British Holocene geomagnetic master curve, which has been discussed earlier. Thompson and Turner's (1979) master curve is reproduced in Figure 7.2 to provide a comparison between it and the Gormire declination data. Several workers have attempted to devise cross-core correlation methods suitable for comparing magneto-stratigraphies (Denham, 1981; Rudman and Blakely, 1976; Gordon, 1973, 1982). Thompson and Oldfield (1986) concluded however that none of the proposed procedures had proved to be workable, and that only subjective trial and error methods can be used for matching palaeomagnetic data to the appropriate regional geomagnetic master curve.

The Gormire declination data have thus been matched by eye with the British Holocene geomagnetic master curve from Windermere to produce the annotated Gormire declination curve in Figure 7.1. It is clear that the two curves show many similarities, and that the features a - k on the Gormire curve accord well with those features in the Windermere curve. The very marked westerly declination swing at the top of the core is a very distinctive feature of the Holocene geomagnetic field changes which has been recorded in observatory records as occurring in A.D. 1815 (Oldfield 1981). Figure 7.2 also shows the Loch Lomond declination curve constructed by Thompson and Turner (1978). This provides a very good example of the variability that the palaeomagnetic signature from different lake cores can exhibit, whilst still providing a dated magneto-stratigraphy.

LAKE WINDERMERE
PALEOMAGNETIC RELATIVE DECLINATION CURVE



LOCH LOMOND
PALEOMAGNETIC RELATIVE DECLINATION CURVE



after, Thompson and Turner (1978)

Figure 7.2

Table 7.1 is the chronology that Thompson and Turner (1979) produced for the Windermere declination features. The dates are in calendar years, calibrated by reference to Clark's (1975) dendrochronology data for features "a" to "h". For older features Thompson and Turner (1979) assumed that calibration changes smoothly from 6500bp to zero correction at 10000bp, an assumption also made by Thompson and Edwards (1982) and Edwards and Thompson (1984) in their work on developing a geomagnetic master curve for Ireland. Matching the Gormire declination data with that from Windermere therefore provides a relatively reliable chronology of Holocene sediment accumulation in the Lake Gormire. Figure 7.3 shows the Gormire declination data with the declination features annotated according to Thompson and Turner's (1979) calibration given in Table 7.1.

Table 7.1 **Timescale for Declination Features**

Dec. Feature	C^{14} Date bp	Calibrated Calendar Date BP
a	150	150
b	450	450
c	600	600
d	1000	1000
e	2000	2000
f	2500	2600
g	4200	4900
h	6200	7100
i	7400	8300
j	8800	9100
k	10000	10000

Although the methods that are used to identify the secular changes in declination from the Gormire sediments and the subsequent matching with the magnetic master curve from Windermere cannot match the mathematical precision used by Stober and Thompson (1977) Clarke and Thompson (1979), and Thompson and Edwards (1982) in their studies, selective palynological investigation of the Gormire sediments can provide a secure means of checking the validity of the interpretation of the palaeomagnetic data.

The palynological record from Gormire has already been described by reference to the work of Blackham et al. (1981). Blackham et al. (1981) clearly demonstrated the similarities between the

Lake Gormire : Palaeomagnetic Data

Dated Relative Declination Curve

a,b, etc.: Declination features

Dates Calendar Year BP

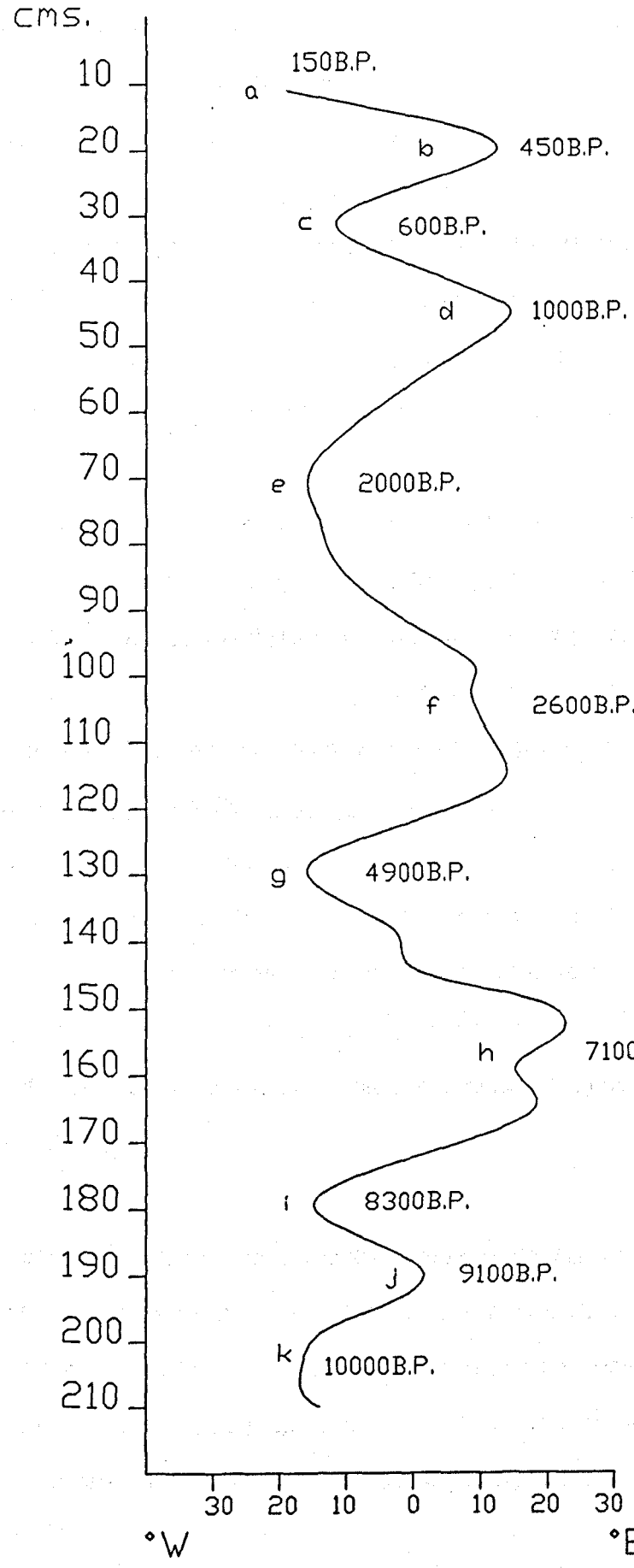


Figure 7.3

Gormire pollen record and other C14 calibrated regional pollen data, such as the expansion of Betula after 10000bp, the alder rise at 7000bp (c.7900BP) and the late Holocene period of massive deforestation and concomitant expansion of ruderals. Therefore if the dated magnetic features (a - k) have been correctly identified in the Gormire core, then palynological analysis on samples taken from the levels where the magnetic features occurred should reveal pollen assemblages distinctive of those ages (Thompson and Turner, 1979). Atherden's (1976) radiocarbon calibrated regional pollen record for the North York Moors from Fen Bogs provides the established pollen assemblages that should be identifiable in the Gormire sediments from any magnetically dated level in the core. Using pollen analysis, Huttunen and Stober (1980) similarly dated the palaeomagnetic record that they identified in Finnish lake cores.

Samples for palynological analysis were taken from the levels of magnetic features i (8300BP; 7400bp); at h (7100BP; 6200bp); at g (4900BP; 4200bp); at e (2000BP; 2000bp) and halfway between e (2000BP; 2000bp) and d (1000BP; 1000bp); and at d (1000BP; 1000bp) itself. These magnetic features were chosen because the pollen assemblages expected at these levels should be readily identifiable. At i, the expected pollen assemblage would be from the late Boreal (Zone VI), dominated by Pinus and Corylus/Myrica. The pollen assemblage at h should reflect the Quercetum Mixtum of the Atlantic period, while the sample taken at g should show evidence of woodland reduction and the Ulmus decline. The sample from the level of e should be characterised by the massive Iron/Roman Age woodland clearances, and the sample from between e and d should demonstrate woodland regeneration during Saxon times. The sample from d should show a further phase of woodland clearance which occurred during Viking and early Medieval times.

These various features of the pollen assemblages are fundamentally reflections of how the tree pollen sum changes with respect to the Total Dry Land Pollen Sum (TDLP), and of changes in the species composition of the tree pollen rain. Pollen counting was therefore undertaken to establish major differences in the proportion of the pollen sum accounted for by trees, and the species composition of the tree pollen. Pollen counting of dry land pollen continued until 100 tree

pollen were recorded. Only trees were recorded to species, and of the shrubs, only Corylus/Myrica and Ericales were recorded. All herbs records were summed into one category.

Pollen analysis from Level i

Trees: 51% TDLP; Corylus/Myrica 42% TDLP; Herbs 6% TDLP

Tree pollen accounts for 51% of the dry land pollen sum. This figure suggests a moderately wooded environment in the vicinity of the lake. The table below gives the different tree taxa percentage figures.

Table 7.2 **Level I : Tree Species as % of Total Tree Pollen Sum**

Species	% TDLP
Betula	15.0
Pinus	70.0
Ulmus	6.5
Quercus	5.0
Tilia	0.0
Alnus	3.5
Fraxinus	0.0

These percentages suggest that woodland at the site was dominated by Pinus, with Betula forming the secondary woodland component, typical of much of the Boreal forest cover, while Corylus/Myrica accounts for 99% of the shrub pollen. These figures represent a very similar pollen assemblage to those reported by other workers (Atherden 1976; Jones 1976) from Zone VI sediments on the North York Moors.

Pollen analysis from Level h

Trees: 68% TDLP; Corylus/Myrica 23% TDLP; Herbs 9% TDLP

Tree pollen accounts for 68% of the dry land pollen sum. This figure suggests a dense woodland cover with a few breaks. The table below gives the different tree taxa percentage figures.

Table 7.3 **Level h : Tree Species as % of Total Tree Pollen Sum**

Species	% TDLP
Betula	11.0
Pinus	3.5
Ulmus	8.0
Quercus	22.5
Tilia	5.0
Alnus	50.0
Fraxinus	0.0

These percentages indicate that the dense woodland was dominated by Alnus and Quercus. Alnus does not become so dominant in the Holocene flora until the Alnus rise at the start of the Atlantic period. There are also significant records of Tilia, probably the most thermophilous tree species in the British vegetation, and the records for Ulmus suggest that this species had not yet suffered the reductions at the Ulmus decline at the end of the Atlantic. This predominance of tree pollen and the types of tree found is therefore similar to that reported by Atherden (1976) from Fen Bogs.

Pollen analysis from Level g

Trees: 55% TDLP; Corylus/Myrica 33% TDLP; Herbs 12% TDLP

Tree pollen accounts for 55% of the dry land pollen sum. This figure suggests a moderate amount of woodland in the area, very similar to that recorded at Level i. considerable woodland cover, but with significant breaks and open areas. The table below gives the different tree taxa percentage figures.

Table 7.4 **Level g : Tree Species as % of Total Tree Pollen Sum**

Species	% TDLP
Betula	15.0
Pinus	3.0
Ulmus	4.0
Quercus	19.0
Tilia	4.0
Alnus	52.5
Fraxinus	2.5

These figures clearly show a marked decrease in the counts for Ulmus which are reduced by half, together with small declines in the counts of Tilia and Quercus. Betula undergoes a significant increase, and Fraxinus is recorded for the first time in a core from Lake Gormire. The latter two species are heliophytic, suggesting the decrease in Ulmus and Quercus opened up clearances within the woodland, beyond the heavy shade that these species would cast. The decline in Ulmus alone suggests that this sample post dates the Ulmus decline at the end of the Atlantic period. Atherden (1976) identified the Ulmus Decline in the Fen Bogs pollen record from a level radiocarbon dated to 4730 +/- 90 bp. The presence of Fraxinus, which is generally identified with the opening of the Sub-Boreal period (Pennington, 1965) supports this age interpretation for this Level.

Pollen analysis from Level e

Trees: 13% TDLP; Corylus/Myrica 21% TDLP; Ericales 2%; Herbs 64% TDLP

Tree pollen accounts for 13% of the dry land pollen sum. This figure suggests a massive clearance of woodland from the vicinity of Lake Gormire. The table below gives the different tree taxa percentage figures.

Table 7.5 **Level e : Tree Species as % of Total Tree Pollen Sum (TTP)**

Species	% TTP
Betula	22.5
Pinus	3.0
Ulmus	3.5
Quercus	10.0
Tilia	2.0
Alnus	50.5
Fraxinus	8.5

These figures show that within the largely de-forested landscape of the time, the primary closed-woodland trees, Quercus, Ulmus and Tilia are less important than the heliophytic Betula and Fraxinus. Alnus is by far the most important species, but this is probably as a result of its survival on the wet sites surrounding the lake and consequent over-representation in the pollen record at this time. The reduction in Quercus, Ulmus and Tilia would also have the effect of making the Alnus count appear relatively more important. Compared with level g, both Betula and Fraxinus show a further significant increase. As was noted at Level g, the latter two species readily colonise areas where previous forest shade has been opened up by primary woodland clearance. The other significant feature of the pollen assemblage from this Level is the huge expansion of herbaceous plants, which would have colonised the large areas newly cleared of woodland.

These features of the pollen assemblage present a clear indication of Iron Age clearances, described by Atherden (1976) and others (see Chapter 6) as being the most severe anthropogenic impact on Holocene vegetation in the North York Moors.

Pollen analysis from midway level between e and d

Trees: 27% TDLP; Corylus/Myrica 32% TDLP; Ericales 3% TDLP; Herbs 38% TDLP

Tree pollen accounts for 27% of the dry land pollen sum. This figure suggests a limited degree of woodland regeneration compared to Level e. The table below gives the different tree taxa percentage figures.

Table 7.6 **Level e-d : Tree Species as % of Total Tree Pollen Sum (TTP)**

Species	% TTP
Betula	22.5
Pinus	3.5
Ulmus	4.0
Quercus	11.0
Tilia	3.0
Alnus	42.5
Fraxinus	14.0

These figures show that an expansion of the heliophytic species, Fraxinus and Betula accounted for most of the woodland regeneration, and that the main forest trees did not experience such a degree of recovery. The Alnus counts are depressed but this is again probably a relative effect caused by the increase in the Fraxinus and Betula counts. The main closed woodland trees, Quercus, Ulmus and Tilia show very little signs of revival at this time. The high counts for herbs and Corylus/Myrica suggest that woodland regeneration was limited in extent, and that large areas remained open and colonised by weeds, with hazel forming a fairly widespread shrubby understorey. The slightly increased Ericales counts show that heather moorland was continuing to expand, although at some distance from the Gormire catchment.

As was discussed in Chapter 6, Atherden (1976) reports such a limited regeneration of heliophytic trees from the Fen Bogs site together with high Corylus/Myrica and herb counts, but the dominant feature of the Fen Bogs record from the Dark Ages is the massive expansion of Ericales on the moorlands surrounding the Fen Bogs site.

Pollen analysis from Level d

Trees: 18% TDLP; Corylus/Myrica 21% TDLP; Ericales 6% TDLP; Herbs 55% TDLP

Tree pollen accounts for 18% of the dry land pollen sum. This figure indicates another phase of major woodland clearance, although somewhat less severe than that seen at level e. The table below gives the different tree taxa percentage figures.

Table 7.7 **Level d : Tree Species as % of Total Tree Pollen Sum (TTP)**

Species	% TTP
Betula	26.5
Pinus	3.0
Ulmus	3.0
Quercus	7.0
Tilia	2.5
Alnus	44.5
Fraxinus	15.5

These figures show a very similar pattern to that recorded at Level e. The major component of the arboreal pollen influx to Lake Gormire is from the Alnus fringing the lake itself, followed by Betula and Fraxinus. This phase of woodland clearance has little effect on the relative species composition of the arboreal pollen rain. The most significant feature of the pollen record at this level is the higher proportion of the Total Dry Land Pollen sum (TDLP) accounted for by herbs. It would seem that this woodland clearance also had a major detrimental effect on the Corylus/Myrica population resulting in the formation of even larger areas of open ground for the ruderals to colonise. Ericales continues its gradual increase, suggesting that the heather moorland was extending its coverage.

This second period of woodland clearance, which succeeded Dark Age regeneration, has been widely identified from sites across the North York Moors, as discussed in Chapter 6. A radiocarbon date of 1060 +/- 160 bp from Fen Bogs (Atherden 1976) was obtained from material providing similar pollen evidence of a post-Dark Ages clearance in the central Moors.

This pollen analysis confirms, at six levels in the Gormire core, the match which has been made between the Gormire magneto-stratigraphy and the Windermere geomagnetic master curve. The Gormire magneto-stratigraphy can therefore be used as a secure chronology for the subsequent analysis of patterns of geochemical and sedimentological change in the lake sediments.

The continuous nature of the palaeomagnetic chronology that has thus been established above also confirms that the core used for this study has sampled sediments which have not been subject to radical post-depositional reworking or slumping during the Holocene.

7.4 Analysis of Core Sediments

Sedimentological and chemical analyses were carried out on the same 42 samples that were used in the palaeomagnetic investigations. The total volume of sediment analysed was increased to 20ml by extraction of additional material from the levels at which palaeomagnetism was measured. This was necessary to provide sufficient material on which subsequent analyses could be carried out after the sample had been dried.

7.4.1 Particle Size Analysis

Particle size analysis of the Gormire core sediments was carried out on a Coulter Counter apparatus. Preparation of samples for Coulter Counter analysis was based on the method of Shideler (1976), as used by Behrens (1978). Moist 5.0mm^3 samples were prepared by first treating them with H_2O_2 to remove organic matter. The samples were boiled in H_2O_2, and this treatment was continued until addition of further fresh H_2O_2 caused no further bubbling of the sample. Peroxidation was followed by wet sieving through a 63um sieve to separate out sand size particles from the silts and clays. The silt and clay suspension that passed through the sieve was then treated with Calgon (sodium hexametaphosphate) to disperse the particles fully. Sieving at 63um revealed there to be no sand-sized material in any of the samples taken from the core.

7.4.2 Sediment Geochemistry

a. *Erosion Indicators (K, Na, and Mg), and Ca*

The lack of material coarser than 63um in the Gormire sediments means that those elements identified by Mackereth (1966) and Pennington et al. (1972) as potential indicators of catchment erosion - K, Mg and Na - can, inevitably, only be found within the silt and clay sized particle size classes.

When, as is the case for the Gormire sediments, the concentrations of these cations are being assessed in organic-rich sediments of which colloid sized material forms a large proportion, Engstrom and Wright (1984) note that the most widely used extractant used in lake studies (e.g. Likens and Davis, 1975) is 1.0N ammonium acetate buffered to pH 7. Koljonen and Carlson (1975) also noted that ammonium acetate is particularly suitable for extracting K and Mg from the clay minerals which can be found in fine grained lake sediments. Following the recommendation of Engstrom and Wright (1984) therefore, the extraction of K, Mg and Na from the Gormire sediments was carried out with 1.0N ammonium acetate solution (Jackson, 1958), following the procedure of Arnett (pers. comm.). When ammonium acetate is used as an extractant in soil analysis, it provides an assessment of the level of exchangable nutrients in the soil. In lake sediments such concepts of nutrient availability have yet to be defined however, and Engstrom and Wright (1984) recommend that the term "extractable" nutrients is more appropriate in palaeolimnological studies.

Samples for analysis were transferred into porcelain crucibles and dried at 110°C. for 48 hours. The dried material was then ground in a pestle and mortar and weighed. A 5g sample was then taken for further preparation for analysis of K, Mg, Na and Ca content. The ammonium acetate extraction technique is detailed in Appendix 4. Aliquots of the extract were run through a flame photometer to measure levels of K and Na. Atomic absorption spectrophotometry was used to measure Ca and Mg in separate aliquots.

b. Calcium

Ca content in the Gormire core sediments was also analysed by extraction with 1.0N Ammonium acetate. Unlike the three main erosion indicator elements (K, Mg and Na), Ca has been shown in several studies to be closely related to the organic carbon content of lake sediments (Mackereth 1966; Tolonen 1972; Brugam 1978). This is because Ca has an affinity for organic ligands such as humic and fulvic acids which are found in the organic component of lake sediments (Engstrom

and Wright, 1984). It would therefore be expected that Ca values would be higher in the more organic parts of the Gormire core.

c. *Organic Carbon*

The amount of organic carbon in the core sediments was assessed by wet-oxidation. Where lake sediments, such as those from Gormire, contain large amounts of clay, this method is used in preference to the loss-on-ignition method for measuring the proportion of organic carbon in such sediments (Hirons and Thompson 1984). This is because loss-on-ignition drives off interstitial water from the clays and therefore overestimates the organic carbon component of the sediment. The wet-oxidation method uses potassium dichromate and concentrated sulphuric acid, and the excess potassium dichromate after oxidation is complete is determined titrimetrically with ammonium ferrous sulphate. The technique is fully described in Appendix 1. This method of quantitative oxidation produces a measure of the weight of oxygen consumed (O.C.) during oxidation of the organic matter. The weight of organic matter in the sample can then be calculated by multiplying the O.C. by the reciprocal of the value of the oxygen equivalent (O.E.). The O.E. is the weight of oxygen required for complete oxidation of a unit weight of organic matter (Arnett, 1978). The O.E. varies between 1.4 - 1.5 depending on the type of organic matter undergoing oxidation. As the amount of organic carbon in a sample can therefore also be used to assess the organic matter content, it also indicates that the remaining weight of sediment comprises the minerogenic fraction.

iv. Intensity of Natural Remanent Magnetism

Measurements of the magnetic property of Intensity of Natural Remanent Magnetism were obtained during the elucidation of the palaeomagnetic properties of the sediment core for dating purposes, and which were described earlier in the chapter. The Intensity of NRM (INRM) in lake sediments is primarily a function of the quantity of minerals in the sediments which have magnetic properties. The more magnetic mineral particles there are in the sediment, the higher are the

values obtained for Intensity of NRM. In lake sediments, the most important magnetic minerals are iron oxides, which may be either of the spinel or the corundum group. Typical examples from these groups are magnetite and haematite, respectively. Because of their high density and resistance to erosion, magnetite crystals comprise a very common detrital iron oxide component in sedimentary rocks (Thompson and Oldfield, 1986). Consequently, magnetite is also common in superficial deposits derived from a wide range of parent materials. As such compounds of iron are extremely ubiquitous in their distribution throughout the environment, their occurrence in lake sediments is commonly increased when erosion of minerogenic sub-soil materials transports unweathered material into the lake. In the allogenic mineral fraction of lake sediments, magnetite is commonly the most important contributor to the magnetic susceptibilty of those sediments. Chapter 3 provides a description of the property of magnetic susceptibility, wherein it was stated that the parameter was basically a measure of the ease with which material can be magnetised. Several studies have established a relationship between phases of catchment disturbance and increased runoff, and the resultant deposition of lacustrine minerogenic inwash layers which include concentrations of magnetite grains. The identification of such concentrations of magnetite grains has been primarily derived from susceptibility measurements. For example Dearing et al. (1981) and Bjorck et al. (1982) found that the magnetic susceptibility of lake sediments was enhanced when coarse silt and fine sand sized particles were washed into the lakes they were investigating. Analysis revealed that these particles of this size-range contained a high concentration of natural magnetite crystals. Dearing and Flower (1982) also associated land-use changes around Lough Neagh with variations in magnetic susceptibility properties of the lake sediments. They considered that the land-use changes increased peak flow and discharge in the feeder streams, which led to an increase in the erosion of coarser particles and their deposition in the Lough. These particles were of a size in which natural magnetic mineral crystals were found to be concentrated, thereby enhancing the magnetic susceptibility of the lake sediments accumulating at that time.

The association between magnetic susceptibility and magnetite grains in minerogenic inwash layers which has been established by these workers is supported by the studies of others

(Puranen, 1977; Currie and Bornhold, 1983), who found that magnetic susceptibility of natural materials is mainly dependent on their magnetite content. Oldfield and Robinson (1985) in a review of evidence from both marine and lake environments, also concluded that INRM is strongly dependent on changes in magnetic mineral concentrations and grain size. As the magnetite content of a lake sediment sample is also the most important contributor to its Intensity of Natural Magnetism, measurement of INRM can therefore be used as a surrogate for magnetic susceptibility when analysing lake sediments with allogenic minerogenic inwash layers.

