THE MORPHOLOGY, MINERALOGY AND GENESIS OF SOME SOILS ON THE MOOR HOUSE NATIONAL NATURE RESERVE.

By

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ABSTRACT.

The thesis comprises three parts. One reviews pedological research in the area, discusses the soil forming factors and considers the classification of the soils studied. A chapter is devoted to each pedogenic factor and describes its role in soil formation on the Reserve.

Part two comprises a study of several small limestone grasslands. Their microtopography is described using maps which also show soils. Three surfaces are recognised; the surrounding peat surface, a sub-peat 'drift' surface and a dissected limestone surface. Each sub-group in the soil complex is described, i.e. rendzina, brown calcareous soil, acid brown earth and peat podzol: profiles, with analyses, are included. Drift or head is shown to dominate the soil parent material. A contribution from the limestone is present in the shallow soils and dominates in some rendzinas. The inter-relationships of the soils are discussed: they form a sequence reflecting increasing depth of 'drift'. In the shallow soils plants obtain nutrients from the limestone thus offsetting leaching. In the deeper soils the limestone merely maintains free drainage. A history of the grasslands is reconstructed. The smaller areas were, almost certainly peat covered but parts of the larger ones may have remained peat free.

Part three discusses eight of the main soil sub-groups on the Reserve. Their distribution, morphology and pedogenesis are considered: profiles are given with analyses. Iron humus podzols are described and the origin of their platey structure and parent material: these soils are shown to be sedentary. Theories on the formation of peaty gleyed podzols are examined in the light of the work at Moor House. Clay movement in some brown earths is discussed. The distribution pattern of the sub-groups is outlined: a drainage sequence containing calcareous members is present. Parent materials of soils on the Pennine escarpment are briefly examined.

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ABBREVIATIONS.

The following abbreviations are used frequently in the text, tables or figures.

R	Rendzina
B.C.S.	Brown calcareous soil
A.B.E.	Acid brown earth.
B.P.S.	Brown podzolic soil.
P.G.P.	Peaty gleyed podzol.
P.G.	Peaty gley.

U.S.Sand	Sand fraction as defined by the U.S.D.A., i.e. 2.0 m.m. - 0.05 m.m.
I.Sand	International sand fraction, i.e. 2.0 m.m. - 0.02 m.m.
U.S.Silt.	Silt as defined by the U.S.D.A, i.e. 0.5 m.m. - 0.002 m.m.
I.Silt.	International silt fraction, i.e. 0.02 m.m. - 0.002 m.m.
n.d.	Not determined.
% B.S.	Percentage base saturation.
Sat.	The exchange complex is saturated.

The following abbreviations are used in indicating the intensities of the X-ray reflections:

v.w.	very weak
w.	weak
m.	moderate
s.	strong
v.s.	very strong.

PART I

SOIL FORMING FACTORS AND SOIL CLASSIFICATION.

CHAPTER I

General Introduction

1.1 Location.

The Moor House National Nature Reserve lies in the extreme north east corner of Westmorland (Fig 1). It comprises a broad belt of country stretching across the summit ridge of the Pennines just south of Cross Fell, the highest peak in the range. The highest point on the Pennine summit ridge which is within the Reserve boundaries is Great Dun Fell which reaches 2780 feet. To the west of the summit ridge the land falls away steeply to the Vale of Eden and is typical of the steep west facing scarp slopes of the northern Pennines. The particular section of the scarp within the Reserve is delimited by Great Rundale Beck in the north and Swindale Beck in the south while the western boundary is formed by the fell wall. East of the summit ridge the land falls away much more gradually to the rolling, peat-covered hills of upper Teesdale. Rising on the slopes of Cross Fell the River Tees forms the northern and eastern boundary of the Reserve until it is joined by its tributary Mattergill Sike which forms the southern boundary. Between Mattergill Sike on the east and Swindale Beck on the west the southern boundary runs along Knock Ridge.

The summit ridge of the northern Pennines forms the major watershed between the rivers which drain to the Irish Sea in the west and those which eventually reach the North Sea in the east. Those which rise on the western slopes drain into the Vale of Eden and become tributaries of the River Eden which flows into the Irish Sea at the Solway Firth. The streams rising to the east of the summit ridge form part of the Tees drainage system which reaches the North Sea at Middlesborough.

1.2. History of the Moor House Reserve.

The area which now comprises the Moor House Reserve was used for scientific research prior to its purchase by the Nature Conservancy. Professor Gordon Manley had taken meteorological observations at the shooting lodge, which now forms the field station, and on the summit of Great Dun Fell while Mr.J.B.Cragg had carried out research on the blowflies of sheep. At the time of this early work the area was managed as a grouse moor by the Appleby Castle Estate who owned the freehold of the land. On the death of Lord Hothfield the freehold of the land came onto the market and it was purchased by the Conservancy to be managed as a nature reserve. The actual declaration of the reserve was made in May 1952.

Prior to the purchase of Moor House the Nature Conservancy had concentrated on acquiring areas of exceptional scientific interest so that these might be permanently safeguarded. Moor House is rather the preservation of an area of land which is typical of large tracts of the British Isles. Large areas of blanket peat had been envisaged as 'Scientific Areas' but no one area had been selected for acquisition. Dr Verona Conway visited Moor House to assess its value both from the point of view of conservation and also as a site for ecological experiments before it was actually purchased by the Conservancy. The area provided a large stretch of blanket peat along with several other habitats and also the shooting lodge could be converted into a field station on which research work could be centred. The reserve is large enough to allow the twin aims of the Nature Conservancy of conservation and ecological research, in its broadest sense, to be carried out without interferring with each other and both aspects have received equal attention since the foundation.

1.3. Origin and Aims of the Research Project.

The topic investigated in the present study has its origins in work carried out for the Nature Conservancy by Professor K.C.Dunham and Dr. G.A.L.Johnson. This original work, culminated in the publishing of the monograph 'The Geology of Moor House', was proposed by Professor Dunham and, with the backing of the Nature Conservancy, was begun in 1954. Dr. G.A.L.Johnson joined the Durham department as research assistant to help with the survey. The original scope of this work was the solid and drift geology of the reserve but this was later enlarged to include the soil mineralogy and finally a soil map. As might be expected by far the greater length of time was devoted to the geological side of the study and the stratagraphical and paleaontological aspects received the greater emphasis. But sufficient pedological and mineralogical work was carried out to reveal interesting problems within these fields.

The soil mineralogy studies concentrated on the clay fraction and both differential thermal analysis and X-ray techniques were used. The same methods were used to study the clay fraction of the Carboniferous Rocks of the area. At a later stage a soil map was completed and typical profiles of each of the soils types represented were described. Only one chapter was devoted to soils in the monograph, and thus only an outline of the soil investigation was given and many of the questions raised during the soil work had to be left unanswered. At this stage the soils of the Reserve had been named, their distribution had been shown on a map and the dominant clay minerals present in the soils had been determined. No chemical data was available for the soils, no mineralogical data for the +2 micron fraction and no detailed clay mineral analyses had been attempted.

Also no work had been carried out on the relationship of soil type to slope, vegetation and geology.

It was because of these unanswered questions on the soils and the lack of routine physico-chemical data that the present research was undertaken. When work on the Moor House Monograph was completed it was decided that sufficient pedological work remained to justify it being offered as the subject for a study towards the degree of Doctor of Philosophy. The subject was brought to the attention of the writer by Dr. G.A.L.Johnson in the summer of 1963 and work was begun in the October of that year. The existing work was taken as a basis for the new study and in particular the soil map of the Reserve; time has not been spent in remapping, except on certain critical areas. Initially each of the soil types present was described and sampled with a view to analysis. This stage was followed by a more detailed examination of some of the soil types with regard to their major properties and their evolution at particular sites. In the earlier work much attention was paid to the brown soils found over limestones. Now an attempt has been made to classify these soils more accurately and to investigate the interrelationship of the various types of brown soils over limestone which are found on the reserve. The factors which have caused the divergence in the evolution of the soils and hence the variation in soil type have also been examined.

The aims of the research can, therefore, be summarised as follows:

1) The completion of the soil survey already begun by sampling and subsequent analysis of representative soil profiles.

2) The investigation of the evolution and the interrelationship of the soil types present on the reserve as revealed by large scale mapping of certain areas and the detailed chemical and

mineralogical analyses.

3). The provision of a 'manual' of the soils present on the Reserve for the reference of future workers on the area.