7.5 Results of Core Sediment Analyses

7.5.1 Particle Size

The results of the particle size analysis are presented in Fig. 7.4. The figure shows the predominance of fine silt and clay sized material in the lake sediments for all but the basal three samples at 209.5cm, 205.5cm and 201.5cm. In these latter samples coarse silt reaches maximum values for the whole core of 14.2% - 17.7%, and medium silt accounts for an additional 42.5 - 55.6%. Fine silt and clay are reduced to minimal values of 22.9% - 29.2% and 3.8% - 14.1% respectively.

Although there is considerable variability in the percentages of each particle size class throughout the core, the pattern of variation in percentage of clay can be divided into four sections. The basal three samples form the first section, with the very low clay values described above. The second section is the longest, extending from 189.5cm - 91.5cm, wherein the percentage clay reaches a maximum for the core of 46.9%. The mean percentage of clay in this section is 36%, with a Standard Deviation (SD)of 6.35 and a coefficient of variation (CV) of 17.6%. The third section, extending between 86.5cm and 21.0cm, shows the mean clay percentage falling to 25.3%, with a SD of 5.30 and a CV of 21.0%. The fourth section is comprised of the two top samples, in which percentage clay increases to 41.5% - 43.7%.

Gormire Core Particle Size Data

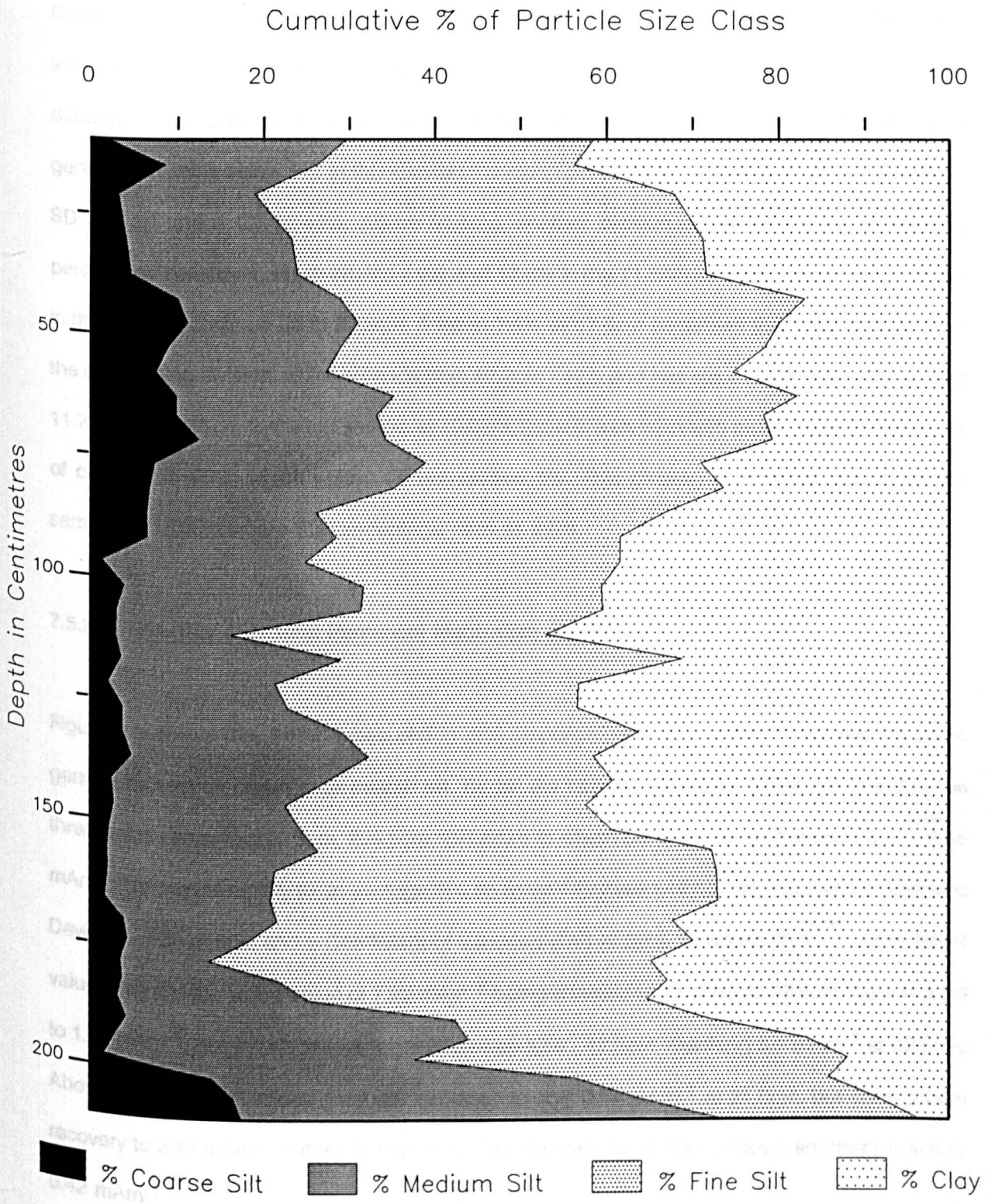


Figure 7.4

The pattern for the percentage of coarse silt is the inverse of that for percentage clay, and it allows the core to be divided into smaller divisions than is possible with the clay percentage. Coarse silt is plotted separately in Figure 7.5. The first division is that comprised of the basal three samples and from which maximum coarse silt percentages are described above. In the second division, which extends from 197.5cm - 91.5cm, the percentage of coarse silt in the core generally remains below 5%. In this division the mean percentage of coarse silt is 3.23% with an SD of 1.29 and a CV of 40%. Above 91.5cm, another division is defined by the increase in percentage coarse silt, which attains a value of 12.5% in the 71.5cm sample. These higher values in this division continue up to 62.5cm. A fall to 7.5% at 57.5cm separates this latter division from the succeeding division, which extends from 52.2cm - 42.5 and has values of coarse silt reaching 11.2%. From 37.5cm to the top sample at 10.0cm, there is a division with much lower percentages of coarse silt within which values do not exceed 5%. This division is however divided by the sample at 15.0cm where the percentage rises to 8.6%.

7.5.2 Intensity of Natural Remanent Magnetism (INRM)

Figure 7.5 shows that INRM, measured in milli-Amperes per metre (mAm^{-1}), follows the same general pattern as percentage coarse silt. By far the highest values for INRM are found in the three basal samples (209.5cm, 205.5cm, 201.5cm) in which readings range between 8.27 and 9.36 mAm^{-1}. Values fall rapidly to an average of 0.65 mAm^{-1} between 197.5 and 91.5cm, with a Standard Deviation (SD) of 0.25 and a Coefficient of Variation (CV) of 39%. Between 86.5 and 71.5cm, INRM values rise rapidly, with a value of 7.92 mAm^{-1} being attained at 71.5cm. At 57.5cm there is a fall to 1.88 mAm^{-1}, but values recover again between 52.5 - 42.5cm, reaching 5.1 mAm^{-1} at 42.5cm. Above 42.5cm, INRM values gradually decrease to only 0.54 mAm^{-1} at 21.0cm, but show a brief recovery to 2.74 mAm^{-1} in the 15cm sample. The top sample, at 10cm, shows another decline to 0.42 mAm^{-1}.

7.5.3 Organic Carbon

Gormire Core Sediment Properties

Organic Carbon, Coarse Silt and Intensity of NRM (INRM)

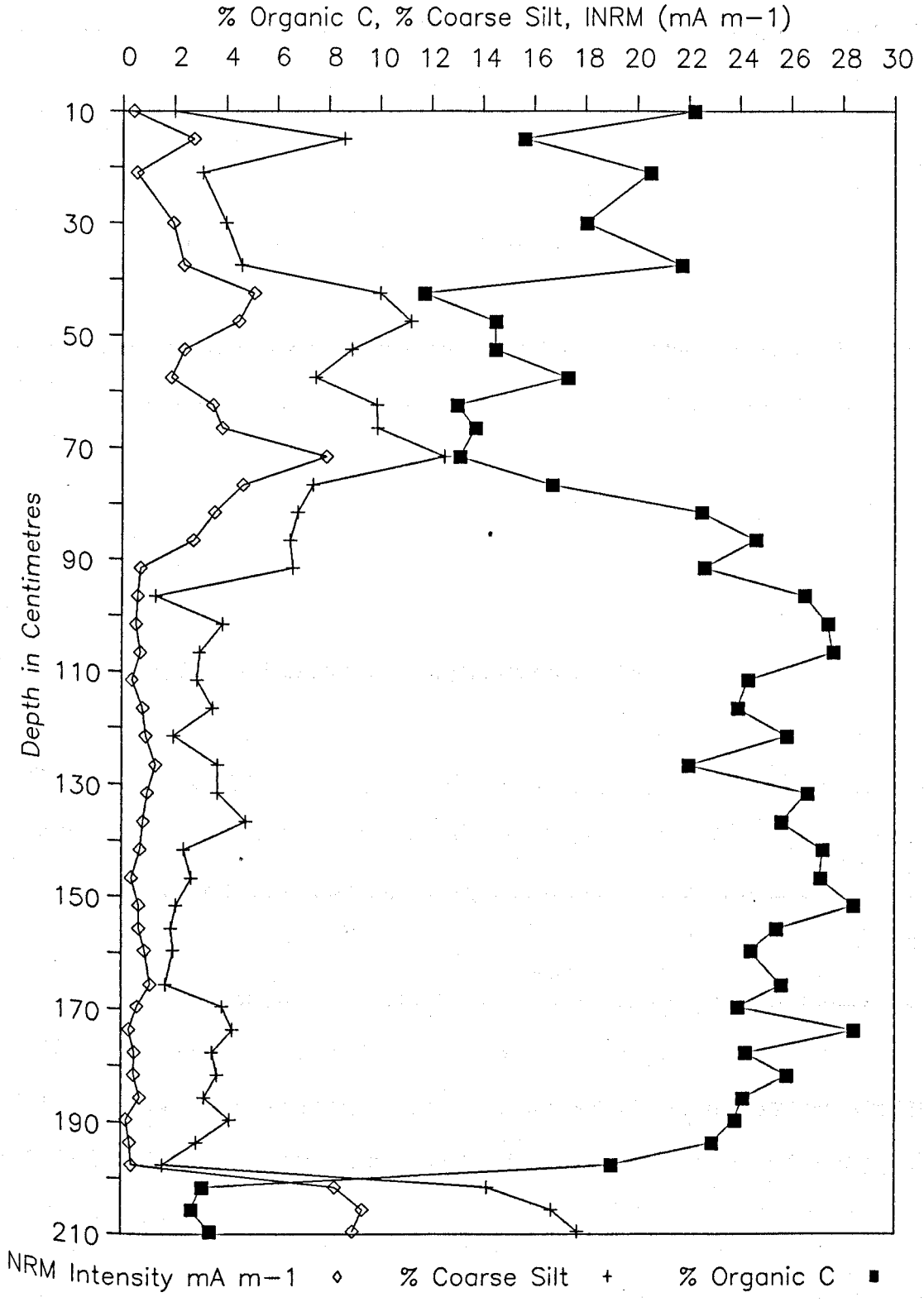


Figure 7.5

The percentage of organic carbon (% O.C.) in the core samples is presented in Figure 7.5. The basal three samples show the lowest % O.C. values for the whole core with % O.C. ranging between 2.7% and 3.4%.

Between 197.5 and 96.5cm the samples show the highest consistent values of % O.C. for the whole core. The mean value within this zone is 25.2%, the SD is 2.15 and the coefficient of variation is 8.55%. At 86.5cm % O.C. starts to decline and values decrease down to only 13.0% in the 62.5cm sample. There is a small recovery to 17.3 % O.C. at 57.5cm but lower values again occur between 52.5 and 42.5cm, when % O.C. fluctuates between 11.7% and 14.5%.

There is a slightly lengthier period of recovery of % O.C. values between 37.5 and 21.0cm when they reach 21.7%. This recovery is interrupted at 15cm by a slight reduction to 15.6%, and above which the 10cm sample shows another recovery to 22.2%.

7.5.4 Geochemistry

a. *Potassium, Magnesium and Sodium (Erosion Indicators)*

Peak values for K (1.34 - 1.47 mg/g), Mg (6.79 - 7.96 mg/g) and Na (4.77 - 4.92 mg/g) are reached in the basal three samples (209.5 - 201.5cm) of the core (see Fig. 7.6). Above 201.5cm, concentrations for these elements drop very rapidly to their minimal values.

Between 197.5 - 96.5cm, K fluctuates between 0.06 and 0.50 mg/g with a mean of 0.33 mg/g, a SD of 0.12, and a CV of 36.4%. Na and Mg are present in slightly higher concentrations, and with lower variability. Na values range between 0.59 and 0.98 mg/g, with a mean of 0.74 mg/g, a SD of 0.11 and a CV of 14.9%; Mg ranges between 0.79 and 0.92 mg/g, with a mean of 0.85 mg/g and SD of 0.4, and a CV of 4.6%.

Gormire Core K, Na and Mg Values

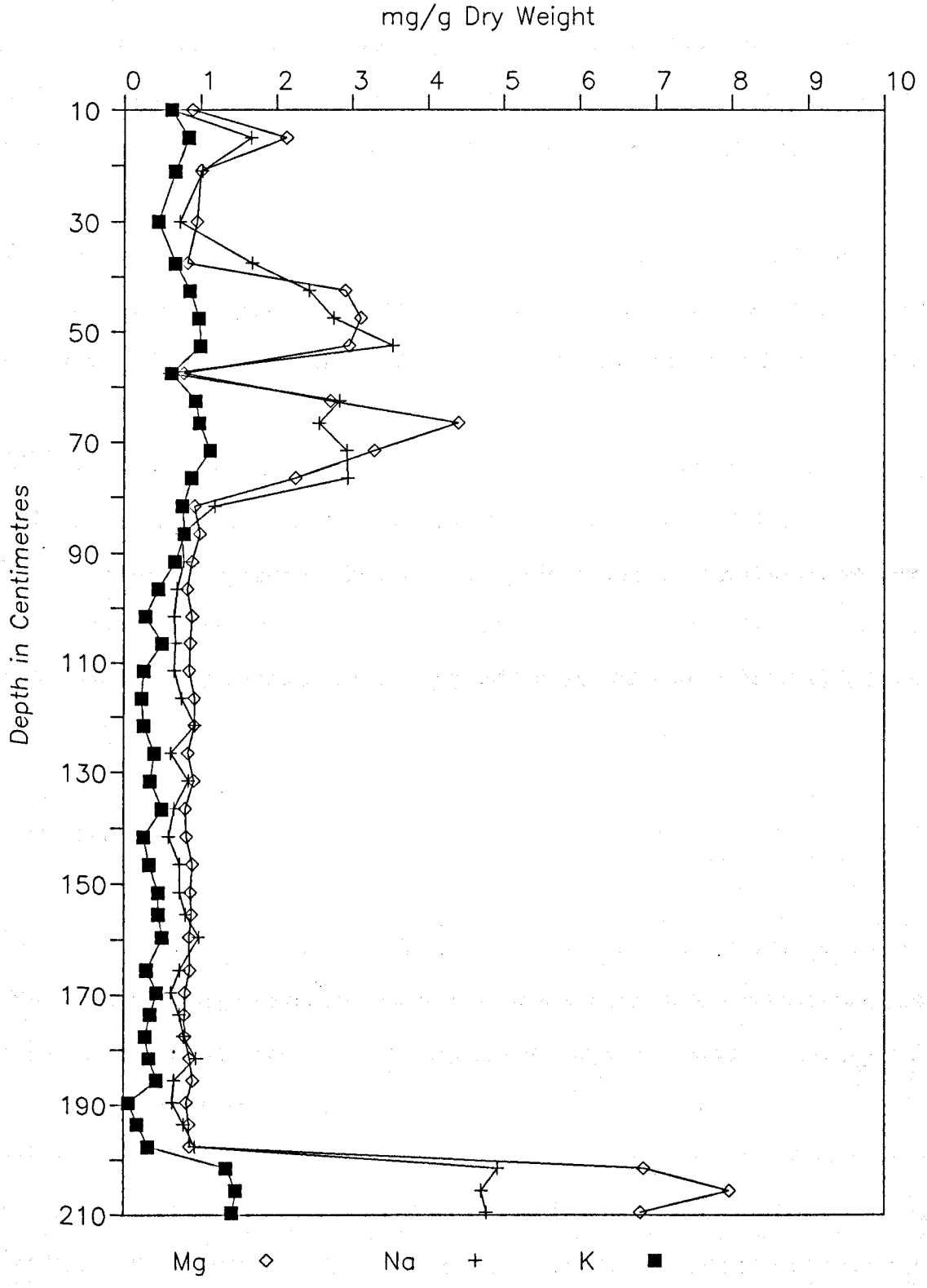


Figure 7.6

K concentrations start to increase at 91.5cm, while Mg and Na increase above 86.5cm. By 76.5cm Mg and Na have increased dramatically, with values of 2.25 mg/g and 2.94 mg/g respectively. Particularly high values for K, Mg and Na are sustained in a zone between 76.5 and 62.5cm. K attains a maximum of 1.13 mg/g, while Mg and Na rise to much higher maxima of 4.41 mg/g and 2.94 mg/g respectively. This zone ends abruptly at 57.5cm, at which point K, Mg and Na revert to close to minimal levels (K 0.62 mg/g; Mg 0.78 mg/g; Na 0.59 mg/g).

The depression in values at 57.5cm is shortlived however as the next sample at 52.5cm shows K, Mg and Na all increasing to high concentrations again. Between 52.5cm and 42.5cm concentrations remain high, with K values reaching 1.0 mg/g, Mg reaching 3.11 mg/g and Na reaching 3.53.

A longer zone of lower values then occurs from 37.5cm up to the topmost sample at 10cm. K, Mg and Na drop to 0.62 mg/g, 0.83 mg/g and 0.61 mg/g respectively. Within this zone there is however at 15cm a small increase in levels of K, Mg and Na, but with much lower levels than are found in the other three zones of enhancement further down the core. Figure 7.6 shows this small increase to give values of 0.84 mg/g, 2.13 mg/g and 1.66 mg/g for K, Mg and Na respectively.

b. Calcium

Ca concentrations, shown in Figure 7.7, throughout the length of the core are more than one order of magnitude higher than the concentrations of K, Mg and Na. A comparison of Figure 7.7 with Figure 7.6 reveals an inverse relationship between Ca values and values of K, Mg and Na, except in the three basal samples.

Figure 7.7 shows high Ca values of 34.35 mg/m - 36.17 mg/g in the three basal samples. At 197.5cm the Ca concentrations fall slightly, and between this level and 91.5cm Ca has a mean value of 27.8 mg/m, a SD of 20.98 and CV of 7.5%. Between 86.5cm and 62.5cm however there is a major reduction in Ca concentrations, with a value of only 16.0 mg/g occurring at 71.5cm. The

Gormire Core Ca Levels

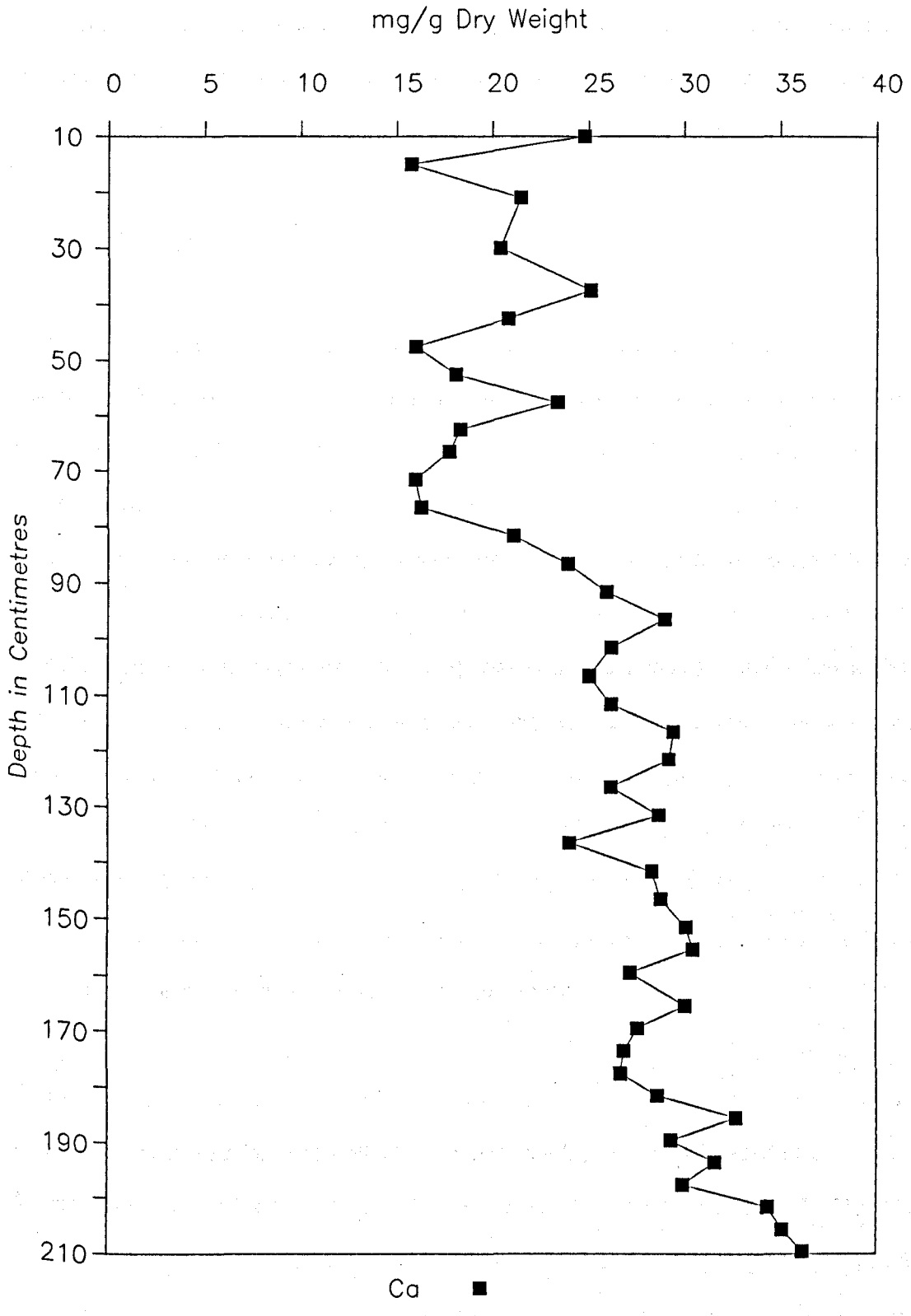


Figure 7.7

57.5cm sample shows a brief recovery of Ca values to 23.4 mg/g, but they drop once again between 52.5 and 42.5cm. Within this latter zone, Ca values fall to 16.0 mg/g.

The top six samples from the core (37.5 - 10cm) show higher Ca values which reach 25.1 mg/g. As was observed with the values for K, Mg and Na however, there is a deviation from the general trend for these six samples at 15cm, where Ca shows an abrupt drop to 15.75 mg/g.

7.6 Discussion

The data from the three basal samples represent accumulation of material in the lake basin before the opening of the Holocene at 10000BP. Maximal values for coarse silt, the erosion indicator elements K, Mg and Na, and the magnetic parameter NIRM and Ca all indicate that the source for the material filling the lake at this time was derived from catchment slopes which had little vegetation cover and little weathering of the superficial deposits. As minerals containing Ca are particularly susceptible to weathering, the maximum Ca values for the core in the basal samples suggest that slope erosion during the late glacial was removing drift material from considerable depths which had undergone virtually no weathering. The extremely low organic carbon values indicate that any autochthonous production of organic material within the lake at this time was totally overwhelmed by the accumulation of allocthonous minerogenic material from slope erosion. The average concentrations of K (1.41 mg/g), Mg (7.16 mg/g), and Na (4.80 mg/g) in the basal late glacial sediments are X4, X8 and X6.5, respectively, the maximum concentrations of these elements in the overlying Holocene organic lake muds.