1.4. Previous research at Moor House.

It is important to remember that the present work on soils is only part of the research activity which is taking place on the Moor House Reserve at the present time. The earliest work carried out on the area has already been mentioned (p.3) and dates from before the area was acquired by the Nature Conservancy. Since then the Nature Reserve was declared this has been followed by a continuous succession of projects, mainly of an ecological nature. Research has been carried out by resident staff and also by visiting scientists and a large number of Ph.D. and M.Sc. projects have been completed in the area.

A major line of study has been grassland productivity related to sheep grazing (Rawes 1961, 1963 and 1965; Rawes and Welch 1964 and 1966): this research is continuing. Botanical work has varied from the construction of a vegetation map (Eddy, Welch and Rawes 1968) to detailed studies on a single species, e.g. *Juncus squarrosus* (Welch 1966). Similarly zoological work has varied, from studies of the populations of a given site, e.g. stream sides (Nelson 1965), to studies of a single species, e.g. *Melophylus ater* (Hadley 1967). Experimental tree plantings have also been carried out by staff from the Nature Conservancy Station at Merlewood (Brown, Carlisle and White 1964). It would be out of place to summarise all the previous research here but the "Moor House Publications" list found in the back pocket of this volume gives eloquent testimony of the wide research interests in the area.

The present research has drawn heavily upon previous work carried out on the Reserve, especially in Part I, and the work is to be seen essentially as part of a much larger programme of research.

1.5. Previous pedological work in the Northern Pennines.

The earliest mention of the soils of the northern Pennine area is probably to be found in early works on the geology, natural history or agriculture of the region. Most of these references to the soils are brief and asides to the general subject, thus Robinson (1709) says of the limestone soils that they are "productive of a great variety of fine sweet Herbs, Plants and Flowers which afford rich feeding". Hutchinson (1794) says of the Cumberland fells, "climate and soil are best suited to grazing".

The Board of Agriculture reports on the agriculture of each county were published in 1794 and often contain some reference to soils with, in some cases, a soil map. The report for Westmorland (Pringle 1794) has no soil map and the only reference to soils is the "Preliminary Observations" by the Bishop of Landaff. The Bishop makes the following reference, "Others constitute extensive mountainous districts, called by the natives fells and moors; the soils of these is, generally speaking, an hazel mould. In its natural state, it produces little else than a coarse benty grass, heath, and fern; or, in the language of the country, ling and brackens". The report for Cumberland (Bailey and Culley 1794) divides the soils of that area into four classes, fertile clays, dry loams, wet loam, and black peat earth. The authors say of the dry loams, "Not only the lower districts, but the steep sides of the mountains, are in general of this soil, and in many places even their summits are covered with a dry sound earth, producing green sward, with little heath". The black peat earth is said to be "most prevalent on the mountainous districts, particularly those adjoining Northumberland and Durham". These comments would appear to be rather more accurate than the Bishop of Landaff's "hazel mould". A soil map is included in the North Riding of Yorkshire report (Tuke 1794) and shows the areas immediately south of the Westmorland border as "Limestone Soils". Tuke divides the north riding up and considers it under these divisions : when discussing the "Western Moorlands" he says the soils "In the lower parts of these moors, is some fine loamy soil, in many places a stiff loam, upon a hard blue lime-stone. The hills covered with grass consist, with scarce any exception, of limestone. The bent generally covers a strong soil lying upon greet, or free-stone rock; the black ling, a reddish peat, upon a red sub-soil, or in many places a loose greet rubble beneath which is greet rock".

Johnston (1844) in his "Lectures on Agricultural Chemistry and Geology" considers each of the geological systems and after first discussing the strata of the system he devotes some attention to the soils developed over the strata in question. In his section on the Carboniferous System Johnston has the following to say about the soils developed over "Mountain Limestone", "From the slowness with which the rock decays, many parts of it are quite naked, in others, it is covered with a thin light porous soil of brown colour". Then, later, "Where the limestones are mixed or interstratified with shale-beds, which decay more easily, a deeper soil is found, especially in the hollows and towards the bottom of the valleys". Sopwith (1833) states that, "the influence of calcareous strata on the soil is very conspicuous." These references, and many similar ones, pick out the soils developed on limestones for attention and this is probably because they provided the best grazing on the lower fells and a break in the peat cover on the higher fells.

In his discussion of the soils of 'Cumbria' Bainbridge (1939) distinguishes three main classes of soil :

a) Mountain Soils

b) Forest Soils

c) Marine Alluvial Soils.

He then sub-divides these classes on the basis of parent material. The Pennine uplands he dismisses as being peat covered.

Detailed examination of the soils is very recent. The late Dr.Crompton, in a series of papers between 1952 and 1958, examined peaty gleyed podzols and related soils associated with impeded drainage. A study of grassland humus forms was carried out by Barratt (1959) and the study was concentrated on the Malham area. She examined shallow soils over limestone and ~~then limestones with~~ th various thicknesses of drift over limestone ~~cover;~~ grassland in lower areas was examined for comparison. Several more Ph.D. and M.Sc. studies have been carried out on the soils associated with limestone outcrops and superficial material covering limestone. Syers (1963) concentrated on the early stages of soil development over limestone and in particular the effect of lichens on the weathering of limestone. This study was carried out in the Malham area as was one by Bullock (1963) but he examined a sequence of soils developed in a thickening cover of superficial material over limestone. Bullock (ibid) examined the parent material in detail and showed a loessial and drift contribution. Fadlalla (1963) working in central Cumberland carried out a similar study to Bullock in that he examined soils developed in various depths of superficial material over limestone and related soil type to depth of material.

The previous work carried out on soils on the Moor House Reserve by Johnson (Johnson and Dunham 1963) has been mentioned already (p. 4). Prior to this work Park had begun preliminary studies on the soils of various sites chosen for detailed botanical work : the results of this work by Park is to be found in the Moor House Reserve Records. Many soil analyses have been carried out in connection with botanical work on the Reserve and some of these have been incorporated into the present study. In connection with an experimental tree plantation at Green Hole a soil map was made of a small area by three students, this is also used in this study.

CHAPTER 2.

The Soil Forming Factors - Introduction.

The principle of soils being the result of the interaction of various, identifiable factors was first ennunciated by the Russian soil scientist Dokuchaev. It is now known that much earlier writers, e.g. Lomonosov (1711-1765) recognised the importance of external and internal agents in soil formation but Dokuchaev was the first to state the factors involved. Crocker (1952) quotes Dokuchaev as saying the following about soils, they are "always the result of the mutual action of the following agents, living and dead organisms (plants and animals), maternal rock formations, climate, and the relief of the location". These, then, were the soil forming factors as seen by Dokuchaev. Hilgard, a contempory of Dokuchaev's, working in the U.S.A., came to similar conclusions to those of Dokuchaev but he considered climate to be of overriding importance, this was also true of many of Dokuchaev's pupils and successors in Russia.

The publication of Jenny's book, "Factors of Soil Formation" in 1941 caused renewed interest in the factoral approach to soil genesis. In his book Jenny lists the soil forming factors as parent material, climate, topography, organisms and time; organisms included vegetation and man. It was in this same book that Jenny began the "functional factoral" approach to soil science. In this approach he attempted to represent the soil forming factors as variables in an equation which defined the soil. He gave his "fundamental equation of soil forming factors" as :

$$s = f\ (cl, o, r, p, t, \ldots),$$

where cl, o, r, p, and t represent climate, organisms, topography, parent material and time respectively and 'f' stands for "function of" or "dependent on". Jenny added a number of dots after his soil forming factors in case "additional soil formers have to be included". The functional aspect of Jenny's work has been criticised, e.g. Gerassimov (1947), but the book was important as it revived the factoral approach.

Rode (1947) added to the soil forming factors of Jenny. In the conclusions at the end of his book he states that three more factors have to be added, namely gravity, water (surface, soil and ground) and the economic activity of man. Sub-surface water is still considered a separate factor by German workers, e.g. Muckenhausen 1962, but most other workers consider it as a function of topography. Muckenhausen (ibid) also divides the 'organisms' of Jenny (1941) into vegetation, animals and man, thus giving eight factors in all. Most other writers, e.g. Duchaufour (1960), use vegetation and man as separate factors but not animals : Duchaufour (ibid) has six soil forming factors. Duchaufour (ibid) also introduces a subdivision of the factors into "facteurs passifs", i.e. parent material, and "facteurs actifs", i.e. climate, vegetation, topography and man. Muckenhausen (1962) states the same thing in a slightly different way when he says that climate, vegetation, water, relief, animals and man act upon the parent material in time.