Analyses of pre-Holocene lake sediments in the British Isles invariably show results similar to these. In Lake Ennerdale, Mackereth (1966) found that Mg concentrations of 17.0 mg/g in the late glacial clays were X2 the concentration in the overlying Holocene organic muds. The late glacial clays in Blea Tarn (English Lake District) which were analysed by Pennington (1969) had <1.0% organic carbon, while Na values of 19.0 - 24.9 mg/g were up to X4 as great as in the overlying Holocene organic muds. Late glacial clays from Blelham Tarn, also in the Lake District, gave K

levels of 23 mg/g, which were X2 the K concentration in the succeeding early Holocene organic muds (Pennington, 1977). Thompson and Edwards (1982) in their study of Lough Catherine in Northern Ireland found organic carbon percentages of 1.9% - 2.1% in samples from the basal late glacial clays, and much higher intensities of Natural Remanent Magnetism (INRM) than in the overlying, more organic Holocene sediments, with the exception of one highly minerogenic inwash layer.

The Gormire sediments which accumulated between approximately 9700 BP and 2500 BP provide a marked contrast to the preceding late glacial material. Minimum values for the erosion indicators occur during this period, together with minimal values for INRM and the percentage of coarse silt in the sediments; little variation in the values of these parameters occurs in this section of the core. Conversely organic carbon content and clay size material attain their highest values. Ca values remain at high levels, although reduced slightly from the basal samples. Pennington (1969, 1977), Thompson and Edwards (1982) and Hiron and Thompson (1986) all reported such a combination of results from their analysis of lake sediments which dated from c.9700bp - c.5000bp. These data suggest that very little soil erosion occurred in the Gormire catchment during the early to mid-Holocene period.

Climatic amelioration during the Boreal and Atlantic periods resulted in the rapid spreading of deciduous trees and the eventual establishment of the Quercetum Mixtum during the postglacial climatic optimum of the Atlantic period. Under these conditions, slopes in the Gormire catchment must have become stabilised as soils developed on them, and erosion down through to the drift deposits underlying the soils ceased. Absence of erosion is indicated by the reduction in coarse silt and values for the erosion indicators in the Gormire sediments formed at this time. The increase in vegetation cover and soil depth would have reduced the number and extent of exposures of drift material available for erosion. Possibly a more significant constraint on soil erosion was however a reduction in the frequency and competence of overland flow events transporting coarse silt into the lake. As Gormire has no stream inflow, and there is no evidence of a past stream course, overland flow represents the only surface water flow into the lake during

the Holocene. The development of soils with mor or moder surface humus horizons during the early and mid-Holocene would have provided a highly absorbant surface which could support rapid infiltration rates, and a consequently much reduced incidence of overland flow and the associated transport of coarse silt into the lake.

Reduction of overland flow to very low levels, or its complete absence, under similar temperate woodland conditions to those existing in the Gormire catchment at this time has been well documented by studies in modern catchments. Imeson and Jungerius (1974) working in the experimental Birbaach catchment in the Ardennes (Luxembourg) found no evidence for Hortonian overland flow occurring even under extreme rainfall events on >11° slopes which supported oak and beech woodland. Similar to the brown earths in much of the Gormire catchment, the soil covering all but the floodplain in the Birbaach catchment was an Ochric Cambisol (Acid Brown Forest Soil), developed on Weichselian solifluction deposits derived from sandy Devonian schists (Imeson and Jungerius, 1974). Bridges and Harding (1971) and Imeson (1971) working in the same catchment found that no surface soil erosion occurred under woodland vegetation with a litter cover or understorey vegetation. Evidence that increased organic matter content in the A horizon increased its aggregate stability was also presented by Imeson and Jungerius (1974) for the Birbaach catchment.

Such increasing slope stability during this period would probably have resulted in catchment processes being predominated by chemical weathering and leaching (Oldfield, 1977), with Ca being the only cation investigated in this study actually undergoing an increasing concentration in the sediments at this time. The minimal flux to the lake sediments of unweathered material from the catchment sub-soil also resulted in lake sediments displaying high values for organic carbon and clay content at this time. The concentration of Ca in lake sediments has been shown to be closely linked with organic matter, (and therefore also with organic carbon), by a number of workers. Koljonen and Carlson (1975) note the strong direct relationship between Ca and organic matter in their study of four lakes in southwest Finland, as do Liken and Davis (1975), in their study of Mirror Lake, New Hampshire, which formed part of the Hubbard Brook Ecosystem Study

(Likens and Bormann 1972, 1974). Guppy and Happey-Wood (1978) also identified a pattern of increased Ca and organic carbon concentrations in a core from Llyn Padarn in North Wales which extended back to 7,000 bp, as did Brugam (1978) from a core in Linsley Pond, Connecticut, which dated back to 1,010 +/- 75 bp. Ca has also been directly associated with bio-accumulation processes in streams in southeast Ontario (Ongley et al.,1981). Ca has a strong association with organic matter because it is a major nutrient and is absorbed by humic and fulvic acids (Engstrom and Wright, 1984). The Gormire lake waters during this early to mid-Holocene period would have received large influxes of these organic acids in the form of leachate from throughflow through the well developed organic A-horizons in the catchment soils. Ca in solution in the lake waters, also derived from leaching of the catchment soils, neutralizes the slightly polymerized water-soluble organic acids and precipitates them in the form of highly polymerized humus, or dy, which accumulates in the lake sediments (Koljonen and Carlson, 1975). Ca is more soluble in warmer conditions, and the elevated temperatures during the climatic optimum of the Atlantic period would have permitted it to be leached at a greater rate from the catchment soils. Under such climatic conditions, organic productivity and decomposition would also have operated at increased rates. The combined result would have been a greater concentration of Ca in the larger accumulations of organic detritus and precipitated organic matter that formed at this time.

Although values for Ca have thus been shown to remain high in the Gormire sediments between c.9700BP - c.2500BP, during which period the most organic sediments accumulated, it is notable that the peak Ca values were reached in the late glacial clays. It was suggested above that this may reflect particularly intense slope erosion conditions during the late glacial. This degree of erosion transported to the lake material from deep within the drift cover on the catchment slopes, from which weathering had not leached out the Ca. This is a similar situation to that reported by Pennington (1969) from Angle Tarn in the Lake District, where influx of "unweathered soil", rich in Ca as well as K and Na can be distinguished from the influx of "weathered soil", in which Ca values are low while K and Na values are high, during a period of Neolithic activity in the Tarn's catchment.

The clay content of the Gormire sediments between c.9700BP and c.2500BP is not only a relative effect of the reduction of coarser material deposited at this time, but also because clay deposition was actively increased during this period. This process would have occurred as clay minerals were flocculated in the lake waters by the high organic acid content of the waters (Pennington, 1969), and eventually settled out of suspension onto the lake bed.

The early to mid-Holocene organic muds in Lake Gormire are therefore likely to have accumulated under climatic and vegetation conditions which many lakes studies in Europe and North America have shown to be characteristic for this stage of the postglacial. The organic rich and K, Mg and Na deficient nature of the lake sediment which accumulated during this period is therefore typical of the generally stable landscape in the early to mid-Holocene period for which other lake studies in the British Isles (Mackereth, 1966; Pennington 1969, 1977; Pennington et al. 1972, Hirons and Thompson 1986) have provided evidence. From 9700 BP - 2500BP the geochemical and sedimentological record in the Gormire lake sediments thus suggest that the catchment slopes remained undisturbed and stable.

The pollen evidence of Blackham et al. (1981), and that carried out for this study, indicate that the Gormire catchment experienced vegetation change typical of that generally reported at the Elm Decline. Atherden (1976) recorded the Elm Decline from the Fen Bogs site on the central watershed of the North York Moors, and radiocarbon assay dated the Decline to 4720 +/- 90 bp. The nature of the Gormire sediments at the Elm Decline suggest that this period of limited woodland clearance was not accompanied by slope destabilisation in the Gormire catchment. This could be due to elm not having been present in large numbers in the Gormire catchment before the decline. If man was the primary agent in the Elm Decline, the effects of felling in the catchment would then have been relatively small. It seems unlikely however that elm would have grown any less prolifically in the Gormire catchment than in the surrounding landscape, and the pollen data presented earlier, showing Ulmus at 10% TDLP indicate that it was widely distributed in the region immediately before the Elm Decline. Whatever the cause for the Elm Decline,

whether climatic or anthropogenic, or a combination of both, the evidence from the Gormire sediments suggests that it did not cause a major disturbance of the catchment soils.

As a contrast to the Gormire situation, Mackereth (1966), in the English Lake District, identified increased Na and K concentrations just after 5000bp in lake sediments, which he attributed to increased catchment erosion. He considered that the increase in catchment erosion could have resulted from a diminishing tree cover in the catchment area at the Elm Decline, as suggested by the local pollen evidence, or by a general deterioration of soil and climatic conditions which may have caused greater and therefore more erosive runoff. Pennington (1969) reported that all the lakes she examined in the English Lake District which provided pollen evidence of Neolithic exploitation of the forest at the Elm Decline also had a significant decline in the levels of organic carbon at that time. In two lake catchments, Angle Tarn and Blea Tarn, there was also considerable evidence of Neolithic axe factories which exploited the local volcanic outcrops. The geochemical record in these lakes' sediments demonstrates progressive erosion down through the catchment soil horizons. Erosion first removed material from the more organic A-horizons, and the sediment influx to the lake shows high values for organic carbon and Ca, the latter associated with the organic matter. This was followed by erosion of the more weathered, mineral (B) soil horizons, and the resultant lake sediment had higher erosion indicator (K and Na) values and reduced Ca values. Finally erosion reached the unweathered drift parent material, which contained minerals still containing Ca as well as K and Na. Pennington (1969) only found this distinctive geochemical signature in the sediments of those lakes which had pollen evidence of the Elm Decline; lakes with such pollen evidence coincided with the distribution of archeaological evidence for the presence of Neolithic populations. She thus concluded that the activities of Neolithic man were instrumental in the extensive lake catchment soil erosion at that time, and for which the lake sediments provide clear evidence.

At another Lake District site, Blelham Tarn, Pennington (1977) found no evidence for the Elm Decline in the local pollen record, but she still identified an increase in K values and higher minerogenic influx to the lake at 5000bp. There was also no archaeological evidence for Neolithic

man in the catchment. Pennington and Lishman's (1971) earlier work on iodine levels in Lake District and Northern Scottish lake sediments had indicated increased rainfall at the time of the Elm Decline. This would have led to greater runoff and stream channel erosion, and Pennington (1977) therefore concluded that the increased K and mineral matter in the Blelham Tarn core at c.5000bp was a result of change to a wetter climate in the west of Britain.

The Gormire geochemical and sedimentological record provides no evidence of Bronze Age disturbances in the catchment, although there is considerable pollen and archaeological evidence for Bronze Age anthropogenic activity in the North York Moors. Spratt (pers. comm) for example notes the presence of Bronze Age cairns and earthworks on the margins of the Jugger Howe Beck catchment (see Figure 2.6). Simmons (1969), Jones (1971, 1976 & 1978) and Simmons and Cundill (1974a & 1974b) all report that sites throughout the North York Moors show a marked decline in tree pollen, although with little change in the species composition of the tree pollen. This decline was accompanied by a consistent increase in heathland vegetation, which was marked in the pollen evidence from higher altitude sites, and also by increases in ruderal taxa. Atherden (1976) found no evidence from the Fen Bogs site in the central watershed of the North York Moors of cereal cultivation during the middle Bronze Age, and Dimbleby (1962) similarly found no cereal pollen when examining buried soils beneath middle Bronze Age barrows at Burton Howes, also located on the central watershed. Furthermore, artifacts associated with arable cultivation such as grain storage pits, querns, and sickles were also absent. In a complementary investigation of pollen in buried brown soils beneath middle Bronze Age barrows located at the eastern end of the lower altitude Tabular Hills however, Dimbleby (1962) did find evidence of cereal pollen and arable weeds, suggesting that the more favourable climatic and soils conditions on parts of the Tabular Hills did support arable agriculture during this period.

There is a lack of evidence in Gormire's sedimentological and geochemical record for middle Bronze Age anthropogenic activity in the catchment. It may be that there was only a scattered pattern of middle Bronze Age agriculture on the Tabular Hills, and the Gormire catchment was not itself cleared for cultivation. A contributory factor in this may have been the difficult access to

the Gormire catchment from the scarp top for a population which, as is suggested by the distribution of Bronze Age cairns, had a definite predilection for plateau and hilltop locations in the North York Moors.

The pollen evidence from the Gormire core is unfortunately not of sufficient resolution to aid the interpretation of these findings. It is notable however that other lake studies have found that at some cultural levels, even where there is pollen evidence of widespread anthropogenic activity including arable cultivation, such activity does not necessarily result in catchment soil erosion of sufficient intensity to cause minerogenic inwash to the lake sediments. For example Hirons and Thompson (1986) in their study of Killymaddy Lough, Northern Ireland found that concentrations of K did not increase in the lake sediments through the Neolithic, Bronze Age and Iron Age periods, despite there being pollen evidence for woodland clearance and agriculture at those times. The representative situation, in an inter-drumlin hollow, suggests that the vegetation changes and anthropogenic intervention indicated by the pollen analysis, should have been experienced equally in the Killymaddy Lough catchment and in the surrounding area. It appears that these changes were not of sufficient intensity to cause erosion of sub-soils and the consequent transport of unweathered material into the Lough.

Hirons and Thompson (1986) did however note that the incidence of deteriorated pollen grains increased markedly during these clearance phases. Peck (1973) suggests that periods of clearance cause a change in the relative importance of air and waterborne pathways of pollen into lakes. The clearance could cause local changes to catchment hydrology so that larger amounts of pollen could be transported via increased overland flow and higher peak stream discharges to the lakes. Simultaneously the amount of pollen recruitment to lakes from airborne pollen would be reduced by the removal of trees during the clearance phase. As a result of these changes, a higher proportion of the pollen being deposited in the lake would be preferentially waterborne types; pollen types concentrated by differential destruction in the soils; and pollen grains corroded by exposure to non-preserving environments (Hirons and Thompson, 1986). Also all the pollen transported by water would be much more likely to sustain damage during

transportation to the lake (Pennington 1979; Hirons 1983). Soil erosion restricted to the A-horizon would result in the deposition of both large quantities of soil pollen and of minerogenic material from which weathering would have removed many cations, such as K. These factors led Hirons and Thompson (1986) to conclude that in the Killymaddy Lough catchment soil erosion during Neolithic, Bronze Age and Iron Age times was no more severe than the partial removal of A-horizon material.

The Gormire sediments which accumulated between approximately 2500BP and 900BP (late Bronze Age - early Medieval) show marked changes to those which formed between 9700BP and 2500BP. The erosion indicators K, Mg and Na, and amount of coarse silt and INRM values all increase rapidly after 2500BP. Figures 7.5 and 7.6 shows that most of these parameters peak at 2000BP. During this period of accumulation, concentrations of K increased by over X3 compared to the average K values between c.9500BP and 2500BP. The relative increase in Na concentrations was also of the order of X3, while Mg values increased up to X6. By contrast, the values for organic carbon, amount of clay and Ca show a rapid decline. This pattern of change has been considered an indicator of influx of minerogenic material to the lake sediments as a result of erosion of catchment soils, and is typical of the observations made by workers in the English Lake District (Mackereth 1966; Pennington 1969, 1977,; Pennington et al. 1976), Scotland (Pennington et al. 1972, 1981), North Wales (Elner and Happey-Wood 1980; Guppy and Happey-Wood 1978) and North America (Brugam 1978; Likens and Davis 1975).

Most of the British studies reveal that lake catchment erosion gradually increased from middle Bronze Age times, c. 3500bp (3850BP). For example, Guppy and Happey-Wood (1978) note that K and Na concentrations in their core from Llyn Padarn in North Wales show a gradual increase after 3500bp, this geochemical evidence coinciding with a decrease in arboreal pollen in the core. These data were suggested to indicate some woodland clearance occurring in or near the lake catchment. At 3090 +/- 140 bp (3380BP), Pennington (1969) reported greatly accelerated erosion into Seathwaite Tarn in the Lake District. The lake sediments from this time showed a marked fall in organic carbon content. The pollen record showed evidence of clearances, and

there was archaeological evidence of Bronze Age settlement in the catchment. The clearances were considered to be for pastoral farming however, as there was no record of cereal pollen. This latter situation is therefore similar to that described by Atherden (1976) and Dimbleby (1962) for the Bronze Age clearances for pastoralism on the central Moors of the North York Moors.

In the Gormire catchment, the degree of woodland clearance and soil erosion, and the period over which these conditions were maintained, appears to be amongst the most extensive recorded from lake sediments deposited during early Iron Age through to late Romano-British times. The erosion indicators, K, Mg and Na start to increase in value at approximately 2500BP, but the most severe effects occur at approximately 2000BP. Values of K, Mg and Na are increased by X3.2, X5, and X4 respectively, organic carbon content is halved, and inputs of coarse silt peak at 12.5%. It is notable that values of Ca do not increase, as they did in the core samples from the late glacial clays, but instead undergo a sharp reduction. This probably reflects soil erosion of soil B and C horizons from which all the Ca had been removed by approximately 7000 years of leaching, since the onset of stable Holocene slope conditions permitted development of soils. As formation of the soils proceeded over this period, profiles gradually deepened, and unweathered drift in which Ca levels remained higher only existed at much greater depths. By 2000BP therefore erosion of Ca rich material from the catchment slopes would have required a complete stripping of the deep soils that had developed during the Holocene. The Gormire evidence indicates that such a degree of soil erosion was not reached even during the severe catchment disturbances of the Iron Age and Romano-British periods.

Both Blackham et al.'s (1981) pollen analysis and the palynology carried out for this study provide evidence for extensive woodland clearance at this time, with tree pollen figures of only 10% TDLP and 13% TTP respectively being recorded. This indicates very few trees remaining in the vicinity of Gormire at that time. Cereal pollen is also first recorded in Blackham et al.'s (1981) core at this time. Similar pollen data are available from the Fen Bogs record from the central watershed of the North York Moors, which shows the most marked woodland clearance of the postglacial occurred at approximately 2000BP, when tree pollen fell to 5% of total dry land pollen. Atherden (1976)

provides a radiocarbon assay from just below this clearance level of 2280 +/- 120 bp (2365BP). Such a degree of clearance is also indicated at this time from other sites on the central watershed, notably Simon Howe Moss and May Moss, where tree pollen percentages fell to 2% and 10% respectively (Atherden 1976).

Evidence of the Iron Age and Romano-British period of woodland clearance is also found in several other studies in Britain. In the Llyn Padarn sediments, Elner and Happey-Wood (1980) identified the start of rapid deforestation at 2500bp (2705BP). Organic carbon also showed a marked decrease from 10% to 5%, while the minerogenic fraction of the sediments increased. Additionally, Na and K concentrations from Llyn Padarn showed a X3 increase. In the Lake District, lake sediments from Blelham Tarn dated to 2295 bp (standard errors not quoted) show a X2 increase in K, this coinciding with organic carbon values falling from 18% to 9% (Pennington 1977).

There is considerable evidence for the presence of man in the vicinity of the Gormire catchment during the Iron Age and Romano-British period. On the scarp top above Lake Gormire are numerous Iron Age linear earthworks. The Iron Age had a feudal society in which local communities were established in settlements, protected by such earthworks, commonly located in hilltop situations for defensive purposes. Whilst no excavations have been carried out on the earthworks above Gormire, very similar features on Levisham Moor, 35km east of Gormire in the Tabular Hills have yielded late Iron Age pottery (Hayes, 1983). Casten Dyke (South), located only 1.5km southeast of Gormire above Roulston Scar, is a cross-ridge dyke which has a rampart 7 metres wide and 3.5 metres high, and a 5 metre wide ditch. The dyke encloses an area of 50 acres and is one of the largest and strongest of the northeast Yorkshire promontory forts. Only 1.0 km southeast of Gormire, Casten Dyke (North) starts at the top of Sutton Bank. This earthwork is 3.5 metres wide, 1.75 metres high and has a large tumulus at the Sutton Bank end. Casten Dyke (North) intersects another linear earthwork 250 metres east of Sutton Bank. This earthwork is Cleave Dyke, the longest linear earthwork in the area. It has been traced for approximately 9.0 km northwards along the western scarp of the North York Moors, and is 3.5 metres wide and

1.25 metres high. These earthworks indicate that the area around Gormire was an important one for Iron Age settlement.

Later in the Iron Age, the Roman occupation of this area of Yorkshire included the development of a sizeable Roman town near Malton on the southern edge of the Vale of Pickering, and numerous smaller settlements along the southern margin of the Tabular Hills also developed. Many villas were established which were run on a manorial basis. The villa formed a nucleus for native British farmsteads, and an extensive area around the villa would have been farmed. Significantly, there are traces of a Roman villa at Hood Grange, only 800 metres south of Gormire at the foot of Sutton Bank. It is likely that the establishment of the Hood Grange villa had a major impact on the Gormire catchment, with both woodland clearance and arable cultivation taking place. The most suitable area within the Gormire catchment for arable cultivation is the flatter land between the lake and the base of Whitestone Cliff, the southern and western margins of the lake being too steeply sloping for cultivation. Before the mid-18th Century cliff fall from Whitestone Cliff, the area between the scarp and the lake would have been much more extensive, probably extending close to the base of the scarp. The area however has heavy clay soils of the Long Load series, which until the advent of the heavy Belgic or Celtic iron plough in Roman times (Evans 1975) would have been impossible to till. It is thus possible that arable cultivation in the Gormire catchment may have first taken place during Roman times. The period of woodland clearance and severe soil erosion revealed in the geochemical, sedimentological and palynological evidence from the Gormire sediments dating from this period can thus be attributed with some confidence to the impact of man.

This period of catchment disturbance was interrupted at c.1800BP - 1700BP by a change to much more stable catchment conditions. This change is indicated in the analyses on the core sample from 57.5cm. The organic carbon value increases to 17.3%, indicating a reduction in the input of minerogenic matter to the lake, and the amount of coarse silt is reduced to 7.5%. The rise in organic matter content of the sediments is the probable cause for the recovery of Ca values to 23.4 mg/g. The erosion indicators K, Mg and Na and NIRM all show a marked reduction with

values of 0.62 mg/g, 0.78 mg/g, 0.59 mg/g and 1.88 mAm^{-1}. This pattern of change in the Gormire lake sediments during the Dark Ages is also reported from other lake studies in Britain. For example, data from Blelham Tarn (Pennington, 1977) in the English Lake District shows values for K falling from approximately 25 mg/g between 2295bp and 2120bp (2375BP - 2135BP) to only 16 mg/g at c.700bp (635BP). Over this same period organic carbon increases from only 9% to 17%.

Pollen analysis carried out for this study and by Blackham et al. (1981) on the Gormire sediments indicates a period of woodland recovery occurring between 1700BP and 1200BP, with records of tree pollen reaching 27% and 35% respectively. Blackham et al.'s (1981) data show the regeneration to have been quite successful, involving primary woodland species such as Quercus and Ulmus as well as the heliophytic species such as Betula and Fraxinus. The Fen Bogs pollen record (Atherden 1976) provides evidence of a phase of limited woodland regeneration in the central Moors, delimited by radiocarbon assays of 1530 +/- 130 bp (c.1500BP) and 1060 +/- 160 bp (c.1000BP). At Fen Bogs tree pollen recovers from 5% to 20% TDLP. This suggests that greater regeneration was possible on the lower and more fertile Tabular Hills and the adjacent lowland existing around Lake Gormire than on the higher central Moors with their much poorer soils. Pennington (1965) also concludes that in the Lake District the uplands remained predominantly treeless after Romano-British clearances, as the deteriorated soil conditions prevented the Dark Ages woodland regeneration taking place in those areas. In the North York Moors region, therefore, the evidence suggests that the Dark Ages was a period of abandonment of most areas cleared previously for agriculture, and limited woodland regrowth. Increased vegetation cover and a probable cessation of tillage in the Gormire catchment markedly reduced the erosion of catchment soils into the lake. During this period therefore, the sediments which accumulated in the lake were the organic lake muds, with no apparent influx of minerogenic material from the catchment slopes.