In the following chapters parent material, topography, climate, vegetation, man and time are considered as they affect the soils in the Moor House region. To these conventional factors has been added a chapter on "Peat Erosion" (Chapter 9) as in the local conditions prevailing at Moor House this is of great importance : in the presence of a peat blanket the mineral soil is sealed off whereas on removal of the peat the mineral material is once again exposed to action of the "facteurs actifs". In recent years the polycyclic nature of many soils has been realised so that a soil formed under one set of conditions may become a parent material when the conditions change. As a result past as well as present conditions must be considered, hence Muckenhausen (1962) sets the background to his study of West German soils by examining soil forming conditions from the Cretaceous until the present day. In the following chapters the last glaciation is taken as a datum line and changes are considered in the soil forming factors since that time. These chapters have been written with a criticism, made by Crocker (1952), in mind. "All too frequently pedologists approach soil genesis from the starting point of a hypothetical uniform parent material being suddenly presented (soil-formation time zero) to the influence of the other pedogenic factors, and from which soil formation proceeds under uniform conditions until maturity (equilibrium) conditions are approached".

CHAPTER 3.

Parent Materials.

3.1. Introduction

In most soils the influence of the parent material is most marked during the early stages of evolution. In zonal classifications, those soils in which parent material continued to be the dominant factor in the soil's formation even when it was in equilibrium were designated as intrazonal, e.g. soils developed over limestones. Parent material usually influences the soils developed on it in two main ways :-

(i) Through its physical properties
(ii) Through its chemical properties. (Robinson 1949).

The physical properties help to determine the texture of the soil so that shaley parent materials usually result in heavy soils whereas sandstones will give rise to light sandy soils. The permeability of the parent material will also influence soil development as it will help to determine the drainage conditions in the soil. The well jointed nature of limestones is one of the most important factors influencing the development of soils on it as they are usually very freely drained. Well drained soils are often rapidly leached of the cations in a humid climate but poor drainage under similar conditions would tend to produce a gleyed soil.

The chemical properties of the parent material influence the base status of the soil which subsequently forms. Acid igneous rocks and sandstones tend to give rise to soils with a low-base status and basic igneous rocks a high base status; clay rich sedimentary rocks will tend to produce soils with a higher base status than clay poor ones. High base status in a soil encourages biological activity which in turn greatly influences soil development in that it will cause rapid assimilation of humus into the mineral soil and the formation of a good structure. These two factors will tend to work against the processes of podzolisation and 'lessivage' and if they do not prevent them they will retard their effect. The most significant cation seems to be calcium as rocks with a reasonable content of calcium are fairly common and in limestones it forms a major part of the rock. The separation of parent materials into calcium rich and calcium poor types is reflected in vegetation and in soil type.

3.2. Solid Geology

Sedimentary Rocks -

The parent materials of the soils of the area can be divided into two major groups :

1) Those derived from bedrock in situ,
2) Those derived from transported material.

The second group includes glacial drift and colluvial material, and possibly some aeolian addition. The soils formed from bedrock in situ cover very small areas on the Reserve but they are found associated with some of the limestones, the Ordovician tuffs, the Whin Sill and some of the sandstones. The transported materials seem to have been derived from within the area and moved very short distances so that they reflect the local solid geology.

The solid geology is dominated by the Carboniferous rocks which underlay almost the whole of the area (Fig.3). The exception is a small area at the foot of the western escarpment, in the extreme north west corner of the Reserve, which is formed of

Ordovician rocks. The Ordovician rocks, along with Silurian rocks, outcrop as an inlier some twelve miles long stretching along the foot of the escarpment from Melmerby to Hilton. The same rocks are seen again in a smaller inlier at the foot of Cronkley Fell, Teesdale, and it is these rocks which form the basement upon which the Carboniferous rocks of the Alston Block were deposited (Fig.4). The small area of Ordovician rocks found on the Reserve occurs between Middle Tongue Beck and Crowdundle Beck. The sediments in question belong to the Ellergill Beds and are highly folded and cleaved slaty rocks; occassional tuff bands cut these sediments (p.21).

The lowest rocks laid down by the Carboniferous sea as it spread across the platform of Ordovician rocks were conglomerates and good exposures of them are found in Crowdundle Beck and Knock Ore Gill. The conglomerate contains pebbles of vein quartz and the underlying Ordovician rocks in an arenaceous matrix. The conglomerate passes upwards into a series of sandy beds with alternating thin limestones which are collectively known as the Transition Beds; the beds are very poorly exposed. The Basement Conglomerate and the Transition Beds are known collectively as the Basement Series.

After the deposition of the Transition Beds the Melmerby Scar Limestone was laid down. Following this cyclic sedimentation became dominant and is reflected in the regular alternations of limestone, shale and sandstone which are found between the Transition Beds and the Great Limestone. The thickness of the constituent limestones, shales and sandstones varies from cycle to cycle (Fig.5). This alternation of rock type is the underlying cause of the stepped topography of the western escarpment: the limestones and sandstones form the scarps, or faces of the steps, and the shales the benches between.

The first limestone above the Transition Beds is the Melmerby Scar Limestone which is also the thickest limestone of the local Carboniferous. This limestone forms a very prominent feature, especially between Crowdundle Beck and Knock Ore Gill. South of Knock Ore Gill it does not give rise to a definite scarp but the feature caused by it is traceable most of the way to Swindale Beck. The limestone averages about 125 feet in thickness on the Reserve and is divided into posts, or beds, of various thicknesses by 'marly' partings. The colour of the limestone varies from a dull grey to grey-buff or white and it contains bands of pseudobrecciated limestone which has the appearance of a breccia due to patchy recrystallisation, accompanied in places by dolomitisation (Dixon 1911). The Melmerby Scar Limestone is very fossiliferous in certain bands.

The Melmerby Scar Limestone is separated from the next limestone above it by a succession of shales, fine grained sandstones and flaggy sandstones. The total thickness of these shales and sandstones varies rapidly, e.g. it is 17 feet in Swindale Beck and seven feet in Knock Ore Gill; the lithology varies equally rapidly. The next limestone above the Melmerby Scar is the Robinson and it is a grey-buff crinoidal limestone of about 16 feet: it does not give rise to a feature. About 25 feet of micaceous sandstone, limestone and ganisteroid sandstone overlie the Robinson Limestone but are poorly exposed. The beds from the base of the Melmerby Scar Limestone to the base of the Smiddly Limestone are grouped together as the Lower Limestone Group.

Although most of the strata which are included within the Middle Limestone Group can be found at exposure somewhere within the Reserve area, only a few form features. The more important and persistant members of the group will be mentioned here but the others are shown in fig 5. The Smiddy Limestone forms the base of the group and is itself devisable into an upper and a lower member. The Lower Smiddy is about 21 ft. thick and the Upper some 26 ft. ; the two are separated by 7 ft of shales and sandstones. Neither of the limestones give rise to prominent features. The Smiddy Ganister, the sandstone above the Upper Smiddy Limestone, is about 50 ft. thick on the escarpment and is a hard, light coloured ganister ; on the escarpment the ganister forms a discontinuous feature and areas of heavy scree.

The next two limestones, the Lower Little and the Jew are respectively 21 ft. and 28 ft. thick and are overlain by 40 feet and 30 feet of shales respectively. They have a very limited outcrop which is essentially restricted to streams. The Tyne Bottem Limestone outcrops over a fairly large area around Moor House itself where the full thickness of 26 feet can be seen. On the escarpment it is found immediately above or below the Whin Sill and may give rise to a small feature although this is usually insignificant compared to the feature due to the sill. The top 3 to 4 feet of the limestone are very impure and shaley. Some 30 feet of hard dark shales, the Tynebottem Plate, overlie the limestone and these give way in turn to a hard light coloured sandstone, the House Hill sandstone, which is well exposed near the Moor House Field Station.

The impersistant limestones, the Maize Beck (3 to 4 feet), the Single Post (11 feet) and the Cockle Shell (8 feet) form the next part of the succession. The outcrop of these limestones and the associated shales and sandstones is usually restricted to stream sections.

The Scar Limestone is the next persistant limestone and is at least 37 feet thick. It forms a distinct feature on the escarpment and a rather less distinct one on the dip slope at 2100 feet; it gives scattered outcrops along these features. The limestone is light grey and contains a persistant fossiliferous band, rich in large colonies of the coral Lithostrotium junceum, between six and fifteen feet above the base. The shale and sandstone above the Scar Limestone vary from a combined thickness of 18 feet on the escarpment to 40 feet on the dip slope. The sandstone, called Slaty Hazle, forms the top of Currick Hill.