This period of relative landscape quiescence ended at c. 1200BP. The 52.5cm sample from Gormire shows another rapid change in the sediments deposited in the lake at this time. The

change is very similar to that which occurred at 2500BP, with marked increases in K, Mg, Na and INRM and coarse clay, and reductions in organic carbon and Ca. Figures 7.6, 7.5 and 7.7 show that values for these paramaters reach similar levels to those during the Iron Age / Romano-British period, indicating another significant period of catchment disturbance, with catchment soil erosion taking place with a comparable degree of intensity. Reference to the magneto-stratigraphy suggests that this period lasted for approximately 300 years. The Gormire pollen data from Level d (see Table 7.7 above), which corresponds to this disturbance phase provides evidence for further woodland clearance at this time, with tree pollen falling to 18% TDLP. Blackham et al. (1981) also identified a phase of woodland clearance at this time with tree pollen falling to only 11% TDLP, together with records for cereal pollen.

This phase of catchment disturbance took place during Viking / early Medieval times. A number of lake studies report such clearance and catchment disturbance phenomena occurring at this time. In the Lake District, Pennington (1965) reported pollen evidence of Viking woodland clearance from Lakes Loweswater and Thirlmere and from Loughrigg Tarn. Similarly, describing the sediments from Blelham Tarn, Pennington (1977) reported a steep fall in arboreal pollen and a marked increase in deposition of K. Organic geochemistry revealed that the soil erosion mainly affected the surface organic horizons of the catchment soils, a conclusion also suggested by the increased influx of pollen. Also within a 50cm deep sediment layer spanning this disturbance phase, several radiocarbon assays provided a date of c.900bp (standard errors not quoted), indicating that there was a chaotic process of soil organic matter erosion. This probably involved soil erosion of the surface organic horizons taking place at varying times at different locations within the catchment. A probable mechanism for this is the clearance being both spatially and temporally variable within the catchment. Pennington (1977) attributed these changes in the Blelham Tarn catchment to the historically recorded settlement of the Lake District by Viking immigrants. She also notes that the Viking woodland clearances were concentrated in the Lake District valleys, as the uplands had remained treeless during the Dark Ages. Viking colonisation in northwest England occurred at about A.D.950 (1000BP), the result of later invasions than those that took place in eastern England.

In Northern Ireland Hirons and Thompson (1986) report marked increases in values for K and a major drop in organic content of sediments from Weir's Lough taking place at approximately 800 BP. Hirons and Thompson (1986) consider this to be a function of early medieval farming in the area disturbing the catchment soils. Also in Northern Ireland, sediments from Lough Catherine (Thompson and Edwards 1982) revealed a X6 increase in K values and a decrease in organic carbon values from 4.25% to 2%. These values were obtained from samples overlying a level which provided a calibrated radiocarbon date of 1130 BP.

Both the influx of Vikings and medieval farming practices have thus been considered to be likely causes of lake catchment soil erosion at c. 1000 BP and the resultant influx of minerogenic material into lake sediments. The suggested date of c.1200 BP for the start of post-Dark Ages disturbance in the Gormire catchment and its continuance until c.900 BP indicates that it may have been initiated by Viking immigrants. The Viking colonisation of northeast England, including the North York Moors region was complete by A.D. 886 (c.1070BP). There is clear evidence provided by pollen analysis from the North York Moors of a period of woodland clearance at this time. For example Atherden (1976) reports that tree pollen in the Fen Bogs pollen record from the central Moors falls to approximately 15% at a level dated to 1060 +/- 160 bp (c.1000BP). The vegetation changes in the Gormire catchment at this time were therefore similar to those occurring over the North York Moors generally. Place name evidence for Viking activity has also been shown to be widespread in the North York Moors.

The major effects of this phase of catchment clearance on the sedimentology and geochemistry of the Gormire sediments ceases at c. 900 BP. This date indicates that there appears to have been no slope disturbance in the Gormire catchment attributable to the expansion of monastic sheep farming in the North York Moors. The Cistercian order in particular desired unpopulated and isolated areas in which to establish their monastic houses, and the North York Moors fulfilled these requirements well. Beginning in the latter half of the 11th century (c.870BP) several monastic houses were established in the area surrounding Lake Gormire, the most notable of which is the Cistercian Rievaulx Abbey, 8km east of Gormire in the valley of the River Rye. In

addition, the Cistercian Byland Abbey was 6.5km to the SE and the Augustinian Newburgh Priory was 8km to the SSE of Lake Gormire. Vast tracts of the North York Moors became incorporated into monastic lands, and the Gormire catchment is thought to have been contained within the lands of Rievaulx Abbey (Waites 1967). It is possible that the Gormire catchment was unsuitable for monastic farming practices, and was consequently not affected by such activities.

In the 37.5cm sample all the parameters revert to almost pre-2500 BP levels, indicating a return of more stable catchment conditions. Organic carbon values are slightly depressed, but still show a major revival after the preceding clearance phase. These stable conditions are maintained up to the top of the core, with the exception of a brief period of minerogenic inwash to the lake which is sampled at the 15cm level. This accumulation of minerogenic material is only 2cm thick, much less than that associated with the disturbance phases at c.2000 BP and c.1000BP. The erosion indicators, INRM and percent coarse silt all increase in this sample, while Ca and percent organic carbon decline. Figure 7.6, 7.5, and 7.7 show however that the intensity of change is not as great as in the preceding two disturbance phases. Blackham et al.'s (1981) pollen record from the Gormire sediments is not of sufficient resolution to identify any vegetation changes occurring simultaneously with the inwash, nor to suggest a date for the inwash. The magneto-stratigraphy does however provide two dated points above and below the inwash layer. Figure 7.3 shows the lower magnetic feature (b) at the 20cm level to have a date of 450bp and the upper feature (a), at the 10 cm level, a date of 150 BP. It is possible that the cliff-fall of March 1755 (c.200BP) from Whitestone Cliff (Richards et al. 1986) on the eastern margin of the Gormire catchment may have resulted in this inwash layer.

The topmost sample from the Gormire core, at the 10cm level, demonstrates a rapid reversion to more stable catchment conditions after the cliff-fall. This is indicated by the erosion indicators, INRM and percent coarse silt falling back to values similar to those pre-2500 BP, and percent organic carbon and Ca recovering to values only slightly less than those found in pre-2500 BP samples. The magneto-stratigraphy dates this sample to c.150 BP, indicating that the early 19th century was a period of relative quiescence in the Gormire catchment. Although Blackham et al.

(1981) record cereal pollen up to the present day, cereal cultivation is not carried out in the Gormire catchment at present. The cereal pollen must therefore be windblown into the Gormire catchment, primarily from the arable fields in the Vale of York to the west. The continued recovery of trees up to the present day suggests instead that the catchment experienced planting of hardwoods during the late 18th and early 19th centuries, a period when there was considerable ornamental tree planting, particularly on country estates (Tuke 1800).

7.7 Conclusions

Data from the core taken from Lake Gormire have provided a continuous stratigraphic record of changes within the lake catchment since the Late Glacial. Geochemical erosion indicators provide a means of distinguishing periods of lake catchment stability and instability, whilst palaeomagnetic data provided a continuous dating record for theses phases of activity in the lake catchment.

There is evidence of three major phases of disturbance in the catchment with intervening phases of relative stability. The oldest disturbance phase, recorded in the base of the core, is related to the severe climatic conditions and sparsely vegetated catchment slopes of the Loch Lomond Stadial (11000 - 10000BP). The early and middle Holocene has been shown to have been a period of catchment stability, reflected in the deposition of organic lake muds. This long period of catchment stability was succeeded at 2500BP by the first and most severe phase of Holocene disturbance, which lasted until c.1750BP. A brief period of catchment stability then ensued from c.1750BP - 1200BP. The second major Holocene disturbance phase occurred between 1200BP - 900BP, and was followed by a period of alternating stability and instability in the catchment, which has continued to the present day.

Reference to the pollen and palaeomagnetic evidence indicates that the two major Holocene phases of instability reached their acmes at c.2000BP and 1000BP, dates which correspond with the Iron Age/Roman and Viking/early Medieval periods respectively. The third, and most recent,

minor phase of instability appears to correspond with a slope failure in A.D. 1755 on Whitestone Cliff, on the eastern margin of the Gormire catchment.

Data from the lake core therefore provide a continuous record of Holocene hydrological and sedimentological changes within the lake catchment which can form a basis for correlations with changes in the two valley sites, Dovedale and Jugger Howe Beck, under consideration in this thesis.

Chapter 8

Holocene Valley Floor Landform Development in the North York Moors : Its Environmental and Regional Significance and Context in Upland Britain

8.1 Introduction

The three study sites selected for examination in this thesis are located at the eastern edge of the Central Moors region, (Jugger Howe Beck), the Tabular Hills, on the southern part of the North York Moors, (Dovedale Griff), and the western edge of the North York Moors, (Lake Gormire). This distribution of field sites provides a regional spread within the upland region of the North York Moors. The identification of phases of synchronous behaviour between sites is therefore likely to be indicative of changes taking place on a regional scale whilst instances of site specific instability may need different interpretation. Comparison of the phases of instability and stability identified from Jugger Howe Beck, Dovedale Griff and Lake Gormire should enable correlations to be made between dated periods of erosion and stability in the continuous lacustrine record and the discontinuous valley floor alluvial records. Comparison of dated phases of stability and instability in both the lake sediments and the valley floor record with known vegetation and climate changes as well as documented evidence of anthropogenic activity should enable some assessment to be made for causes of change.

The phases of environmental change as they have been identified from the data presented in this thesis are summarised in Figure 8.1. The regional characteristics of the vegetation changes, as they are represented by the age-calibrated Fen Bogs pollen diagram are also shown on the same diagram. For the purposes of discussion all C^{14} dates have been calibrated using Clark's (1975) curve so that all dates are referable to the continuous dating record provided by the palaeomagnetic dates from the Lake Gormire core.

Phases of Holocene Landscape Change in the North York Moors

FEN BOGS (Atherden 1976)

Holocene Vegetation Change

Calendar Years BP	Vegetation Characteristics and Landuse		Local Pollen Zone & C^{14} Dates	Historical / Cultural Period	Vegetation Assemblage
Present	Heather moorland management		G	early 18th - 20th Century	Callunetum
	Lowland woodland regeneration	*Sub Atlantic*	F	late 14th - 17th Century	*Betula - Corylus/Myrica; Calluna*
			390bp		
	2nd. Major Woodland Clearance		E	Viking - early Medieval	*Gramineae* - Ruderals
1000			1060bp		
	Limited Woodland Regeneration		D	Saxon (Dark Ages)	*Betula - Corylus/Myrica; Calluna*
			1530bp		
2000	1st. Major Woodland Clearance		C	Iron Age / Roman Colonisation	*Gramineae* - Ruderals, *Cyperaceae - Ericaceae, Plantago sp.*
			2280bp		
	Increasing extent of temporary woodland clearances with weed pollen becoming more important	*Sub Boreal*	B	middle - late Bronze Age	*Quercus-Alnus-Fraxinus; Gramineae - Pteridium* - Ruderals
			3400bp		
4000	Elm Decline accompanied by creation of small temporary clearances, with rise in frequency of weed pollen reflecting colonisation in the clearances	*Boreal*	A	Neolithic - early Bronze Age	*Quercus - Alnus; Plantago - Rumex*
5000			4720bp		
6000	Post glacial temperature & precipitation maximums: maximal development of deciduous woodland vegetation with the very few clearings only surviving on the highest parts of the central Moors	*Atlantic*	VIIa	Late Mesolithic (Sauveterrian microlith period)	Quercetum Mixtum *Quercus - Alnus - Ulmus - Tilia; Corylus/Myrica;*
7000					
8000	Open woodland with, with pine succeeding birch as dominant tree, with clearings supporting grassland and heather in places	*Boreal*	VI	Early Mesolithic (Maglemosian period)	*Pinus - Corylus/Myrica; Gramineae*
9000			V		*Betula - Pinus - Corylus/Myrica; Gramineae*
10,000					

LAKE GORMIRE

Lake Sediment Analysis

Calendar Years BP	Catchment Slope Stability	Physical Properties of Core Sediments		Erosion Indicators	Lake Catchment Vegetation (Taxa %'s as TDLP)
Present	Stability	Increased clay & less coarse silt	Increasing Organic C	Decline in K, Mg & Na	Continued woodlnad recovery
	Instability	More coarse silt;	Less Organic C	Rise in K, Na, Mg	Continued woodland recovery
	Stability	Increased clay & less coarse silt	Increasing Organic C	Decline in K, Mg & Na	Woodland recovery
1000	Instability	More coarse silt;	Less Organic C	Rise in K, Na, Mg	Major Clearance - Trees18%, Corlyus/Myrica 21%, Herbs 55%
	Stability	Increased clay & less coarse silt	Increasing Organic C	Decline in K, Mg & Na	Limited woodland recovery - *Alnus - Fraxinus - Betula* Trees 27%, Corylus/Myrica 32% Herbs 38%
2000	Instability	High values for coarse & medium silt	Less Organic C	Rise in K, Na, Mg	Major Clearance: Trees 13%, Corylus/Myrica 21% Herbs 64%
3000					
4000					Elm decline - temporary woodland clearings; *Alnus - Quercus - Betula - Fraxinus* Trees 55% Corylus/Myrica 33% Herbs 12%
5000					
6000	Stability	Highest values for clay; Lowest values for coarse silt.	Maximum values for Organic C	Lowest values for K, Na & Mg	Maximum development of deciduous woodland: *Alnus - Quercus - Ulmus - Tilia* Trees 68% Corylus/Myrica 23% Herbs 9%
7000					
8000					*Pinus - Betula - Corylus / Myrica* woodland with open areas Trees 51% Corylus/Myrica 42% Herbs 9%
9000					
10,000	Greatest Instability	Highest coarse and silt & lowest clay values	Lowest Organic C values	Highest K, Mg & Na values	

VALLEY FLOOR LANDFORM DEVELOPMENT

Calendar Years BP	Jugger Howe Beck		Dovedale	
	Slope/ Valley Floor Stability	Valley Floor Development	Slope/ Valley Floor Stability	Valley Floor Development
Present	Stability	Stream "locked" into bedrock; pedogensis begins on most recent terrace deposits	Stability	Confined meanders & "locked" into bedrock; pedogensis begins on most recent terrace deposits
	Instability	Much valley fill reworking; fan building; gravel aggradation & terrace formation	Instability	Valley fill reworking, gravel aggradation and terrace formation
	Stability	Pedogenesis proceeds on new terrace deposits	Stability	Pedogenesis proceeds on new terrace deposits
1000	Instability	Fan building; gravel aggradation and valley fill re-working; braiding	Instability	Much valley fill reworking; fan building gravel aggradation & terrace formation
2000	STABILITY	PEDOGENESIS ON UPPER BENCH AND MAIN FAN UNITS	STABILITY	PEDOGENESIS ON UPPER TERRACE AND FAN SURFACES AND AGGRADED SURFACE DOWNSTREAM
3000				
4000				
5000				
6000				
7000	STABILITY		Instability	Upstream incision, downstream aggradation; upper terrace formation
8000				
9000				Valley floor aggradation; probable braiding and lateral channel migration; High sediment yield : discharge ratio
10,000	Instability	Intensive slope erosion; valley floor aggradation with mud and debris flows & fan building	? Instability	

Figure 8.1

The data presented in Figure 8.1 suggest that there have been two periods in the Holocene when events common to all three study sites have resulted in catchment instability. These are at about 1000-900BP and about 300BP. An early phase of catchment instability in the Loch Lomond Stadial and around the opening of the Holocene is common to both Lake Gormire and Jugger Howe Beck whilst a long period of stability in the early-to-mid Holocene also appears to have taken place at these two sites. The most obvious differences between the three study sites are a major phase of instability in the Lake Gormire catchment at about 2500BP, the absence of evidence for a phase of Loch Lomond early Holocene filling in Dovedale Griff and the phase of valley floor instability in Dovedale Griff at about 7100BP.

8.2 Phases of Stability and Instability in the landform development of the North York Moors

Jugger Howe Beck and the Lake Gormire catchment are characterised by a phase of instability which probably began in the Loch Lomond Stadial and continued beyond the opening of the Holocene until about 9700BP. In the basal sediments of Lake Gormire, maximum values for the erosion indicators, coarse silt, the elements K, Mg, and Na, and high values for the magnetic parameter all indicate that the basal layers represent a zone of instability and inwash into the lake. As minerals containing Ca weather very rapidly, the maximum Ca values in the basal sediments suggest that slope erosion in the catchment was removing drift material from depth and from material which had undergone little weathering. Pollen analyses indicate that the catchment slopes would have had only a sparse vegetation cover. The upper boundary of this zone of instability in Lake Gormire has been placed at about 9700BP.

Although no direct dating control is available to indicate the onset of unstable conditions in Jugger Howe Beck it is likely that widespread hillslope erosion was taking place in the Loch Lomond and immediate post-Loch Lomond period (Chapter 4). Destabilisation of slopes at this time is likely to have taken place on both the steep slopes of the Hollin Gill tributary valley catchment and in the main Jugger Howe Beck valley at a time when thawing of the sparsely

vegetated frozen ground was taking place. Such conditions would have contributed to widespread erosion of the Hollin Gill and Jugger Howe Beck hillslopes and sedimentation in the valley floors to produce the silty-clay deposits of the oldest sedimentation unit.

The evidence for very early Holocene activity in Dovedale Griff is less clear than that for Jugger Howe Beck and Lake Gormire. Similar mass movement accumulations may have formed on the valley floor in Dovedale, although there is no existing evidence in the present valley fill to suggest that this has been the case. There is, however, considerable evidence that solifluction processes were active in the Dovedale catchment during cold periods. This evidence takes the form of deep stony head deposits, derived from the Lower Calcareous Grits and Passage Beds sandstones, which mantle the valley side slopes. It seems likely that the climatic and hydrological conditions which formed the head deposits on the steep Dovedale slopes would also have resulted in the accumulation of head material on the valley floor.

Pollen records from sites in the North York Moors, including Lake Gormire, suggest that recovery from the cold conditions of the Loch Lomond Stadial occurred rapidly. This is suggested by the abrupt change in sedimentological characteristics of cores, and from associated pollen assemblages. The changes from minerogenic sedimentation to organic accumulation were abrupt and pollen analytical evidence suggests that vegetation responded rapidly to the warmer conditions with a change from dwarf birch-juniper scrub to hazel/birch woodland by 10350bp (Chapter 6). This rapid expansion of woodland at the start of the Holocene would have brought about stabilisation of the slopes in the region.

The upper boundary of basal sediments in the lake core has been placed at about 9700BP. After this time there ensued a long period of stability in the lake catchment. Stability in the lake catchment is indicated by minimum values for the erosion indicators together with minimum values for coarse silt and maximum values for clay. Little variation in the erosion indicators was found in this section of the core sediments and the combination of parameter values is indicative of very little soil erosion occurring within the lake catchment (Chapter 7). Catchment slopes were

thus undisturbed and stable. During this time the slopes surrounding the lake would have developed relatively deep soils which show no evidence of disturbance in the core sediments until about 2500BP. The available evidence from the more discontinuous record of the valley floor sedimentary units in Jugger Howe also indicates a long period of relative stability and pedogenesis on the upper bench and main fan unit following the widespread hillslope erosion of the post-Loch Lomond period.

The temporal sequence of events in Dovedale shows a marked departure from that of either Lake Gormire or Jugger Howe Beck with valley instability and bed elevation changes taking place at about 7100BP (Figure 8.1). As noted in Chapter 5.2 it is difficult to state with any certainty when aggradation of the gravels that form the upper terrace commenced. The soil pollen evidence derived from the basal organic layers of an upper terrace soil indicates that organic accumulation of the upper soil horizon probably did not begin much before 7000BP. This then suggests that there may not have been a stable land surface on the valley floor of Dovedale Griff prior to this time. Valley filling in Dovedale is likely to have taken place during the early Holocene with the steep floodplain slope represented by the present upper terrace suggesting that aggradation and increasing bed elevation was occurring as a result of input of coarse sediment from the headwaters and tributaries in the catchment. Aggradation of the outer fan elements of the Egg Griff fan must also have been taking place during this time. The change from an aggrading, probably braided stream to a stream that was lowering its bed occurred in the Atlantic about 7100BP.

It was during the Atlantic, a period when both temperature and precipitation was higher than the present, that blanket peat and peat slacks began to accumulate on the high Moors (Jones, 1979). Pollen analysis from some of these peat sites has revealed evidence for anthropogenic activity during the Atlantic period and it has been suggested that the coincidence of increased rainfall at the onset of the Atlantic and anthropogenic activity may have led to the initiation of blanket bog growth across large parts of the highest areas of the North York Moors. Mineral inwash layers in some of the peat bogs suggest localised slope erosion in these areas (Chapter 6).

The pollen evidence from the North York Moors at this time indicates however, that such clearings occupied only a very small proportion of a regional landscape that was otherwise dominated by dense woodland. This regional pollen picture is supported by that presented for Lake Gormire (Chapter 7) whilst sedimentological analysis from Gormire indicates that such a densely wooded landscape was also accompanied by stable slope conditions. Valley alluviation under these regional conditions is relatively unlikely.

Evidence from the valley floor deposits in Dovedale indicates that the Atlantic period was one of valley floor incision upstream and aggradation of evacuated deposits at the downstream end of the valley. The regional environmental conditions of increased woodland but also increased rainfall, acting in concert with the local site conditions within the Dovedale catchment, appear to have combined to produce valley floor instability in this valley in the early Atlantic.

The bedrock lithology in the Dovedale catchment produces alluvial deposits that offer little resistance to lateral erosion. The Soil Survey Memoir (Bendelow and Carrol, 1976) notes the very stony nature of the parent materials formed from the Lower Calcareous Grit whilst the Passage Beds weather to form soil parent material which has a very high fine sand content, with low amounts of silt and clay. Such cohesionless deposits offer little resistance to erosion whilst the steep slope of the Dovedale floodplain in the early Atlantic (about 0.036) would have offered the potential for high specific stream power and a high potential for channel change. Increased rainfall in the Atlantic coupled with a decrease in sediment yield from forested slopes would have resulted in a decline in the sediment yield : streamflow ratio, which may have initiated upstream incision that, in turn, resulted in the burial of the alder wood at the downstream C^{14} site at about 7100BP. The changes in the Dovedale valley floor at this time may thus be referable to climatic change at the Boreal/Atlantic transition acting upon a landscape undergoing major natural vegetation changes, coupled with the high potential for change in the catchment given the local site conditions.

Neither the Gormire geochemical and sedimentological record, nor the discontinuous record from the valley floors of Jugger Howe Beck and Dovedale, provides evidence for early or mid-Bronze Age disturbances in the catchments, although Bronze Age cairns have been found in the margins of the Jugger Howe Beck catchment (Chapter 7). Thus in the Gormire catchment stable conditions predominated throughout the early and middle Holocene periods. At about 2500BP however, a marked change in the sediment parameters was observed (Figure 8.1). Organic carbon values decline and are accompanied by high values for the erosion indicators of K, Na and Mg, as well as increasing amounts of coarse silt in the particle sizes entering the lake. The changes in these parameters present a marked contrast to the preceding stable period which had lasted for much of the Holocene. The erosion indicators suggest an influx of minerogenic material to the lake as a result of erosion of catchment soils (Chapter 7). Values of tree pollen fell from the 55% TDLP in the preceding sub-Boreal period to 13% TDLP in this zone thus associating accelerated erosion into the lake with forest clearance of the surrounding slopes.

Reference to Figure 8.1 shows that this second zone of instability in Gormire which began about 2500BP and continued until about 1750BP is coincident in time with the first of the major clearance phases that have been identified in the Fen Bogs pollen core (Atherden, 1976). This clearance phase is the most marked of the three clearances identified from the regional pollen diagrams, and it has been dated to 2365BP (2280+/-120bp). In the Fen Bogs core values for arboreal pollen were reduced to less than 10%, thus recording the same dramatic reduction in tree pollen as in the Gormire pollen analysis. This clearance phase was associated with arable cultivation in parts of the Tabular Hills and with pastoral agriculture being practised in the Central Moors region (Chapter 6). It is suggested that records for aquatic species in the Fen Bogs pollen assemblage at this time may be indicative of an increase in humidity associated with the beginning of the sub-Atlantic (Atherden, 1976).

Although there is some evidence for increased wetness in the sub-Atlantic period, the clearance activities of man and consequent disruption to the vegetation cover are likely to be the primary cause of accelerated erosion into Lake Gormire. The second inwash zone in the Gormire core is most likely to represent a phase in the late Holocene in which soil stability on the surrounding catchment slopes was being diminished by clearance of trees by man.

Whilst this phase of late Holocene hillslope destabilisation had a significant impact on the lake sediments in the form of a major inwash layer, and evidence for major vegetation clearance occurs in the regional pollen diagram from Fen Bogs, the available evidence suggests that at about this time the catchments of the two valley sites remained relatively undisturbed.

It is possible that during the major clearance phase which appears to have begun at 2500BP, Jugger Howe Beck and Dovedale were beyond the major areas of clearance and cultivation, and did not experience marked reduction in woodland vegetation, slope disruption, and accelerated soil erosion. The widespread palynological evidence of regional woodland clearance suggests, however, that such clearance was experienced throughout the North York Moors, and that the Dovedale and Jugger Howe Beck catchments would not have escaped these clearance activities. It is also possible that preservation of events related to this clearance phase may not have survived on the valley floors of the two valley sites, although absence of evidence for a land surface dating to this period from both valleys would tend to suggest that this has not been the case.

A more likely explanation for absence of evidence of woodland clearance in the two valley sites under consideration may be that despite palynological evidence of woodland clearance on a regional scale, the intensity and nature of land use during Romano-British times was spatially highly variable. Much of the clearance in the Moors at this time was thought to be predominantly to fuel the iron smelting industry and there were probably centres of activity to which felled wood was transported for iron smelting. Such a site has been identified at Levisham Moor, 5km to the west of Dovedale. The Levisham site has provided much evidence of Romano-British habitation,

arable and pastoral agriculture and iron smelting (Hayes 1983). This site on the Tabular Hills was ideal for settlement, as it lay at the junction of land suitable for grazing to the north, and land to the south which provided good soils suitable for arable farming. In addition it is situated close to the Corallian scarp which divides the Tabular Hills from the central Moors. It therefore occupied an optimal location between the two areas of the North York Moors which supported contrasting land uses, with rough grazing on the central Moors and more planned arable agriculture on the Tabular Hills (Hayes 1983).

The intensity and nature of land use at the Levisham site, indicated by the archaeological evidence, was considered by Curtis (1975) to have resulted in the extensive evidence of k-cycles of episodic soil erosion that he identified on Levisham Moor. A similar combination of archaeological evidence of intensive land use closely linked with evidence of extensive soil erosion has yet to be reported from any other site in the North York Moors from this time. The minerogenic inwash evidence from the Gormire lake sediments is the only other substantiated example of significant soil erosion processes occurring in Romano-British times in the North York Moors region. The lack of evidence of slope and valley floor instability during Romano-British times from Dovedale and Jugger Howe Beck would therefore appear to be unexceptional for the North York Moors region.

At about 1200BP-900BP all three sites experienced unstable conditions which in the valley floors led to widespread gravel aggradation and in Lake Gormire produced a further major phase of minerogenic inwash. In Dovedale and Jugger Howe Beck the evidence from the discontinuous alluvial record suggests that the phase of catchment instability that was initiated at around 1000 - 900BP was the first major phase of change to have significant impact on valley floor landform development since 7100BP for Dovedale and about 10000BP for Jugger Howe Beck. The beginning of unstable conditions at about 900BP appears to mark the onset of a period when all three sites were to experience alternating phases of stability and instability which were to continue until the recent past.

In the Dovedale catchment onset of unstable conditions may have occurred as early as 1125BP. At this time infilling of the Bridestones Griff slack was initiated, with the first phase of slack infilling probably continuing until about 900-850BP (Chapter 6). Pollen from the basal samples of the slack revealed the presence of a range of ruderals associated with both pastoral and arable cultivation in the vicinity of the slack. A large amount of disturbed ground and rough ground in the catchment area is indicated by high Plantago sp. Soil-stratigraphic data indicate that the phase of gravel accumulation that resulted in the development of the middle terrace surface in Dovedale also occurred at about 900BP; this estimated age from the soil-stratigraphic data correlates well with the initial phase of slack infilling in the Bridestones catchment. This evidence suggests that the catchment was responding as a whole to a phase of increased sediment delivery from the hillslopes.

In the Gormire lake sediments, marked increases in K, Mg, Na and INRM, and the percentage of coarse clay, and declining amounts of organic carbon and calcium, are all indicative of a period of minerogenic inwash to the lake (Figure 8.1). This phase of inwash was initiated at about 1200BP and continued until about 900BP thus spanning the same time period as the initial phase of slack infilling in the Bridestones Griff slack.

Instability in the Juggerhowe Beck catchment at about 900BP is indicated by the dated phase of gravel aggradation that was responsible for the burial of the upper organic infill of the palaeochannel at the upstream C^{14} site (Chapter 4). It is likely that this phase of gravel accumulation at the upstream C^{14} site resulted in the aggradation of a thin gravelly stratigraphic unit that was more extensive throughout the study reach.

The date of 1125-900BP for the beginning of slack infill in the Bridestones Griff catchment, the 1200-900BP phase of minerogenic inwash into Lake Gormire and the date of 900BP for gravel aggradation in Juggerhowe Beck all accord closely with the date of 1000BP for the second major clearance phase in the regional pollen assemblage presented by Atherden (1976) from the Fen Bogs core (Figure 8.1). This phase of clearance was attributed to extensive Viking settlement in

many parts of the North York Moors region. The Vikings introduced sheep farming to the area, although the mixture of arable and pastoral weeds indicated by the regional pollen assemblage and that from the Bridestones bog suggests that they also engaged in arable agriculture in less exposed valley locations (Chapter 6). The regional evidence for a phase of disturbance across the North York Moors at a time when the imprint of Viking settlement in the region was both marked and widespread, strongly suggests a common pattern of response to human influence in all three study sites with all the catchments responding to increased sediment delivery during a period of anthropogenic disturbance.

Evidence from the sediments in Lake Gormire indicates that after the phase of instability in the catchment which ended at about 900BP there ensued a period of relative stability which was probably attributable to a phase of woodland regeneration (Chapter 7). This phase of stability lasted until approximately 250BP when a further phase of inwash of minerogenic sediments in the lake ensued related to a major rock fall that occurred at Whitestone Cliff on the western edge of the Gormire catchment in 1755AD.

In Juggerhowe Beck and Dovedale it is likely that the floodplains of the 900BP aggraded gravel units were stabilised rapidly. This is indicated by the relative degree of soil maturity of the profiles developed into the gravels of the middle terrace in Dovedale and the 900BP landform element in Juggerhowe Beck (Chapters 3 and 4). Subsequent to this time both valleys experienced a further phase of catchment erosion some time about 300BP, with the age range of the calibrated dates from Jugger Howe Beck, that is from AD 1485 to 1860, encompassing the generally accepted dates (AD 1500-1700) for the secular climatic changes of the "Little Ice Age".

Although the phase of inwash in Gormire is related to the extreme event of the Whitestone Cliff fall, the timing of this event as well as that of the latest period of valley floor instability in the two valley sites suggests at least a broad climatic link. The widespread nature of the valley floor changes in Jugger Howe Beck suggests that a more vigorous period of catchment instability was felt in Jugger Howe Beck than in Dovedale Griff. It may be that the increased storminess that

accompanied the climatic changes of the "Little Ice Age" provided the necessary trigger to initiate widespread hillslope erosion on the slopes of Jugger Howe Beck which are prone to debris flow activity.

The resolution in the available dating control for the phases of instability in the valley floor deposits of Dovedale Griff and Juggerhowe Beck may not allow unequivocal association of the sedimentation units making up the fill deposits to different phases of Holocene environmental change. Further, it is difficult to establish unequivocally the background environmental controls governing the sediment yield : stream flow ratio responsible for determining valley floor sediment surface elevation changes. Nevertheless, the evidence presented above does allow some tentative conclusions to be advanced regarding Holocene valley floor landform development in the North York Moors. Two main phases of synchronous behaviour between the valley floors of the two valley sites and the lake site occurred at about 1000 - 900BP and again around about 300BP. A significant phase of landscape instability was also experienced in both Jugger Howe Beck and Lake Gormire about 10000BP. The very early phase of landscape instability is referable to major climatic change at the end of the Loch Lomond Stadial and beginning of the Holocene, while the 900BP phase of instability was attributable to widespread anthropogenic activity including substantial woodland clearance. The most recent phase of instability may have been the result of secular climatic change and its increased incidence of high magnitude storms.

Site specific instances of landscape instability are found in Dovedale at 7100BP and also in the Gormire lake sediments beginning at about 2500BP. The Dovedale phase of instability was probably a consequence of climatic and vegetation changes that occurred at the Boreal-Atlantic transition acting in concert with local site characteristics of the valley. The minerogenic inwash phase starting at about 2500BP in Gormire is most likely to be a response to the first major woodland clearance period in the North York Moors which, however, failed to cause landscape response in the catchments of Dovedale Griff and Jugger Howe Beck.

8.3 Regional Patterns of landform development in upland Britain

Phases of valley floor landform development documented from sites in upland Britain are shown on Figure 8.2 together with phases of valley landform development in the two valleys in the North York Moors studied in this thesis. These studies provide evidence from sites in the central highlands of Scotland, the uplands of northwest England, the North York Moors of eastern England, and from mid-Wales. All C^{14} dates from the literature have been re-calibrated using Clark's curve in order to provide a common scale of dates.

The evidence summarised in Figure 8.2 suggests that a regional picture of Holocene landform development is beginning to emerge for upland Britain. Most valleys possess a Late Glacial/very early Holocene surface and two to three subsequent phases of low terrace development. The phase of valley filling and landform development around the opening of the Holocene is commonly followed by a period of relative stability. Most valleys are also characterised by a phase of alternating unstable and stable conditions beginning around 1000BP, with this late Holocene phase of landform development being associated with at least one or two phases of terracing and associated alluvial fan development. However, the picture presented by phases of terrace development between the period of relative stability following the opening of the Holocene and the onset of the 1000BP phase of unstable valley floor conditions involves significant regional, and in some cases, between-valley variation in timing of events. Dating evidence for phases of terrace and alluvial fan development thus ranges from about 7100BP for terracing in Dovedale Griff in the North York Moors, to 6000BP for gravel aggradation in the Bowland Fells, to 4000BP for terracing in the central highlands of Scotland and 3000-2000BP for gravel aggradation in the Howgills and in mid-Wales.

Explanation for this emerging pattern of Holocene valley floor development may be viewed in the context of causes of landscape change and the effect of river character on the nature of adjustment to changes in the background environmental conditions. Both of these factors will

Phases of Holocene Regional Landscape Change in Upland Britain

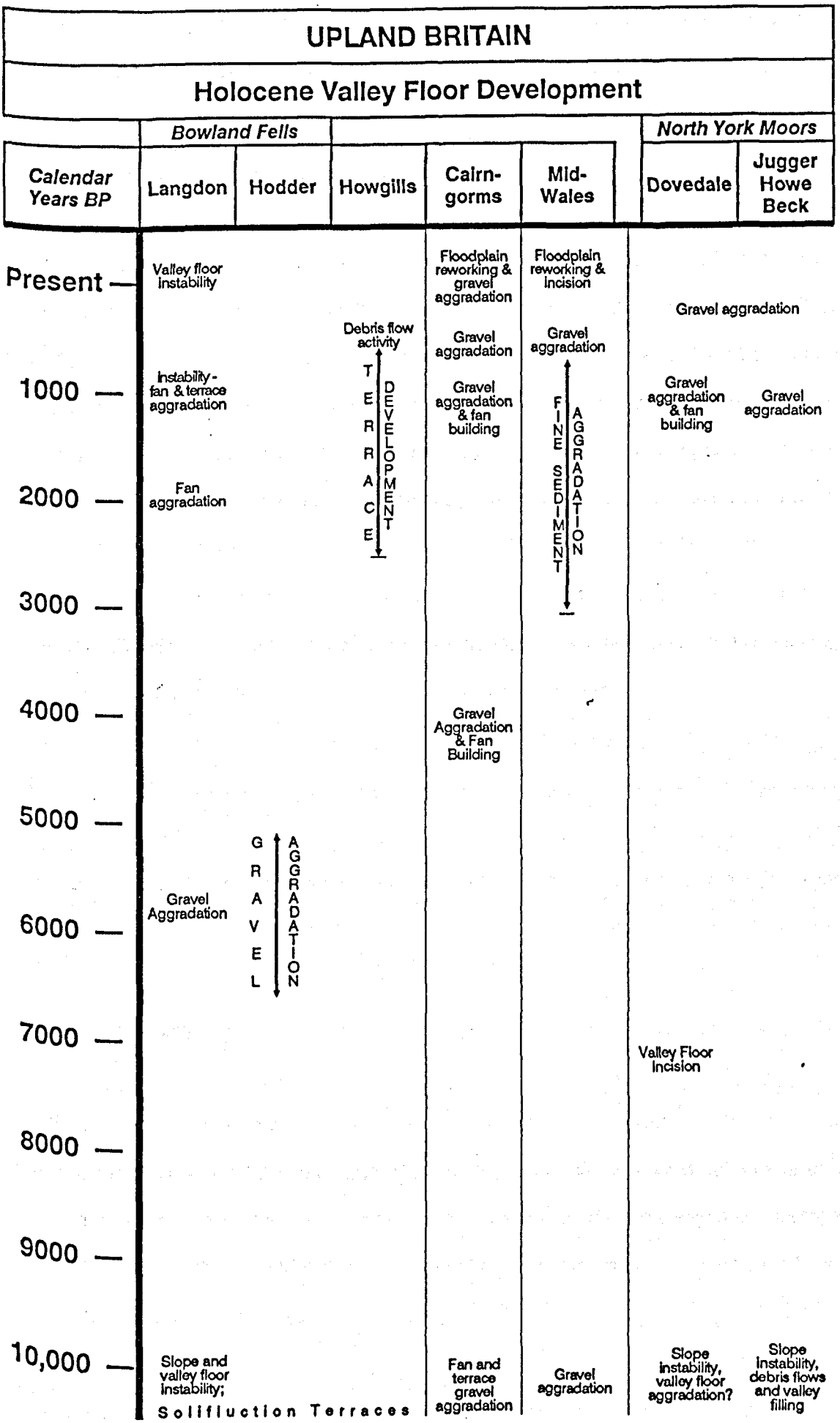


Figure 8.2

influence the changing balance of the sediment yield : stream flow ratio that ultimately determines the valley floor sediment surface elevation changes involved in alluvial fill development.

8.3.1 Causes of landscape change

Terrace formation fundamentally reflects one, or both, of two controls; relative base level changes and/ or variation in the sediment yield : stream flow ratio imposed by the catchment (Richards, 1982). Although Sissons (1979) has described sequences of terraces in Glen Spean and Glen Roy that relate to base level fall in the situation of the ice dammed lake, many valley floors in Britain have experienced terracing as rivers have undergone internal adjustment of river long profiles in response to changes in the sediment yield : stream flow ratio during the postglacial period (Ferguson, 1981). Such changes are initiated by the varying background environmental conditions of climate, vegetation and sediment supply, these variations being a response to secular climatic changes, random high magnitude events and man-induced changes in hydrology and sediment yield associated with land use change.

Establishing the environmental significance of terrace and fan sequences thus requires a careful consideration of the environmental factors likely to produce change in the river system, as well as the dating control necessary to correlate valley floor changes with documented environmental evidence.

I. Climatic change

Although the causal links required to relate terrace sequences to changes in the environment may be difficult to establish unequivocally, some phases of valley fill development in upland Britain have been related to climatic change and its associated natural vegetation changes. It is notable, however, that in upland Britain phases of terrace and fan development linked to climatic change exhibit significant regional variation.

Probably the most marked climatic changes that have resulted in widespread upland valley fill in Britain are those changes which occurred at the close of the Loch Lomond Stadial and the opening of the Holocene at about 10000BP. Stratigraphically well-defined evidence for the transition from the cold conditions of the Loch Lomond Stadial to the warmer conditions of the pre-Boreal is available from lake sediments such as those discussed from the Gormire core. Thus in this thesis the period of catchment instability and erosion into the lake at the opening of the Holocene was correlated with the period of hillslope erosion and valley filling responsible for the stratigraphic unit of the upper bench and main fan unit in Jugger Howe Beck.

Evidence for the severe climatic conditions during the Loch Lomond Stadial and the rapid recovery from stadial conditions is well documented from many sites in upland Scotland and northwest England using pollen stratigraphic data (Walker, 1984; Pennington 1977). A feature of the pollen cores at the opening of the Holocene is the rapid replacement of minerogenic sedimentation by organic accumulation and a corresponding response of the vegetation to the warmer conditions that were prevailing by about 9700-9500BP.

Several lines of evidence may thus be used to establish the cause of change in this early phase of Holocene landform development. It is notable however, that the dating evidence required to link valley alluviation unequivocally to established changes in climate and vegetation is generally lacking. For example, Harvey (1985) has described high terraces which characterise the valley floors of many of the Howgill valleys and the upper Lune in the Bowland Fells. These terraces are composed of coarse cobbles and are suggested by Harvey (1985) to have been deposited by high-energy, probably braided streams at the end of the Late Glacial/very early Holocene. However, there is no absolute dating control to confirm the suggested age. In the Rheidol terrace sequence described by Macklin and Lewin (1986) from mid-Wales a spatially restricted second terrace has a probable Late Glacial/early Holocene age although there is no absolute dating control to confirm this age. Similarly, the upper bench and the main fan unit in Jugger Howe Beck were related in this study to the climatic changes which accompanied the close of the Loch Lomond Stadial and opening of the Holocene, although no direct dating evidence was available.

The lack of absolute dating control for these early surfaces may be due to extensive erosion of prior land surfaces, and hence buried soils and organics, during the severe conditions of the Loch Lomond Stadial (Rose et al., 1985). Rose et al. (1985) draw attention to the relative scarcity of Late Glacial buried palaeosols in the British Quaternary stratigraphy. They suggest that their relative absence is due to extensive soil removal during the Loch Lomond Stadial when severe cold and a maritime location caused conditions of ground ice activity, slope instability and snowmelt run-off. This situation would have been exacerbated in small headwater catchments, such as those in the Howgill Fells and in the North York Moors, where valley sides are steep, hillslope/river coupling is direct and the valley floors are narrow and therefore potentially subject to rapid reworking.

Harvey et al. (1984) have used surface soil stratigraphy to distinguish and relatively date the Late Glacial/early Holocene surfaces in the Howgill Fells. Here the solifluction surfaces and high terraces exhibit mature podzolic profile development thus suggesting a long period of time has elapsed since onset of soil formation. In the central highlands of Scotland surface soil stratigraphy was also used to distinguish landform surfaces developed in the immediate post Loch Lomond period (Robertson-Rintoul, 1986a). Here marked differences were noted between the soil profiles developed into kettled outwash deposits formed about 13000BP and the 10000BP surfaces.

In this thesis the mature gleyed profiles developed into the upper bench of Jugger Howe Beck and the freely drained brown podzolic soils developed into the fluvial deposits of the main fan unit were suggested to be about 10000BP in age. Comparison of the freely drained brown podzolic soils with those developed into the 7100BP surface in Dovedale showed that the Jugger Howe Beck soils were at a more advanced stage of soil profile development, thus implying a greater length of time available for the operation of the soil-forming processes. Absence of evidence for periglacial soil-forming processes on the fan or upper bench was taken to indicate that the most likely date for alluviation of the stratigraphic unit forming the upper bench and fan was immediately after the Loch Lomond Stadial. This then gave a maximum age for onset of pedogenesis on this surface.

The surface soil stratigraphic data from the Howgill Fells, the central highlands of Scotland and Jugger Howe Beck suggest that the development of a regional surface soil stratigraphic unit capable of distinguishing the stratigraphic units of the Loch Lomond period may aid in the subdivision of Late Glacial and very early Holocene deposits.

Evidence for the relationship between secular climatic change and valley alluviation in upland Britain in the middle Holocene period appears to be regionally variable. Reference to Figure 8.2 suggests that during the early and middle Atlantic period valley floor instability is relatively uncommon, with most valley floors experiencing a period of relative stability and pedogenesis during this time. It would appear, however, that the combination of secular climatic and vegetation changes in the early Atlantic were coupled with the specific local site conditions within the Dovedale catchment to produce valley floor instability at about 7100BP. As discussed above, the combination of the cohesionless gravels making up the floodplain deposits and the steep slope of the valley fill would have offered a high potential for channel change. Increased rainfall in the Atlantic coupled with a decrease in sediment yield from forested slopes combined to produce an increase in specific stream power necessary to exploit the local site conditions.

Secular climatic change and vegetation change in the middle Holocene period may have been responsible for catchment-wide changes in hydrology and sediment yield in valleys in northwest England and the central highlands of Scotland. In the Bowland Fells the extensive development of terraces along the River Hodder and its tributaries, as well as their presence both upstream and downstream of bedrock-controlled reaches suggests the possibility of their regional environmental significance (Harvey, 1985). Phases of gravel aggradation in these Bowland Fells valleys have been dated to around 5000BP and possibly earlier. These phases of landform development cannot be linked unequivocally to climatic changes. However, evidence from the Lake District suggests the possibility of climatic change in northwest England at about 5000BP. Pennington et al. (1977) examined a core from Blelham Tarn and found evidence of increased erosion of potassium-bearing minerals into the tarn at about 5400BP. They found no evidence for local vegetation disturbance in the catchment which might have resulted in increased potassium

inputs to the lake and came to the conclusion that increased erosion of potassium-bearing minerals into the tarn was probably the result of climatic deterioration, with increased rainfall and runoff causing soil erosion. It is therefore possible that the early phase of gravel accumulation in the Bowland Fells may be the result of channel disequilbrium caused by increased sediment delivery to the streams as a consequence of destabilisation of slope deposits in response to this period of climatic change.

Evidence from lake sediments derived from Cairngorm corrie lakes suggests that at about 4000-3500BP there was probable climatic deterioration in the central highlands in the form of increased wetness and cooling (Rapson, 1984). Evidence from pine stumps preserved in peat in northern Scotland (Birks, 1975) may be indicative of a period of climatic change and increased wetness in northern Scotland beginning about 5200-4500BP and possibly affecting the Cairngorms about 4000BP. Pollen records also indicate that the period around 4000BP saw the beginning of vegetation changes on a regional scale in the central highlands of Scotland with forests being replaced by heathland (Walker, 1984). This period of climatic and vegetation change in the central highlands of Scotland may have been associated with higher river discharges. In the Feshie basin palaeohydrological reconstruction for the terrace surface dated to about 4000BP reveals that discharges roughly equivalent to the mean annual flood were about 180-210 cumecs in the upstream reaches of the River Feshie, in comparison with the 80-90 cumecs of the present river. Rapid aggradation of gravels to produce the extensive 4000BP terrace is suggested to be a response to these basin-wide changes in background environmental conditions (Robertson-Rintoul 1986b). It is interesting to note however that there is also some evidence to indicate that incursions of populations were taking place in the Speyside area at about 4045BP (Walker, 1984). The possibility of anthropogenic disturbance of the vegetation cover in a landscape already experiencing changes in vegetation and climate cannot therefore be discounted.

The studies from the Bowland Fells and the central highlands of Scotland indicate that regional landform response to probable climatic change may be a middle - middle late Holocene characteristic of the valleys in upland Britain. Subsequent to this time the importance of

anthropogenic interference in affecting the mode and rate of operation of geomorphic processes in upland Britain is such that the separation of climatic influences from the significant effects of man-induced changes in hydrology and sediment yield becomes difficult.