The Five Yard Limestone is about 20 feet thick and may be split by a shaly parting. Fifteen feet of dark shale overlie the limestone and this is followed in turn by a thick series of sandstones (The High Brig Hazle = Six Fathom Hazle) which varies in thickness from 55 ft. in the west to 30 feet in the east. The sandstone forms a distinct feature on Hard Ridge and on the escarpment an almost continuous feature and the abundant scree material of High Raise Band and High Carle Band.

The Three Yard Limestone is about 11 feet thick and is followed by 40 feet of shale and 40 feet of sandstone, the Nattrass Gill Hazle, but the outcrop of all three is restricted. The Four Fathom Limestone is about 21 feet thick and is a medium grey, fine grained limestone in thick beds. It forms a small, discontinuous feature below the Great Limestone on the escarpment and the dip slope. It also forms a 'rim' around that section of Hard Hill on which the trig point is situated. The shale and sandstone above the Four Fathom total some 40 feet; the sandstone, the Quarry Hazle, is an important aquifer giving rise to a series of springs on Knock Fell and Hard Hill. The upper limestone of the Middle Limestone Group is the Iron Post Limestone, some two feet of impure limestone overlain by calcareous shales : its outcrop is very restricted.

The remainder of the Carboniferous rocks which outcrop within the Reserve boundaries belong to the Upper Limestone Group. The Great Limestone is the basal member of this group and is the second thickest limestone in the local Carboniferous succession being about 60 feet thick. It is an extremely persistant bed and forms a persistant feature, usually between 2400 and 2500 feet, and at Green Castle it gives rise to cliffs. The limestone is blue-grey, fine grained and well bedded. The upper part contains dark shale and marly bands and is known as the Tumbler Beds.

Above the Great Limestone the cyclothemic deposition of limestone, shale and sandstone is not found. The succession is mainly thick shales with subordinate sandstones and grits and only thin impure limestones and marine bands. These beds were laid down in shallow water with occassional marine transgressions. Immediately above the Great Limestone is a highly variable series of sandstones with interbedded shales and coals. The three main sandstones are the Low Coal Sill, the High Coal Sill and the White Hazle ; these are yellow and white medium grained sandstones with plant remains and ganisteroid bands. Exposure of these beds is poor but they form a feature which can be traced around the Dun Fells; they also form the highest parts of Knock Fell and Knock Ridge.

A thin, two feet, impure limestone, the Lower Little Limestone, overlies the Coal Sills but is poorly exposed. Thick shales succeed this limestone and they reach a thickness of 100 feet in Dun Fell Hush. Three marine horizons occur within these shales. Above the shales is the Firestone Sill, a medium grained sandstone which is some 20 feet thick, buff coloured and micaceous. The Crag Limestone is separated from the Firestone Sill by about ten feet of shales. This limestone is usually very impure and varies in thickness from 14 inches to five feet. Another 30 feet of dark shales overlie the Crag Limestone, these in turn give way to eight feet of fossiliferous cherty limestone, = the Lime Plate.

The succession of shales and sandstones continues above the Lime Plate and 100 feet are found before the next limestone, the Lower Fell Top Limestone. The more resistant sandstones in the 100 feet of shale and sandstones are the Slate Sills and form a feature around Great and Little Dun Fell. The Lower Fell Top Limestone is only one foot thick and it gives way to more shales and sandstones; a three inch coal is found within this sequence of shales and sandstones. The capping of Great and Little Dun Fell is formed by the Dun Fell Sandstone (= Low Grindstone Sill) which is some 60 feet thick, massive and medium to coarse grained.

Exposure of all the beds above the Coal Sills is extremely poor as the slopes of the Dun Fell's are covered by a layer of superficial material. This superficial material is affected by active creep and is derived from upslope and hence the beds above and including the Coal Sills. Much of the blanket of superficial material blanketing the upper flat surface of the Great Limestone will also have been derived from these beds.