However, in the historical time scale valley floor instability may be referable to both the secular climatic changes of the "Little Ice Age" and to random extreme events. The differentiation between these two climatic factors may be difficult, however, unless there is direct dating evidence which allows the unequivocal association of a sedimentological unit with a single event or series of events. The necessary precision of dating is unlikely to be feasible, except where documentary evidence and direct recording of events has occurred.

Such evidence is more often forthcoming for debris flow activity than for phases of terracing. All documented recent debris flows in upland Britain have been shown to have occurred during exceptionally intense rainstorms (Brazier and Ballantyne, 1989). Further, direct evidence of the effect of high magnitude events comes from the Howgill Fells where Harvey (1986, 1987) has documented evidence of widespread changes in valley floor sediments following a high magnitude storm in 1982. As a consequence of this event a renewed phase of debris flow activity, unequalled since the regional phase of debris flow activity at 900bp, caused widespread hillslope erosion and valley floor sedimentation.

Whilst the debris flow activity in the Howgills in 1982 might have been a response to high magnitude events, Brazier and Ballantyne (1989) have suggested a broad climate link with secular climatic change during the "Little Ice Age" for a phase of debris flow activity initiated about 350BP in upper Glen Feshie. It is likely that the increased storminess that accompanied the "Little Ice Age" increased the possibility of the high magnitude events necessary to initiate slope failure.

The secular climatic change of the "Little Ice Age" may also have resulted in the widespread changes that took place in the Jugger Howe Beck catchment around 300BP. However, it is entirely possible that the increased probability of high magnitude storms that accompanied this

period of climatic change may also have been responsible for triggering the widespread slope erosion that resulted in extensive removal of the 900bp surface and deposition of about 1.5m of sediment over the valley floor of the study reach. Similarly the extreme event that produced the Whitestone Cliff fall occurred within the period of secular climatic change encompassed by the "Little Ice Age". Thus although not independent of climate, or land use change, meteorological and hydrological events may be more direct controls on landform development than both climatic averages and vegetation history, although the data, particularly for the Holocene timescale, are elusive (Richards et al., 1987).

ii. Anthropogenic Activity

Whilst Holocene climatic changes have probably contributed significantly to the development of valley floor landforms in upland catchments, the soil stability on hillslopes has been diminished by human influences throughout the late Holocene, and the resulting accelerated slope erosion has contributed to the evolution of valley fill sedimentary units (Richards et al. 1987). However, because the steep, narrow floored catchments in upland valleys such as those found in the Howgills or North York Moors tend to be more susceptible to the effects of localised meteorological events and because the marginal nature of upland agriculture may result in more frequent abandonment and use, late Holocene slope destabilisation may be a variable response to human activity in both time and space.

In the Rheidol valley in mid-Wales the activities of man are suggested to have had an effect on the development of the valley floor from about the late Bronze age at around 2950BP (Macklin and Lewin, 1986). The very extensive third terrace appears to represent a period of late Holocene sedimentation which may have been initiated about 2950BP. Pollen evidence suggests that the sedimentary unit making up this terrace level represents an extended period of late Holocene sedimentation in the valley, possibly extending from late Bronze Age to medieval times and related to large scale vegetation clearance in the late Bronze Age, and to the development and expansion of sedentary agriculture in the early Iron Age (Macklin and Lewin, 1986).

Evidence of man causing destabilisation of slope deposits in the late Bronze Age - Iron Age is recorded in the Gormire lake sediments. Here evidence of a period of major minerogenic inwash was identified beginning at about 2500BP and continuing until about 1750BP(Chapter 7). It was suggested above that this period of inwash was related to the regional vegetation clearance associated with arable cultivation in parts of the Tabular Hills, with pastoral agriculture being practised in the Central Moors region.

Whilst this phase of late Holocene hillslope destabilisation had a significant impact on the lake sediments in the form of a major inwash layer, the available evidence suggests that at about this time the catchments of Jugger Howe Beck and Dovedale Griff remained relatively undisturbed, probably because of variation in intensity and nature of habitative land use during Romano-British times. The only other substantiated evidence of significant soil erosion for the North York Moors during late Bronze Age- Iron Age times comes from Levisham Moor (Curtis, 1975).

It is interesting to note that a similar phenomenon was observed by Harvey et al., (1981) in the Howgill Fells. Here a phase of regional vegetation change occurred at some time between 2700BP and 900BP with the vegetation changing from forest to moorland. However, as with the North York Moors situation, this change in vegetation did not appear to create major disturbance on the valley floor. Rather, slope destabilisation appears to have been triggered later with the introduction of sheep.

Reference to Figure 8.2 shows that beginning around 1000BP there was widespread disturbance in catchments in upland Britain. Instances of catchment disturbance have been described from the valleys of northwest England, in the valleys in the North York Moors and in the central highlands of Scotland. A number of lake studies also report clearance and disturbance phenomena within the lake sediments at about 1000-900BP. Studies from the Lake District (Pennington, 1965, 1977) and the Cairngorm corrie lakes (Rapsom, 1984) show comparable trends in the erosion indicators to those discussed above for Lake Gormire and indicating a phase of soil erosion in the catchments. In the Lake District Pennington (1965, 1977) attributed these changes to the

historically recorded settlement of the Lake District by Vikings. She also notes that the Viking woodland clearances were concentrated in the valleys. In Lake Gormire this phase of inwash which began about 1200BP and continued until about 900BP was also attributed primarily to the influx of Viking farming practices in the North York Moors region. Providing a contrast to the situation in the uplands of northwest and eastern England, the phase of accelerated slope erosion beginning around 1000BP in the Cairngorm corries was attributed to an overall deterioration in climatic conditions (Rapsom, 1984).

Vegetation changes induced by clearance and /or the introduction of grazing animals appears to have had a marked effect on both the processes operating on the slopes and on the valley floors. In the Howgill Fells the introduction of sheep is suggested to have provided damage to the surface cover required to initiate a regional phase of debris flow activity that contributed large amounts of sediment to alluvial cones at the valley slope/valley floor junctions and to sedimentary accumulation in the valley floors (Harvey et al., 1981). Similarly in the Bowland Fells the period beginning around 910BP saw a phase of fan and terrace aggradation in the headwater valleys of the Langden (Harvey and Renwick, 1987).

In the North York Moors continued agricultural activity, suggested by the persistence of the pollen of agricultural weeds in the Gormire sediment, from the base of the Bridestones Griff slack and from Fen Bogs, as well as the archeological evidence of late Saxon-early Medieval earthworks in the Dovedale catchment suggests that anthropogenic interference of the sediment yield from the hillslopes is likely to have been accelerated by the land use practices of man. This increased sediment yield probably resulted in widespread gravel and sand aggradation on the valley floors in both Dovedale and Jugger Howe Beck. The evidence of a regional phase of disturbance across the North York Moors, the Howgill Fells and some headwater valleys in the Bowland Fells at a time when the imprint of Viking settlement in both regions was both marked and widespread, strongly suggests a common pattern of response to human influence in both northwest England and the uplands of eastern England.

Historical evidence for direct anthropogenic influence on the sediment yield : stream flow ratio comes from studies of the effects of mining on river response. Aggradation and incision of the most recent terrace in the Rheidol sequence has occurred in historic times with this latter phase in the development of the valley fill deposits being a response to upstream mining activities in the late nineteenth century (Macklin and Lewin, 1986). Similar examples of historical valley alluviation in mid-Wales have been described from the Afon Ystwyth (Lewin et al. 1983). Here a phase of sediment aggradation by a braided channel was initiated as a result of increased sediment load arising from man-induced mining waste as well as from associated destabilisation of older and coarser alluvial fill deposits. When the mining activity declined and sediment load decreased the channel pattern changed from a braided channel to a single-thread channel with mid-channel bars which incised through the deposits creating low sinuosity meander cutoffs and incision terraces. These channel changes took place over a few decades and represent a phase of sudden channel change in response to an extended pulse of increased sediment delivery to the stream.

Whilst the regional studies of Holocene landform development discussed above have in general been able to relate landscape response to either secular climatic change, high magnitude events or the effects of man induced changes in slope hydrology and sediment yield, the environmental significance of a particular landform may not be easy to establish. For example, in the Rheidol valley soil erosion arising from agricultural activity may have declined by medieval times thus ending the phase of aggradation which began around 2950BP (Macklin and Lewin, 1986). It is interesting to observe that this decline is likely to have accompanied the introduction of sheep to the area. In the Howgills, and possibly the North York Moors, the introduction of sheep provided a trigger for accelerated slope erosion, previous late Bronze Age clearances apparently having left many of the headwater catchments relatively stable. It would therefore seem that landscape response to introduced land use practises may be determined in part at least by antecedent conditions in the particular catchment concerned so that it may not be valid to apply predictions of landscape response to change based on evidence from one catchment.

iii. Equifinality of landscape response

Landscape response to catchment instability, either as a consequence of a random high magnitude event or by man-induced changes in hydrology and sediment yield, may be similar, therefore making it difficult to assess the environmental significance of a landform. Anthropogenic disruption of the vegetation cover is likely to have been responsible for the reworking of debris flow deposits in Glen Etive, in the western Highlands of Scotland. In Glen Etive a complex debris flow site has been examined by Brazier et al. (1988). These workers present the results of pollen analyses and C^{14} assay on buried soils which are associated with complex debris flow and alluvial fan deposits. A date of about 550 bp on an upper buried soil gives a maximum age for deposition of the sand and gravel upper unit of the cone. These sands and gravels are fluvially reworked sediments deposited as an alluvial fan overlying the debris deposits. Pollen analysis of the buried soils demonstrated that the onset of fluvial activity coincided with a sudden change in vegetation at the site from one dominated by Corylus, Pinus and Alnus, to one dominated by Gramineae, Plantago and Calluna. Large pieces of charcoal found in the buried soils suggest that burning of the vegetation cover is likely to have accompanied the change in vegetation at the site. The pollen evidence from this site strongly suggests that the renewed fluvial activity at about 550bp was contemporaneous with man-induced disruption of the vegetation cover. Similarly, Innes (1983) concluded that debris flow activity in the Scottish Highlands over the past 250-300 years is likely to be a response to change in land use practices, especially burning and overgrazing. However, the climatic trigger for the onset of historical debris flow activity in Glen Feshie contrasts with the suggestion of Innes (1983) that debris flow activity in the Scottish Highlands over the past 250-300 years is likely to be a response to change in land use practices and the evidence from Glen Etive that renewed activity at the site was a result of man-induced vegetation changes.

Whilst the initiation of some of the debris flows in the Scottish Highlands may well have the result of destabilisation of slope deposits as the vegetation cover was destroyed by burning it seems likely that some at least of the debris flows investigated by Innes were induced by high magnitude

rainstorm events, a process common to the Scottish Highlands today (Brazier et al. 1988; Brazier and Ballantyne, 1989). These studies thus emphasise the difficulty of establishing the environmental significance of valley floor landforms and the danger of inferring regional environmental change from landforms which may be produced as a consequence of a random extreme event which could affect a single slope at any time.

These studies stress the requirement for multivariate lines of environmental evidence as well as detailed dating control in attempting to establish the environmental significance of particular landforms in a valley fill sequence.

iv. The influence of local site characteristics on landform development

Superimposed on and interacting with the background environmental conditions of climate, vegetation and sediment yield is the effect that river character has on the nature of adjustment to imposed change. This factor will influence the potential capacity of a catchment for change. Factors which may affect the response of a valley floor to imposed change include geological materials, catchment size and the potential for long term storage of introduced sediment, the variability of sediment storage patterns and sediment transfer histories within and between river systems, and the nature of river/slope coupling.

Examination of the Holocene landforms in several tributaries of the River Feshie using a combination of radiocarbon dating, sediment stratigraphy and soil stratigraphy has shown that the tributary valleys possess fluvial stratigraphic units which correlate with the already identified 4000BP and 960BP surfaces in the main valley (Robertson-Rintoul et al. in prep). However the nature of landform development is seen to differ between the main and tributary valleys. The main valley is characterised by a series of four inset terraces below the surface of the palaeosandur. By contrast the tributaries generally possess three terrace levels. Exposures through the tributary valley terrace sediments revealed evidence of overlapping stratigraphies as fluvial stratigraphic units deposited about 4000BP bury podzolic soils developed into the post Loch Lomond land

surface. The creation of the overlapping stratigraphy in the tributary valleys may be a function of tributary valley catchment size, a more direct coupling of river channel and valley side slopes than is experienced in the main Feshie valley, and the large amount of sediment produced from the slopes thus creating a high sediment yield : stream flow ratio. These combined factors may have resulted in very rapid aggradation of gravels in the tributaries resulting in burial of a prior landsurface and storage of sediment in the tributaries. Data from the neighbouring basin of the upper Tromie suggests that the landform sequences described from Glen Feshie may be common to several valleys in the central Highlands of Scotland. Under these circumstances correlation of stratigraphic units is not straightforward. In the case of Glen Feshie correlation of fluvial stratigraphic units was provided by a combination of age-calibrated surface soil-stratigraphic units and buried palaeosols.

In the Bowland Fells the capacity of the system to store sediment may be responsible for lack of late Holocene terraces in the Hodder valley observable in Figure 8.2. In the Langden valley and Hodder valley aggradation of terrace gravels took place before 5400BP and 4960BP respectively (Harvey and Renwick, 1987). In the Hodder valley aggradation of the low terrace began some time around 4960BP whilst by contrast further upstream in the Langden valley low terrace development as well as tributary valley alluvial fan activity also took place in two phases at about 1900BP and 900BP. There is therefore a contrast between the late Holocene activity in the upstream tributary and the downstream main valley. This contrast may be attributable to buffering of the downstream sites from the effects of the late Holocene sediment changes due to storage of sediments in the tributary fans and terraces.

Valley catchment dimensions may also influence the long term survival of stratigraphic units in an alluvial fill. Steep headwater valleys, such as Jugger Howe Beck, with their high stream power and narrow valley floors, may be subject to rapid reworking of cohensionless valley floor deposits where they exist. Thus it is likely that most of a prior 900BP landsurface in Jugger Howe Beck was removed during the phase of rapid valley floor change which took place around 300BP. By contrast the Rheidol valley in mid Wales has elements of at least five fluvial surfaces preserved in

it. Here, despite the high stream powers and active braiding of past streams the width of the valley floor and the slower delivery ratio of sediment characteristic of a larger catchment has meant that total reworking of the valley floor has not removed evidence of terrace surfaces of Late Glacial age, Late Glacial/early Holocene age, as well as surfaces of late Holocene and historical age.

Lithological properties may also influence river response to imposed change. In the case of the Dovedale catchment the local geological conditions appear to have resulted in the accumulation of a steep valley fill of cohensionless sediment which was thus susceptible to possible increases in discharge during the early Atlantic period. This may be compared with the cohesive nature of the fine grained sediments making up the upper bench in Jugger Howe Beck which has probably contributed to its survival on the valley floor.

Finally, some landforms may be a response to intrinsic river processes so that local site stratigraphies which form an intergral part of the valley fill may develop when a system geomorphic threshold is crossed. The distinction between overlapping stratigraphies in the downstream reaches of Dovedale was seen to contrast with the inset terraces in the upstream reach. The base level controls imposed by Staindale and the bedrock outcrop at the valley constriction in Dovedale appear to have contributed to the operation of a complex response mechanism in the downstream reach of the valley which has resulted in the development of an overlapping stratigraphy probably not attributable to the external stimulus of climatic control.

8.4 Conclusion

A regional picture of Holocene landform development appears to be emerging for upland Britain with most valleys possessing a Late Glacial/very early Holocene terrace and two to three phases of low level terrace development. Compound alluvial fan development at tributary valley/main valley junctions and debris flow activity in headwater valleys also appears to be a common

landform response to destabilisation of sediment stores as a result of changes in background environmental conditions in the catchments of the upland valleys.

However, although river terrace and alluvial fan development is a shared response to Holocene sediment destabilisation and channel disequilbrium, the timing of phases of landform development in the central highlands of Scotland, the upland valleys of northwest England, the North York Moors of eastern England and the valleys of mid Wales exhibits significant regional differences. These regional and in some cases between-valley variations in the timing of phases of Holocene landform development reflect differences in the background environmental causes for landscape change as well as the sensitivity of the landscape to imposed change.

In North America, studies carried out by Brakenridge (1980) and Knox (1985) have identified regional landscape response to climatic changes by plotting histograms of dated episodes of valley alluviation and relating these to periods of known climatic change. However, the studies discussed in this chapter indicate that, in any one river basin in upland Britain, Holocene valley floor landform development is likely to reflect a complex sequence of events set against varied background environmental causes. An approach such as that adopted for certain North American studies is unlikely to be feasible for upland Britain. Rather, explanation of valley floor landform development in upland Britain on the Holocene time scale requires the integration of detailed morphological and stratigraphical investigations of valley fill alluvial landforms, together with a chronology of development, and information concerning those background environmental changes thought to create landscape instability.

Chapter 9

Conclusions

Detailed investigation of the valley fill deposits of Dovedale Griff and Jugger Howe Beck, together with a sedimentological and palaeomagnetic investigation of the sediments of Lake Gormire, have provided the basis for an integrated analysis of the temporal and palaeoenvironmental aspects of Holocene valley floor landform development in the North York Moors.

Two main phases of synchronous behaviour between the valley floors of Dovedale Griff and Jugger Howe Beck and the catchment of Lake Gormire have been identified. These occurred at about 1000 - 900BP and again around about 300BP. A significant phase of landscape instability was also experienced in both Jugger Howe Beck and Lake Gormire about 10000BP. This very early phase of landscape instability was shown to be referable to the major climatic changes associated with the close of the Loch Lomond Stadial and opening of the Holocene. The widespread changes that occurred between about 1000 - 900BP were shown to be related to vegetation changes induced by forest clearance and the introduction of grazing animals which accelerated the sediment yield from the valley side slopes and caused valley floor filling. The most recent phase of instability at all three study sites may have been the result of secular climatic change and its increased incidence of high magnitude storms.

Site specific instances of landscape instability were found in Dovedale in the early Atlantic, a time of relative stability in many upland valleys in Britain. The Dovedale phase of instability at 7100BP was probably a consequence of climatic and vegetation changes that occurred at the Boreal-Atlantic transition acting in concert with the local site characteristics of the valley. The Gormire lake sediments also record a phase of site specific instability beginning at about 2500BP. The minerogenic inwash phase starting at about 2500BP in Gormire was shown to be a response to the first major woodland clearance period in the North York Moors which, however, failed to cause landscape response in the catchments of Dovedale Griff and Jugger Howe Beck.

Correlation of alluvial sequences between upland valleys is often inhibited because of a lack of datable material in the coarse fill deposits. A Holocene alluvial chronology was developed for Dovedale Griff and Jugger Howe Beck based on surface soil stratigraphy, radiocarbon dating, morphology and sediment stratigraphy and revealed at least three alluvial stratigraphic units in the development of each fill.

The surface soils developed into the massive gravelly deposits of the Dovedale Griff terrace fragments were divided statistically into three groups of soils using a combination of Principal Components Analysis and Cluster Analysis. The Principal Components Analysis abstracted the main variance trends from the data matrix of soil properties from 23 soil sites whilst the Cluster Analysis statistically allocated the soil profiles into groups on the basis of their principal component scores. The first principal component was shown to be a compound index of soil properties that represented some of the main morphological and chemical properties of brown podzolic soils and the grouped soils were shown to represent a chronosequence of brown podzolic soils.

Each cluster of soil profiles was shown to represent one soil-stratigraphic unit defining a particular phase of gravel aggradation in Dovedale Griff. Using the soil stratigraphic units, three principal alluvial surfaces, and associated with these, three phases of tributary valley alluvial development, were found to make up the valley fill deposits of Dovedale Griff.

Discriminant analysis was used to allocate several soil profiles with C^{14} dating control to an established soil stratigraphic group so providing some age calibration for the three soil stratigraphic units derived from the Dovedale Griff soil sites. As C^{14} dating control was only available from a limited number of sites some additional dating control from soil pollen analysis was used in attempt to establish approximate dates for onset of pedogenesis on the upper and middle terrace surfaces in Dovedale Griff. The age-calibrated surface soil stratigraphic units from Dovedale Griff were then used to interpret the alluvial surfaces of the Jugger Howe Beck study reach. Data from the soil profiles developed into the deposits of Jugger Howe Beck were

classified using a discriminant analysis procedure which enabled the landforms into which the soils are developed to be correlated with surfaces of the same relative age, and also enabled estimates to be made of the ages of undated valley floor surfaces in Jugger Howe Beck. An additional soil stratigraphic unit was identified from Jugger Howe Beck. This fourth unit was shown to have a freely drained phase and a gleyed phase and was estimated to be about 10000bp in age.

In Dovedale Griff the alluvial surfaces were dated to about 7100BP, 900BP and about 300BP. Valley floor development was characterised by an early phase of valley floor instability which resulted in redistribution of sediment within the valley floor of Dovedale Griff. A late Holocene phase of catchment wide sediment delivery which was also recorded in the infill of the Bridestones Griff slack resulted in the development of contemporaneous fan and terrace units throughout the valley about 1000 - 900bp while a more minor phase of terracing occurred in historical times. Comparison of the sediment record between the lower reach of the stream and the upper reaches serves to emphasise the complexity of the spatial relationships between aggradation and incision in valley fill evolution, for overlapping stratigraphies have developed downstream whilst three inset terraces characterise the upstream reaches.

In Jugger Howe Beck the main alluvial surfaces were shown to be about 10000BP, 900BP and about 300BP in age. The stratigraphic evidence from the valley revealed a very early phase of widespread hillslope erosion, mass movement and valley floor sedimentation followed by a prolonged period of stability and pedogenesis and two later phases of gravel aggradation. This valley appears to exhibit a high potential for valley floor change as suggested by the probable reworking and scouring of the 900BP gravelly infill by a relatively powerful braided stream about 300BP.

The terraced valley fills of Dovedale Griff and Juggerhowe Beck were shown to record the response of the valley floors to several phases of catchment-wide instability and valley floor sediment surface elevation changes. In an attempt to relate the discontinuous valley floor record

to a continuous record of Holocne environmental change, and to expand the regional picture of Holocene landscape stability and instability in the North York Moors, a core was taken from the sediments of Lake Gormire. The data from the core were found to provide a continuous stratigraphic record of changes within the lake catchment since the Late Glacial. Geochemical erosion indicators provided a means of distinguishing periods of lake catchment stability and instability, whilst palaeomagnetic data provided a continuous dating record for these phases of activity in the lake catchment. The sediments revealed three major phases of disturbance in the catchment with intervening phases of relative stability. The oldest disturbance phase, recorded in the base of the core, was related to the severe climatic conditions and sparsely vegetated catchment slopes of the Loch Lomond Stadial (11000 - 10000BP), whilst, as in Jugger Howe Beck, the early and middle Holocene was a period of slope stability. Several phases of late Holocene instability at about 2500BP and 1200BP were shown to be related to regional vegetation clearance and correlated well with major vegetation changes as shown on the regional pollen diagrams and the picture presented by the analysis of the pollen from the Bridestones Griff slack. A minor phase of instability was related to the Whitestone Cliff fall which may have been a high magnitude event prompted by the secular climatic changes of the "Little Ice Age".

The Holocene environmental changes that have been identified in this thesis from the North York Moors are not exceptional in upland Britain. River terrace and alluvial fan development is a shared response to Holocene sediment destabilisation and channel disequilbrium in upland valleys in the central highlands of Scotland, northwest England and mid-Wales. A regional picture of Holocene landform development is emerging for these areas, including the North York Moors, with most valleys possessing a Late Glacial/very early Holocene terrace and at least two to three phases of low level terrace development. Compound alluvial fan development at tributary valley/main valley junctions and debris flow activity in headwater valleys is also common.

However, although river terrace and alluvial fan development is a shared response to Holocene environmental change, and whilst a broad regional picture may be characteristic of the upland valleys, the timing of phases of landform development in the central highlands of Scotland, the upland valleys of northwest England, the North York Moors of eastern England and the valleys of mid Wales is seen to vary and does exhibit significant regional differences especially in the middle to later Holocene period. These regional and in some cases between-valley variations in the timing of phases of Holocene landform development reflect differences in the background environmental causes for landscape change as well as the sensitivity of upland catchments to imposed change. In consequence chronologies of valley floor landform development for upland regions in Britain may not reveal a common temporal pattern of response to changes in climate, vegetation and sediment yield.

APPENDIX 1

Laboratory Procedures for Soils Investigations

A. Organic carbon content

The method of determination is a modification of that of Tinsley (1950), developed by Chartres (quoted as personal communication in Ellis (1978a)). A 0.5g sample of <2mm soil, or 0.1g in the soil was very organic-rich, was weighed into a 500ml conical flask and 10ml N $K_2cr_2O_7$, were added, followed by 20ml conc. H_2SO_4. The mixture was shaken for 30 seconds and then allowed to cool for 30 minutes. 190ml water were then added, followed by 10ml 88% H_3PO_4, leaving the mixture for 10 minutes to cool. This was titrated against a solution of 0.5 N ammonium ferrous sulphate, freshly dissolved in 0.75 N H_2SO_4, using approximately 10 drops of diphenylamine indicator freshly prepared as a 0.5% solution in approximately N H_2SO_4. The colour change was from brown, through purple to green. A blank was prepared exactly as above, and this was also titrated against ammonium ferrous sulphate solution.

Ammonium ferrous sulphate solution is, however, rather unstable and its normality was checked daily. This was achieved by adding to 10ml N $K_2Cr_2O_7$, 50ml water followed by 10ml H_3PO_4, and titrating the resulting solution against ammonium ferrous sulphate using the indicator as above. The normality (N) of the solution was then calculated thus:

N = 10 / ml of titre of ammonium ferrous sulphate

To determine the percentage organic carbon by weight, the following equation was used:

%C = (0.3 (ml blank - ml test titre) * N * 1.33) / weight of soil in g

B. Pyrophosphate and Dithionite extractable Fe and Al sesquioxide content

The following methods (after Bascomb (1974)) use deionised water throughout.

B1. Pyrophosphate Extraction

0.5g <2mm oven-dry soil was placed in a 50ml polypropylene centrifuge tube to which was added 50ml 0.1M $K_4P_2O_7.3H_2O$ solution. The tubes were shaken overnight and then centrifuged at 2000rpm for 15 minutes. The supernatant (the pyrophosphate extract) was decanted into a polythene bottle for storage.

B2. Dithionite Extraction

0.5 <2mm oven-dry soil was placed in a 50ml polypropylene centrifuge tube to which was pipetted 50ml sodium acetate /glacial acetic acid buffer (pH 3.8) and 2.0g sodium dithionite ($Na_2S_2O_4$) powder. The tubes were shaken overnight and then centrifuged at 2000rpm for 15 minutes. Centrifuging must begin immediately as sodium dithionite decomposes rapidly in solution. The supernatant was decanted into a small beaker. A x10 dilution was made up by pipetting 10ml of the supernatant into a 100ml volumetric flask which was then topped up with deionized water. This dilution was transferred into a polythene bottle for storage.

The dithionite and pyrophosphate extracted iron and aluminium was determined in the Atomic Absoroption Spectrophotometer, and calculations of actual content were made applying the following equation:

% extractable Fe, Al, = (ppm Fe, Al * dilution) / 100

C. Particle size analysis

This method is a modification of that as Bascomb (1974). Whole bulk samples were weighed, ground with a rubber pestle and passed through a 2.0mm sieve. The weight of gravel was recorded and expressed as a percentage of the total sample weight.

Approximately 50g of the <2.0mm fraction was treated with 6% H_2O_2 in order to remove organic matter. The material was then oven-dried and weighed, the mass in g being denoted as Wp. The sample was then dispersed by warming for 10 minutes in 100ml sodium hexametaphosphate (Calgon) solution prepared at a concentration of $40gl^{-1}$. Meanwhile a blank 100ml sample of Calgon was oven-dried and the mass denoted as Wc.

After dispersal the sample was wet-seived on a 63um sieve, the material passing through being transferred into a 500ml sedimentation tube. Material retained on the sieve was oven-dried, ground with a rubber pestle and shaken for 10 minutes on a nest of 590, 210 and 63um sieves. Material passing through the 63um sieve was added to that in the sedimentation tube which was then made up to 500ml with distilled water. The sieve residues were then weighed, thus enabling the percentages by weight of coarse sand (2000 - 63um) to be calculated on a gravel-free basis.

The sedimentation tube was placed in a water bath overnight in order to attain constant temperature conditions during sedimentation. After shaking the tube for 1 minute, it was immediately replaced in the bath and the time noted. Sampling the suspension was conducted at 10cm depth with a 25ml pipette whose contents were then transferred to a weighed beaker, oven-dried and weighed (Wd). Sampling was carried out at intervals of 4 minutes 48 seconds, 1 hour and 8 hours after shaking. According to Stokes' Law, at a temperature of 20°C, material of specific gravity 2.5 should settle out through a 10 cm column of water as follows: 200um (4 minutes 48 seconds), 60um (1 hour) and 2um (8 hours). The specific gravity figure of 2.5 was considerd to be realisitic, since this value is

generally accepted as being about the mean in relation to the range of rock types found in the earth's crust.

In order to calculate the percentage by weight of the various size fractions obtained during sedimentation, the following relationship was used:

$$\% \text{ material} < \text{diameter } d = \frac{(Wd\,V - Wc)\,100}{(v)\,Wp}$$

where V = volume of sedimentation tube, and v = volume of sampling pipette. This method allows the percentage by weight of medium silt (20 - 6um), fine silt (6 - 2um) and clay (<2um) to be determined. The percentage of coarse silt (60 - 20um) was calculated by subtraction of the sum total of the remaining fractions from 100%.

D. Hydrogen ion activity (pH)

Measurements were carried out on a slurry of the soil sample in water, made up by placing 10g of soil in a beaker and adding 25ml of distilled water. This was stirred, left for 15mins. and then measured with a glass electrode and electric pH meter. Before readings were taken, the meter was calibrated using a buffer solution at pH 7.

APPENDIX 2

Measurement of Magnetic Susceptibility in Soils:

using the Bartington Instruments Magnetic Susceptibility Meter Model M.S.1

The Meter permits direct measurement of susceptibility when connected to a variety of sensors. Signals from the sensor pass through a co-axial cable to the meter. During operation, the samples are subjected to an applied low frequency 1 Oersted alternating magnetic field. The magnetic property of the sample material then produces a change in frequency in the field which is proportional to the magnetic susceptibility of the sample. The susceptibility reading is shown in a digital display on the meter in S.I. or c.g.s. units.

The sensor used in this thesis was a type M.S.2.A laboratory sensor. This accepts up to 12mm diameter perspex sample holders. It has an operating (applied field) frequency of 0.46kHz, and a measurement period of 1.1sec, and measures susceptibilities down to 2×10^{-7} c.g.s

Measurment of soil susceptibility for this thesis followed the standard operating procedure recommended by Bartington Instruments Ltd. for the most accurate and reliable results. Sample preparation also followed the method given by Bartington Instruments Ltd. These procedures are reproduced below.

Preparation of Samples

All sensors except those specifically designed for outdoor use are calibrated for a particular weight of sample material. For greatest accuracy the sample holders should be filled completely and situated using a spacer to ensure that they occupy the central portion of the sensor cavity. The susceptibility value obtained then has to be divided by the sample weight and mulitplied by the calibration weight given for the particular sensor to provide a measure of specific

susceptibility.

Recommended Operating Procedure

1. For best performance situate the sensor a few centimetres away from the meter or any large ferrous object, and do not allow the sensor to move during measurement.

2. For drift-free performance it is important that sensor and samples are allowed to stabilise to the ambient temperature. For the more sensitive sensors a warm up time of up to 2 minutes is recommended before full stability is achieved. (1 hour was found to be adequate for the M.S.2.A)

3. Select dimensional system and multiplier range to be used.

4. Zero the instrument by pushing the toggle switch to the zero position leaving it there until the display becomes blank. A colon will appear to show that the instrument is busy. Restore the toggle switch to its mid-position and wait for "all zeros to appear".

5. Insert sample into sensor ensuring that it is located in the central portion of the sample cavity. Momentarily select the measure position on the toggle switch and restore to central position.

6. At the end of the cycle the susceptibility value will be displayed. The instrument will continue to recycle for as long as the zero or the measure position is selected on the toggle switch.

7. An audible alarm will announce the completion of the cycle.

APPENDIX 3

Preparation of Pollen Samples

The method given below is based on that of Faegri and Iversen (1964) and adapted by the Geography Department at the University of Hull.

1. Extract approximately 1ml of material from the core/box section sample.
2. Wrap sample in terylene gauze around a glass rod, and hold in place with a rubber band round the rod. Place sample in labelled 15ml centrifuge tube, with enough 10% caustic potash to cover the sample.
3. Heat for a few minutes at 100°. Agitate to release pollen through the gauze. Centrifuge, filtrate and decant.
4. Wash the sample in distilled water. Stir, centrifuge and decant.
5. Wash the sample in dilute acetic acid. Stir, centrifuge and decant
6. Wash the sample in glacial acetic acid. Stir, centrifuge and decant.
7. Make a mixture of 9ml acetic anhydride and 2ml concentrated sulphuric acid. Add 2.5 ml of this mixture to each sample.
8. Heat the sample at 100°C for 4 minutes, stir.
9. Add glacial acetic acid. Stir, centrifuge and decant.
10. Wash the sample in dilute acetic acid. Stir, centrifuge and decant.
11. Wash the sample in distilled water. Stir, centrifuge and decant.
12. Wash the sample in 80 per cent ethyl alcohol. Stir, centrifuge and decant.
13. Wash the sample in 100% alcohol. Stir, centrifuge and decant.
14. Wash the sample in a 50:50 mixturew of absolute (100%) alcohol and tertiary butyl alcohol and stir, centrifuge and decant.
15. Wash the sample in pure T.B.A. Stir, transfer to a small labelled tube, centrifuge and decant.
16. Add a little fresh T.B.A. and silicone oil (AK 2000). Stir and centrifuge. Do not decant. If the

organic sediment is not at the base of the tube, repeat until it is.

17. Let the T.B.A. evaporate overnight in a warm oven. The sample is then ready for mounting.

APPENDIX 4

Determination of Metallic Cations

The methods given below are as used in Geography Department, University of Hull, recommended by R. Arnett (pers. comm.) and adopted for the evaluation of K, Na, Mg and Ca in the Lake Gormire sediments.

A. Preparation of Extract

1. Weigh out 5g of air dry, fine fraction.
2. Transfer to a 50 ml centrifuge bottle and add 33 ml of 1N NH_4OAc.
3. Stopper the bottle and vibrate in shaker for 5 minutes.
4. Centrifuge for 5 minutes at 2000 rpm.
5. Decant the supernatant liquid into 100ml volumetric flask.
6. Add another 33 ml of NH_4OAc to the centrifuge bottle and repeat 3,4, and 5.
7. Add another 33 ml of NH_4OAc to the centrifuge bottle and repeat 3,4, and 5.
8. There is now 99 ml (approx) in the flask, to be made up to 100 ml with deionised water.

This extract can be used for individual cation determinations as given below.

B. Calcium and Magnesium

1. Pipette 2 ml of extract into a 200 ml volumetric flask.
2. Add 2 ml of $Sr(NO_3)_2$ (10% solution).
3. Make up to 200 ml with 0.02M HCL
4. Make up Ca and Mg standards of 0,1,3, and 5 ppm in 0.02M HCL, with each standard also containing 2 ml NH_4OAc and 2 ml $Sr(NO_3)_2$
5. Determine CA and Mg via Atomic Absorption.

6. Calculation; me Ca/100 g. air dry soil = ppm Ca * dilution * 0.08333

me Mg/100 g. air dry soil = ppm Mg * dilution * 0.13706

C. Potassium

1. Make up standard solutions of 10,30,50, and 70 ppm K. in neutral NH_4OAc solution (Dissolve 1.292g. of KNO_3 in neutral NH_4OAc and make up to 500 ml with the same solution. This is now 1000 ppm K).
2. Determine sample of extract on flame photometer, diluting with NH_4OAc if necessary.
3. Calculation; me K/100g air dry soil = ppm K. * dilution * 0.0426

D. Sodium

1. Make up standard solutions of Na in NH_4OAc as for Potassium. (Dissolve 0.924 g $NaNO_3$ in neutral NH_4OAc to give 1000 ppm. Na). Use standards of 0, 10, 20, 40, and 50 ppm Na.
2. Determine Na concentration of extract, diluting if necessary with NH_4OAc.
3. Calculation me Na/100 g air dry soil = ppm. Na * dilution * 0.0725

APPENDIX 5

Soil Data from Dovedale and Jugger Howe Beck Soil Pits

A. Dovedale

Pit No.	$Fe_pB:C$	$Fe_dB:C$	Fe_pA	Z	CDE	Bdepth	RHD	Adark	pH
1	0.084	0.437	1.486	0.838	9	21	0.698	0.477	0.415
2	0.778	0.562	1.464	0.982	18	31	0.778	0.602	0.462
3	0.505	0.494	1.607	0.518	24	35	0.698	0.602	0.389
4	0.360	0.255	1.491	0.778	18	34	0.875	0.778	0.477
5	0.352	0.220	1.672	1.431	18	23	0.602	0.698	0.484
6	0.204	0.383	1.053	0.653	12	21	0.477	0.477	0.278
7	0.698	0.819	1.462	0.959	24	38	0.698	0.698	0.371
8	0.380	-0.096	1.127	0.342	12	10	0.176	0.301	0.312
9	0.113	0.083	0.869	0.278	6	14	0.040	0.301	0.176
10	0.124	0.060	1.278	-0.096	18	30	0.477	0.477	0.477
11	0.124	-0.028	1.113	0.176	8	9	0.040	0.000	0.204
12	0.222	0.050	1.146	0.380	15	23	0.602	0.477	0.398
13	0.080	0.059	1.205	0.176	6	8	0.040	0.301	0.243
14	0.081	0.425	1.146	0.176	15	20	0.477	0.301	0.342
15	0.127	0.124	0.996	0.698	12	21	0.477	0.477	0.290
16	0.352	0.359	1.362	1.287	15	35	0.302	0.698	0.450
17	0.202	-0.043	0.778	0.146	9	9	0.176	0.000	0.176
18	0.585	0.716	1.477	0.934	21	25	0.778	0.602	0.498
19	0.085	-0.013	1.250	0.618	12	23	0.477	0.477	0.418
20	0.041	0.064	1.113	0.454	9	15	0.040	0.000	0.419
21	0.071	-0.060	0.025	0.351	6	15	0.040	0.000	0.385
22	0.348	-0.102	0.056	0.388	9	14	0.040	0.000	0.404
23	0.515	0.060	1.430	0.521	12	20	0.477	0.000	0.418

B. Jugger Howe Beck

	$Fe_pB:C$	$Fe_dB:C$	Fe_pA	Z	CDE	Bdepth	RHD	Adark	pH
24	0.068	0.079	1.560	-	12	25	0.176	0.698	0.236
25	-0.033	-0.075	1.320	-	8	8	0.653	0.602	0.230
26	0.567	0.603	1.701	-	24	50	0.977	0.602	0.493
27	0.603	0.544	1.698	-	24	52	0.977	0.602	0.515
28	0.079	0.040	1.505	-	6	8	0.698	0.698	0.176
29	0.040	0.040	1.531	-	8	8	0.653	0.477	0.114
30	0.079	0.079	1.345	-	8	9	0.653	0.477	0.204
31	0.079	-0.045	1.236	-	8	9	0.653	0.477	0.230
32	0.040	0.079	1.376	-	8	9	0.653	0.602	0.204
33	0.079	-0.045	1.563	-	10	9	0.302	0.477	0.217
34	0.079	0.079	1.403	-	9	11	0.653	0.544	0.235
35	0.080	0.090	1.394	-	8	8	0.653	0.477	0.221
36	0.113	-0.045	1.224	-	8	9	0.653	0.602	0.211

APPENDIX VI

Soil Profile Descriptions

DOVEDALE

Profile 1

Slope:	0°
Vegetation	Grass, heather, bilberry
Soil drainage	Free
Parent material	alluvial sands and gravels
Major soil subgroup	brown podzolic soil

LF: 7cm - 0cm; very dark brown 10YR2/2; no mineral content; semi-fibrous; moist.

Ah: 0cm - 7cm; dark brown 10YR3/3; mineral-organic sandy loam; crumb structure; abundant fine roots and many thick woody roots; moist; crumb structure; merging boundary.

Bw: 7cm - 14cm; dark yellowish brown 10YR4/4; sandy loam; crumb structure; moist; friable; abundant fine roots; few thick woody roots; gradual boundary.

Bs: 14cm - 35cm; yellowish brown 10YR5/6; sandy loam; a few fine roots; occasional medium roots; medium sub-angular to sub-rounded stones; moist; very friable; weak crumb structure; merging boundary.

Cu: 35cm +; brown 10YR5/3; sand; very few fine roots; many sub-angular to sub-rounded stones; moist; friable; single grain structure.

Profile 2

Slope:	2°
Vegetation	Bracken, heather, grass, bilberry
Soil drainage	Free
Parent material	alluvial gravels and sand
Major soil subgroup	brown podzolic soil

LF: 9cm - 0cm; black 10YR2/1; no mineral content; semi-fibrous; moist.

Ah: 0cm - 10cm; very dark grayish brown 10YR3/2; mineral-organic sandy loam; crumb structure; abundant fine and medium roots; many thick woody roots; moist friable; many bleached grains; few stones; gradual boundary.

Bw: 10cm - 22cm; yellowish brown 10YR5/4-6; loamy sand; weak sub-angular blocky structure; moist friable; few fine roots; many medium and thick roots; some sub-angular to sub-rounded stones; gradual boundary.

Bs: 22cm - 50cm; yellowish brown 10YR5/6; loamy sand; some medium and thick roots; many sub-angular and sub-rounded medium stones; moist friable; weak sub-angular blocky structure; merging boundary.

Cu: 50cm +; pale brown 10YR6/3; fine sand; many sub-angular to sub-rounded medium stones, occasional large stones; friable; massive structure.

Profile 3

Slope:	0°
Vegetation	Grass, bracken, bilberry
Soil drainage	Free
Parent material	alluvial sands and gravels
Major soil subgroup	brown podzolic soil

LF: 7cm - 0cm; black 10YR2/1; no mineral content; semi-fibrous; moist.
Ah: 0cm - 13cm; dark brown 10YR3/3; mineral-organic sandy loam; crumb structure; many fine roots; abundant medium roots; moist; very friable; many bleached grains; a few stones; gradual boundary.
Bw: 13cm - 28cm; dark brown 10YR4/3; loamy sand; weak sub-angular blocky structure; moist friable; many medium and thick woody roots; a few stones; gradual boundary.
Bs: 28cm - 55cm; strong brown 7.5YR5/6; sandy loam; few medium and many thick woody roots; many sub-angular to sub-rounded stones; moist; friable; fine sub-angular blocky structure; merging boundary.
B/C: 55cm - 70cm; yellowish brown 10YR5/5; fine sand; a few thick woody roots; many sub-angular to sub-rounded stones, occasional sub-angular large stones; moist; friable; single grain structure; merging boundary.
Cu: 70cm +; yellowish brown 10YR5/4; fine sand; many sub-angular to sub-rounded stones; moist; friable; massive.

Profile 4

Slope:	1°
Vegetation	Bracken, grass, bilberry, heather
Soil drainage	Free
Parent material	alluvial sands and gravels
Major soil subgroup	brown podzolic soil

LF: 5cm - 0cm; black 10YR2.5/1; no mineral content; semi-fibrous; moist.
Ah: 0cm - 15cm; very dark grayish brown 10YR3/2; mineral-organic sandy loam; crumb structure; abundant medium roots; many fine roots; moist; friable; many bleached grains; many small sub-rounded stones; gradual boundary.
Bw: 15cm - 33cm; greyish brown 10YR5/2; loamy sand; weak subangular blocky structure; moist; friable; many medium and thick roots; gradual boundary.
Bs: 33cm - 49cm; yellowish brown 10YR5/6; sandy loam; many medium and thick roots; many sub-angular to sub-rounded stones; moist; friable; fine, weak sub-angular blocky structure; merging structure.
B/C: 49cm - 55cm; yellowish brown 10YR5/6; fine sand; few thick woody roots; many sub-angular to sub-rounded stones; moist ; friable; single grain structure; merging boundary.
Cu: 55cm +; pale brown 10YR6/3; fine sand; some sub-angular to sub-rounded medium stones, few large sub-angular stones; friable; massive.

Profile 5

Slope:	0°
Vegetation	Bilberry , bracken, heather, grass
Soil drainage	Free
Parent material	alluvial sands and gravels
Major soil subgroup	brown podzolic soil

LF: 11cm - 0cm; black 10YR3/1; no mineral content; semi-fibrous; moist.
Ah: 0cm - 11cm; dark yellowish brown 10YR3/4; mineral-organic sandy loam; crumb structure; abundant medium roots; few fine roots; moist; friable; many bleached grains; a few small stones; gradual boundary.
Bw: 11cm - 15cm; dark brown 10YR4/3; loamy sand; weak sub-angular blocky structure; moist; friable; abundant medium roots; a few thick roots; a few stones; gradual boundary.
Bs: 15cm - 33cm; strong brown 7.5YR6/6; loam; some medium and thick woody roots; abundant sun-angular to sub-rounded medium stones; moist; friable; fine, weak sub-angular blocky structure; merging boundary.

B/C: 33cm - 45 cm; yellowish brown 10YR5/6; fine sand; few medium roots; many sub-angular to sub-rounded stones; moist; friable; single grain structure; merging boundary.

Cu: 45cm +; yellowish brown 10YR5/4; fine sand; some sub-angular to sub-rounded medium stones; friable; massive.

Profile 6

Slope:	0°
Vegetation	Grass, bracken
Soil drainage	Free
Parent material	alluvial sands and gravels
Major soil subgroup	brown podzolic soil

LF: 5cm - 0cm; very dark brown 10YR2/2; no mineral content; semi-fibrous; moist.

Ah: 0cm - 15cm; very dark grayish brown 10YR3/2; mineral-organic loamy sand; crumb structure; abundant fine roots; few thick woody roots; moist; friable; gradual boundary.

Bw: 15cm - 22cm; dark brown 10YR3/3; loamy sand; crumb structure; moist; very friable; many fine and medium roots; some sub-angular to sub-rounded stones; gradual boundary.

Bs: 22cm - 40cm; dark yellowish brown 10YR4/4; sandy loam; few fine and medium roots; many sub-angular to sub-rounded stones; moist; very friable; very weak crumb structure; merging boundary.

Cu: 40cm +; brown 10YR5/3; fine sand; a few medium roots; many sub-angular to sub-rounded stones; moist; friable; single grain structure.

Profile 7

Slope:	5°
Vegetation	Bracken, grass, heather, bilberry
Soil drainage	Free
Parent material	alluvial sands and gravels
Major soil subgroup	brown podzolic soil

LF: 9.0cm - 0cm; black 10YR2.5/1; no mineral content; semi-fibrous; moist.

Ah: 0cm - 18cm; dark yellowish brown - brown 10YR4/4-3; mineral organic sandy loam; crumb structure; many medium roots; a few thick woody roots; moist; friable; many bleached grains; few sub-angular to sub-rounded stones; gradual boundary.

Bw: 18cm - 28cm; dark brown 10YR4/3; loamy sand; weak sub-angular blocky structure; moist; friable many medium and thick roots; many sub-rounded to sub-angular medium stones; gradual boundary.

Bs: 28cm - 44cm; yellowish brown 10YR5/8; loam; some medium roots; many sub-angular to sub-rounded medium stones; moist; friable; fine, weak sub-angular blocky structure; merging boundary.

B/C: 44cm - 68cm; yellowish brown 10YR5/4; fine sand; few roots; many sub-angular to sub-rounded stones; moist; friable; single grain structure; merging boundary.

Cu: 68cm +; light grey 10YR6/1; fine sand; many sub-angular to sub-rounded medium stones; friable; massive.

Profile 8

Slope:	0°
Vegetation	Grass, bilberry
Soil drainage	Free
Parent material	alluvial sands and gravels

Major soil subgroup	mineral alluvial soil

LF: 4cm - 0cm; very dark brown 10YR2/2; no mineral content; semi-fibrous; moist.

Ah: 0cm - 8cm; dark yellowish brown 10YR3/4; mineral-organic sandy loam; weak crumb structure; many fine and medium roots; moist; very friable; sharp boundary.

Bw: 8cm - 18cm; yellowish brown 10YR4/4; sandy loam; some fine and medium roots; very weak crumb structure; a few stones; moist; very friable; merging boundary.

Cu: 18cm +; brown 10YR5/3; loamy sand; fine roots; many sub-angular to sub-rounded stones; moist; friable.

Profile 9

Slope:	0°
Vegetation	Grass, heather, bilberry
Soil drainage	Free
Parent material	alluvial sands and gravels
Major soil subgroup	mineral alluvial soil

LF: 9cm - 0cm; very dark brown 10YR2/2; no mineral content; semi-fibrous; moist.

Ah: 0cm - 5cm; dark greyish brown 10YR4/2; mineral-organic sandy loam; weak crumb structure; many fine and medium roots; moist; very friable; sharp boundary.

Bw: 5cm - 15cm; brown 10YR4/3; sandy loam; some fine and many medium roots; very weak crumb structure; medium stones; moist; very friable to loose; merging boundary.

Cu: 15cm +; light olive brown 2.5YR5/3; fine sand; very few roots; many sub-angular to sub-rounded stones; moist; friable.

Profile 10

Slope:	0°
Vegetation	Grass, bracken
Soil drainage	Free
Parent material	alluvial sands and gravels
Major soil subgroup	mineral alluvial soils

LF: 4cm - 0cm; very dark greyish brown 10YR3/2; no mineral content; semi-fibrous; moist.

Ah: 0cm - 9cm; dark greyish brown 10YR4/2; mineral-organic loamy sand; weak crumb structure; many fine, some medium roots; a few thick roots; moist; friable; gradual boundary.

Bw: 9cm - 15cm; dark yellowish brown 10YR4/4; sandy loam; crumb structure; moist; friable; many fine and medium roots; some thick roots; gradual boundary.

Bs: 15cm - 27cm; yellowish brown 10YR5/4; loamy sand; a few medium and thick roots; some sub-angular to sub-rounded medium stones; moist; very friable; very weak crumb structure; merging boundary.

Cu: 27cm +; brown 10YR4/3; fine sand; a few thick roots; many sub-angular to sub-rounded stones; moist; friable; single grain structure.

Profile 11

Slope:	0°
Vegetation	Grass
Soil drainage	Free
Parent material	alluvial sands and gravels
Major soil subgroup	mineral alluvial soil

LF: 5cm - 0cm; very dark brown 10YR2/2; no mineral content; semi-fibrous; moist.

Ah: 0cm - 7.5cm; dark greyish brown 10YR3/3; abundant fine roots; very weak crumb structure; moist; very friable; sharp boundary.

Bw: 7.5cm - 16cm; brown 10YR4/3; sandy loam; many fine roots; weak crumb structure; moist; very friable; moist; merging boundary.

Cu: 16cm +; dark greyish brown 10YR4/2; fine sand; some fine roots; some sub-angular to sub-rounded stones; moist; friable.

Profile 12

Slope:	0°
Vegetation	Grass, bracken, bilberry
Soil drainage	Free
Parent material	alluvial sands and gravels
Major soil subgroup	brown podzolic soil

LF: 3.5cm - 0cm; very dark brown 10YR2/2; no mineral content; semi-fibrous; moist.

Ah: 0cm - 15.5cm; dark brown 10YR3/3; mineral-organic loamy sand; weak crumb structure; abundant fine and medium roots; moist; friable; gradual boundary.

Bw: 15.5 - 20cm; dark yellowish brown 10YR4/4; sandy loam; crumb structure; moist; very friable; many fine roots; some medium and a few thick roots; few stones; gradual boundary.

Bs: 20cm - 35cm; yellowish brown 10YR5/4; sandy loam; some thick roots; many sub-angular to sub-rounded medium stones; moist; very friable; weak crumb structure; merging boundary.

Cu: 35cm +; brown - yellowish brown 10YR 5/3-4; fine sand; very few fine roots; some thick roots; many sub-angular to sub-rounded medium stones; moist; friable; single grain structure.

Profile 13

Slope:	0°
Vegetation	Grass
Soil drainage	Free
Parent material	alluvial sands and gravels
Major soil subgroup	mineral alluvial soil

LF: 5cm - 0cm; very dark brown 10YR2/2; no mineral content; semi-fibrous; moist.

Ah: 0cm - 5cm; dark yellowish brown 10YR3/4; mineral-organic sandy loam; weak crumb structure; many fine roots; some medium roots; moist; friable; sharp boundary.

Bw: 5cm - 13cm; brown 10YR4/3; sandy loam; some fine and medium roots; very weak crumb structure; medium sub-rounded stones; moist; very friable to loose; moist; merging boundary.

Cu: 13cm +; dark greyish brown 10YR4/2; fine sand; very few fine roots; many sub-angular to sub-rounded stones; moist; friable.

Profile 14

Slope:	0°
Vegetation	Grass, bracken
Soil drainage	Free
Parent material	alluvial sands and gravels
Major soil subgroup	brown podzolic soil

LF: 7cm - 0cm; very dark brown 10YR2/2; no mineral content; semi-fibrous; moist.

Ah: 0cm - 5cm; dark brown 10YR4/3; mineral-organic loamy sand; crumb structure; abundant fine roots; some medium roots; moist; friable; gradual boundary.

Bw: 5cm - 11.5cm; yellowish brown 10YR5/4; sandy loam; weak crumb structure; moist; friable; many fine roots; some thick roots; some sub-rounded to sub-angular medium stones; gradual boundary.

Bs: 11.5cm - 21.5cm; yellowish brown 10YR5/5; sandy loam; some fine roots; some thick roots; some sub-angular to sub-rounded stones; moist; very friable; very weak crumb structure; merging boundary.

Cu: 21cm +; brown 10YR5/3; fine sand; very few fine roots; many sub-angular to sub-rounded stones; moist; friable; single grain structure.

Profile 15

Slope:	0°
Vegetation	Grass, bilberry
Soil drainage	Free
Parent material	alluvial sands and gravels
Major soil subgroup	brown podzolic soil

LF: 4cm - 0cm; very dark brown 10YR2/2; no mineral content; semi-fibrous; moist.

Ah: 0cm - 12cm; dark greyish brown 10YR4/2; mineral-organic loamy sand; crumb structure; abundant fine roots; some medium roots; moist; friable; gradual boundary.

Bw: 12cm - 16cm; yellowish brown 10YR5/4; sandy loam; crumb structure; moist; very friable; many fine roots; some medium roots; a few stones; gradual boundary.

Bs: 16cm - 31cm; yellowish brown 10YR5/4; sandy loam; many fine roots; a few medium roots; some sub-angular to sub-rounded stones; moist; friable; very weak crumb structure; merging boundary.

Cu: 31cm +; brown 10YR5/3; fine sand; some medium roots; many sub-angular to sub-rounded medium stones; moist; friable; single grain structure.

Profile 16

Slope:	0°
Vegetation	Grass, bracken, bilberry, heather
Soil drainage	Free
Parent material	alluvial sands and gravels
Major soil subgroup	brown podzolic soil

LF: 7cm - 0cm; black 10YR2.5/1; organic horizon; semi-fibrous; moist.

Ah: 0cm - 16cm; dark yellowish brown 10YR3/2; mineral-organic sandy loam; crumb structure; many fine and medium roots and a few thick woody roots; moist; friable; many bleached grains; sharp boundary.

Bw: 16cm - 26cm; dark brown 7.5YR 4/3; loamy sand; weak sub-angular blocky structure; friable; many medium and thick woody roots; some sub-rounded stones; gradual boundary.

Bs: 26cm - 41cm; strong brown 7.5YR5/6; loamy sand; some medium and thick woody roots; many sub-angular to sub-rounded medium stones; firm; fine, weak sub-angular blocky structure; merging boundary.

B/C: 41cm - 57cm; yellowish brown 10YR5/5; fine sand; very few fine roots; abundant sub-angular to sub-rounded medium to large stones; moist; friable; single grain structure; merging boundary.

Cu: 57cm +; dark yellowish brown 10YR4/4; fine sand; abundant sub-angular to sub-rounded medium and large stones; friable; massive.

Profile 17

Slope:	0°
Vegetation	Grass, heather
Soil drainage	Free
Parent material	alluvial sands and gravels
Major soil subgroup	mineral alluvial soil

LF: 4cm - 0cm; very dark brown 10YR2/2; no mineral content; semi-fibrous; moist.

Ah: 0cm - 6cm; dark brown 10YR3/3; mineral-organic sandy loam; very weak crumb structure; many fine and medium roots; moist; friable; sharp boundary.

Bw: 6cm - 18cm; brown 10YR4-5/3; sandy loam; some medium and fine roots; weak crumb structure; moist; loose; merging boundary.

Cu: 18cm +; dark greyish brown 10YR4/2; fine sand; a few fine roots; some sub-angular to sub-rounded medium stones; moist; friable.

Profile 18

Slope:	0°
Vegetation	Grass, bracken, bilberry, heather
Soil drainage	Free
Parent material	alluvial sands and gravels
Major soil subgroup	brown podzolic soil

LF: 17cm - 0cm; black 10YR2.5/1; no mineral content; semi-fibrous; moist.

Ah: 0cm - 14cm; dark brown 7.5YR3/2; mineral-organic sandy loam; crumb structure; abundant fine and medium roots; some thick roots; moist; friable; many bleached grains; some medium stones; gradual boundary.

Bw: 14cm - 25cm; yellowish brown 10YR5/6; sandy loam; weak sub-angular blocky structure; moist friable; many medium and thick roots; many sub-angular to sub-rounded stones; gradual boundary.

Bs: 25cm - 35cm; strong brown 7.5YR5/7; loam; a few medium roots; some thick woody roots; many sub-angular to sub-rounded medium stones; moist; friable; weak sub-angular blocky structure; merging boundary.

B/C: 35cm - 53cm; yellowish - light yellowish brown 10YR5-6/4; fine sand; few fine roots; some thick woody roots; many sub-angular to sub-rounded stones; moist; friable; single grain structure; merging boundary.

Cu: 53cm +; greyish brown 10YR5/2; fine sand; many sub-angular to sub-rounded medium stones; moist; friable; massive.

Profile 19

Slope:	0°
Vegetation	Grass, bilberry
Soil drainage	Free
Parent material	alluvial sands and gravels
Major soil subgroup	brown podzolic soil

LF: 5cm - 0cm; very dark grey 10YR3/1; no mineral content; semi-fibrous; moist.

Ah: 0cm - 9cm; very dark greyish brown 10YR3/2; mineral-organic loamy sand; crumb structure; many fine roots; some medium roots; moist; friable; gradual boundary.

Bw: 9cm - 16cm; brown 10YR4/4; sandy loam; crumb structure; moist; friable; many fine roots; some medium roots; gradual boundary.

Bs: 16cm - 28cm; yellowish brown 10YR5/5; sandy loam; many fine roots; a few medium roots; moist; friable; weak crumb structure; merging boundary.

Cu: 28cm +; greyish brown 10YR5/2; fine sand; some medium roots; abundant sub-angular to sub-rounded medium stones; moist; friable; single grain structure.

Profile 20

Slope:	0°
Vegetation	Grass, heather
Soil drainage	Free
Parent material	alluvial sands and gravels
Major soil subgroup	mineral alluvial soil

LF: 5cm - 0cm; very dark brown 10YR2/2; no mineral content; semi-fibrous; moist.

Ah: 0cm - 8.5cm; very dark greyish brown 10YR3/2; mineral-organic sandy loam; weak crumb structure; many fine and medium roots; moist; friable; sharp boundary.

Bw: 8.5cm - 17.5cm; dark brown 10YR3/3; sandy loam; some medium and fine roots; weak crumb structure; moist; very friable; merging boundary.

Cu: 17.5cm +; dark greyish brown 10YR4/2; fine sand; a few fine and medium roots; many sub-angular to sub-rounded medium stones; moist; friable.

Profile 21

Slope:	0°
Vegetation	Grass
Soil drainage	Free
Parent material	alluvial sands and gravels
Major soil subgroup	mineral alluvial soil

LF: 3cm - 0cm; black 10YR2/1; no mineral content; semi-fibrous; moist.

Ah: 0cm - 5cm; very dark grey 10YR3/1; mineral-organic sandy loam; very weak crumb structure; many fine roots; moist; very friable; sharp boundary.

Bw: 5cm - 13cm; very dark greyish brown 10YR3/2; sandy loam; many fine roots; very weak crumb structure; moist; loose; merging boundary.

Cu: 13cm +; dark greyish brown 10YR4/2; fine sand; some fine roots; many sub-angular to sub-rounded medium stones; moist; very friable.

Profile 22

Slope:	0°
Vegetation	Grass, heather
Soil drainage	Free
Parent material	alluvial sands and gravels
Major soil subgroup	mineral alluvial soil

LF: 5cm - 0cm; very dark brown 10YR2/2; no mineral content; semi-fibrous; moist.

Ah: 0cm - 9cm; dark brown 10YR3/3; mineral-organic sandy loam; weak crumb structure; many fine and medium roots; moist; friable; sharp boundary.

Bw: 9cm - 18cm; brown 10YR4/3; sandy loam; some medium and fine roots; weak crumb structure; moist; friable; merging boundary.

Cu: 18cm +; dark greyish brown 10YR4/2; fine sand; a few fine and medium roots; abundant sub-angular to sub-rounded medium stones; moist; friable.

Profile 23

Slope:	0°
Vegetation	Grass, bracken, bilberry, heather
Soil drainage	Free
Parent material	alluvial sands and gravels
Major soil subgroup	brown podzolic soil

LF: 9cm - 0cm; very dark brown 10YR2/2; no mineral content; semi-fibrous; moist.

Ah: 0cm - 11cm; dark greyish brown 10YR4/2; mineral-organic sandy loam; weak crumb structure; abundant fine and medium roots; some thick roots; moist; crumb structure; merging boundary.

Bw: 11cm - 17cm; yellowish brown 10YR5/4; sandy loam; crumb structure; moist; friable; abundant fine roots; many medium roots; some thick roots; gradual boundary.

Bs: 17cm - 33cm; yellowish brown 10YR5/6; sandy loam; some fine roots; some medium and thick woody roots; many sub-angular to sub-rounded stones; moist; very friable; weak crumb structure; merging boundary.

Cu: 33cm +; brown 10YR5/3; fine sand; very few fine roots; some thick woody roots; many sub-angular to sub-rounded stones; moist; friable; single grain structure.

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Profile 24

Slope	0°
Vegetation	Grass, bilberry, heather
Soil drainage	Free
Parent material	alluvial gravels and sand
Major soil subgroup	brown podzolic soil

LF : 5cm - 0cm; very dark brown 10YR 2/2; no mineral content; semi-fibrous; moist.

H : 0 - 5cm; black 5YR 2.5/1; well humified organic horizon; crumb structure; abundant fine roots and a few thick woody roots; moist; many bleached grains; friable; gradual boundary.

Bw : 5 - 15cm; dark reddish brown 5YR 3/2; sandy loam; crumb structure; moist; very friable; many fine roots; a few thick roots; some stones; gradual boundary.

Bs : 15cm - 29cm; dark reddish brown 5YR3/3; sandy loam; a few medium roots; many sub-angular to sub-rounded medium stones; moist; very friable; very weak crumb structure; merging boundary.

Cu : 30cm +; brown 7.5YR4/4; fine sand; very few fine roots; many sub-angular to sub rounded stones; moist; friable; single grain structure.

Profile 25

Slope	0°
Vegetation	grass, heather
Soil drainage	Free
Parent material	alluvial sand
Soil type	mineral alluvial soil

H : 0 - 5cm; black 10YR 2/1; no mineral content; semi-fibrous; moist; a few woody roots and medium fibrous roots; gradual boundary.

Bw : 5cm - 12cm; dark brown 7.5YR 4/2; sandy loam; single grain structure; moist; very friable; a few fine roots; boundary very gradual;

Cu : 12cm +: dark yellowish brown 10YR 4/4; fine sand; moist; friable; single grain structure.

Profile 26

Slope	4°
Vegetation	heather
Soil Drainage	Free
Parent material	alluvial gravels and sand

LF : 6 - 0cm; very dark brown 10YR2/2; spongey; moist.

H : 0 - 6cm; dark reddish brown 5YR2/2; organic horizon; well humified; moist fibrous roots; many bleached grains; friable; sharp boundary.

Bw : 6 - 19cm; dark brown 7.5YR 3/3; sandy loam; moist; crumb structure; very friable; many fine roots; some large stones; gradual boundary.

Bs : 19 - 59cm; strong brown 7.5YR5/6; sandy loam; crumb structure; very friable; moist; many fine fibrous roots; many large stones; gradual boundary.

B/C : 59-69cm; yellowish brown 10YR5/4; sand loam; no structure; loose; many large stones; merging boundary.

Cu : 69cm+; dark yellowish brown 10YR4/4; sand; no structure; loose; many large stones.

Profile 27

Slope:	0°
Vegetation	Grass, heather, bilberry
Soil drainage	Free
Parent material	alluvial sands and gravels
Major soil subgroup	brown podzolic soil

LF: 7cm - 0cm; very dark brown 10YR2/2; spongy; moist.

H: 0cm - 5cm; dark reddish brown 5YR2/2; organic horizon; well humified; moist; fibrous roots; many bleached grains friable; sharp boundary.

Bw: 5cm - 21cm; dark brown 7.5YR3/3; sandy loam; moist; crumb structure; very friable; many fine roots; some large stones; gradual boundary.

Bs: 21cm - 61cm; strong brown 7.5YR5/6; sandy loam; crumb structure; very friable; moist; many fine fibrous roots; many large stones; gradual boundary.

B/C: 61cm - 67cm; yellowish brown 10YR5/4; sandy loam; no structure; loose; many large stones; merging boundary.

Cu: 67cm +; dark yellowish brown; 10YR4/4; sand; no structure; loose; many large stones.

Profile 28

Slope:	0°
Vegetation	Heather, grass
Soil drainage	Free
Parent material	alluvial sands
Major soil subgroup	mineral alluvial soil

LF: 4cm - 0cm; very dark brown 10YR2/2; no mineral content; semi-fibrous; spongy structure; moist.

H: 0cm - 5cm; black 10YR2/1; well defined organic horizon; many fibrous roots; moist; crumb structure; sharp boundary.

Bw: 5cm - 14cm; dark brown 7.5YR4/2; sandy loam; some fibrous roots; moist; very friable; no structure; merging boundary.

Cu: 14cm +; dark yellowish brown 10YR4/4; sand; no structure; very few roots.

Profile 29

Slope:	0°
Vegetation	Heather, grass
Soil drainage	Free
Parent material	alluvial sands
Major soil subgroup	mineral alluvial soil

LF: 3cm - 0cm; dark reddish brown 5YR2/2; no mineral content; semi-fibrous; spongy structure; moist.

H: 0cm - 4cm; black 10YR2/1; organic horizon; many fibrous roots; moist; crumb structure; sharp boundary.

Bw: 4cm - 12cm; dark brown 7.5YR4/2; sandy loam; some fibrous roots; moist; very friable; no structure; merging boundary.

Cu: 12cm +; dark yellowish brown 10YR4/4; sand; no structure; very few roots.

Profile 30

Slope:	0°
Vegetation	Heather, grass
Soil drainage	Free
Parent material	alluvial sands
Major soil subgroup	mineral alluvial soil

LF: 4cm - 0cm; very dark brown 10YR2/2; no mineral content; semi-fibrous; spongy structure; moist.

H: 0cm - 4cm; black 10YR2/1; organic horizon; many fibrous roots; moist; crumb structure; sharp boundary.

Bw: 4cm - 13cm; dark brown 7.5YR4/2; sandy loam; a few fibrous roots; moist; very friable; no structure; merging boundary.

Cu: 13cm +; dark yellowish brown 10YR3/4; sand; no structure; very few roots.

Profile 31

Slope:	0°
Vegetation	Heather, grass
Soil drainage	Free
Parent material	alluvial sands
Major soil subgroup	mineral alluvial soil

LF: 4cm - 0cm; very dark brown 10YR2/2; no mineral content; semi-fibrous; spongy structure; moist.

H: 0cm - 4cm; black 10YR2/1; well defined organic horizon; many fibrous roots; moist; crumb structure; sharp boundary.

Bw: 4cm - 13cm; dark brown 7.5YR4/2; sandy loam; a few fibrous roots; moist; very friable; no structure; merging boundary.

Cu: 13cm +; dark grayish brown 10YR4/2; sand; no structure; very few roots.

Profile 32

Slope:	0°
Vegetation	Heather, grass
Soil drainage	Free
Parent material	alluvial sands
Major soil subgroup	mineral alluvial soil

LF: 3cm - 0cm; dark reddish brown 5YR2/2; no mineral content; semi-fibrous; spongy structure; moist.

H: 0cm - 5cm; black 10YR2/1; well defined organic horizon; many fibrous roots; moist; crumb structure; sharp boundary.

Bw: 5cm - 16cm; dark brown 7.5YR4/2; sandy loam; some fibrous roots; moist; friable; very weak crumb structure; merging boundary.

Cu: 16cm +; dark yellowish brown 10YR3/4; sand; no structure; very few roots.

Profile 33

Slope:	0°
Vegetation	Heather, grass
Soil drainage	Free
Parent material	alluvial sands
Major soil subgroup	mineral alluvial soil

LF: 8cm - 0cm; dark reddish brown 5YR2/2; no mineral content; semi-fibrous; spongy structure; moist.

H: 0cm - 5cm; black 10YR2/1; well defined organic horizon; many fibrous roots; moist; crumb structure; sharp boundary.

Bw: 5cm - 19cm; dark brown 7.5YR4/2; sandy loam; some fibrous roots; moist; very friable; no structure; merging boundary.

Cu: 19cm +; dark yellowish brown 10YR4/4; sand; no structure; very few roots.

Profile 34

Slope:	0°
Vegetation	Heather, grass
Soil drainage	Free
Parent material	alluvial sands
Major soil subgroup	mineral alluvial soil

LF: 4cm - 0cm; very dark brown 10YR2/2; no mineral content; semi-fibrous; spongy structure; moist.

H: 0cm - 5cm; black 5YR2/1; well defined organic horizon; many fibrous roots; moist; crumb structure; sharp boundary.

Bw: 5cm - 15cm; dark brown 7.5YR4/2; sandy loam; some fibrous roots; moist; very friable; very weak crumb structure; merging boundary.

Cu: 15cm +; dark yellowish brown 10YR3/4; sand; no structure; very few roots.

Profile 35

Slope:	0°
Vegetation	Heather, grass
Soil drainage	Free
Parent material	alluvial sands
Major soil subgroup	mineral alluvial soil

LF: 3cm - 0cm; dark reddish brown 5YR2/2; no mineral content; semi-fibrous; spongy structure; moist.

H: 0cm - 4cm; black 5YR2/1; well defined organic horizon; many fibrous roots; moist; crumb structure; sharp boundary.

Bw: 4cm - 12cm; dark brown 7.5YR4/2; sandy loam; a few fibrous roots; moist; very friable; no structure; merging boundary.

Cu: 12cm +; dark brown 10YR4/3; sand; no structure; very few roots.

Profile 36

Slope:	0°
Vegetation	Heather, grass
Soil drainage	Free
Parent material	alluvial sands
Major soil subgroup	mineral alluvial soil

LF: 4cm - 0cm; very dark brown 10YR2/2; no mineral content; semi-fibrous; spongy structure; moist.

H: 0cm - 5cm; black 5YR2/1; well defined organic horizon; many fibrous roots; moist; crumb structure; sharp boundary.

Bw: 5cm - 16cm; dark brown 7.5YR4/2; sandy loam; some fibrous roots; moist; very friable; very weak crumb structure/no structure; merging boundary.

Cu: 16cm +; dark yellowish brown 10YR4/4; sand; no structure; very few roots.

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