Igneous Rocks -

The Milburn Beds, the horizon to which the Ordovician rocks outcropping at the western margin of the Reserve belong, consist of highly indurated and contorted shales and tuff bands. These belong to the "basal tuffs" of Hudson's (1937) sequence of volcanic rocks within the Cross Fell Inlier. The tuffs have given rise to small rounded hillocks between Crowdundle Beck and Middle Tongue Beck which will be considered further when discussing their brown ranker soils (p.412)

The Great Whin Sill underlies virtually the whole of the reserve and also has extensive outcrops. The Sill was intruded after the Coal Measures, as dykes connected with it cut these (Holmes and Harwood, 1928), but before - the Upper Brockram (Permian), as pebbles of the Sill have been found in this bed (Dunham 1932). It is very variable in thickness and in places reaches a thickness of 240 feet ; it is also found at various horizons, e.g. on Middle Tongue it is above the Tyne Bottem Limestone whereas in Knock Ore Gill it is below it and in the south east area of the reserve it is below the Lower Little Limestone, hence the sill is transgressive. Petrologically the sill is a quartz dolerite being composed of pyroxene 34%, feldspar 46%, with quartz, orthoclase, hornblende , biotite, chlorite and iron-titanium minerals (Dunham 1948). The petrology and chemistry of the sill will be mentioned further when dealing with peaty podzols developed over the Sill.

An almost continuous exposure of the Whin Sill is found along the escarpment and it generally gives rise to a strong feature at between 1800 and 1900 feet, in places it gives rise to heavy scree and boulders of the sill are a constant and important constituent of the superficial material below its outcrop. In the south east of the reserve it forms the bed of the Tees for some distance and can be seen in the bed of the tributary streams south of Little Dodgen Pot Sike, boulders are an important constituent of the drift in this area.

3.3. The Bedrock as Parent Materials.

Sedentary soils forming over the more massive, pure sandstones, e.g. the Smiddy Ganister, the Quarry Hazle or the Dun Fell Sandstone, would inevitably be very acid and base poor (Chapter 16). The limestones would give a neutral to slightly acid, base rich soil but the depth of soil produced would depend greatly on the purity of the limestone (Chapter 12). The limestones are attacked rapidly by solution and the pure limestones will provide very little insoluble residue to form the mineral basis of the soil, the impure limestones provide much more residue. The shales of the succession are base rich and produce a base rich soil but the soil would be extremely heavy and would almost certainly have impeded drainage.

The Whin Sill and the Ordvician tuffs will both weather very slowly under the climatic conditions prevailing at Moor House and so will carry very shallow soils. The Whin Sill will produce a base rich soil.

3.4. Glacial Geology.

The great bulk of the mineral soils and those underlying peats have been formed in a superficial deposit which has its origin in the glacial episode which affected the northern part of the northern hemisphere in the Quaternary period. In continental Europe four phases of glaciation have been distinguished, along with the associated interglacial periods, but only three of these phases seem to have affected the British Isles. These three phases gave rise to the Scandinavian (Elsterian = Mindel), the Early Scottish (Saalian = Riss) and Main Lake District (Weichselian = Wurm) glaciations. (West 1963). Evidence of the Scandinavian glaciation in this area is restricted to the Maryport - Silloth area but Trotter (1929) traced two drifts, which he correlated with the Older and Newer drifts of eastern England, these are the Early Scottish and Main Lake District glaciations, throughout the Vale of Eden. In the Early Scottish glaciation ice from Scotland and the Lake District affected Edenside but in the Main Lake District glaciation the Lake District, the Howgill Fells and the Cross Fell Range were the source of ice sheets which converged in the Vale of Eden to form a glacier which escaped north-eastwards into the Tyne valley and south-eastwards over Stainmore. At this time all the valleys of the escarpment would be filled with ice but the height to which the upper surface of the glacier extended has been the subject of much discussion. Trotter (1929) reports a Lake District erratic at 2200 ft. O.D. on the western escarpment, but the highest that a foreign erratic has been found on the Reserve is 1875 ft. Trotter (ibid) is of the opinion that at the maximum extent of the ice the western escarpment was covered but that the ground above 2200 ft. O.D. was probably covered with ice similar to the highland ice of the Antartic. Johnson (1963) supports Trotter's view but Raistrick (1931) was of the opinion that the Cross Fell range were nunataks in the Quaternary glaciation and never covered by a permanent ice sheet. Raistrick (ibid) also suggests that the two drifts of Edenside are two phases of thessame glaciation, a view which has not gained acceptance (e.g. Penny 1964, West 1963). The question of whether the fell tops were covered in ice is likely to remain open for a long time, (Johnson and Dunham 1963) but even if the tops were nunataks, soil formation would be restricted due to the intense solifluxion activity. Although Lake District erratics have been found the contribution of foreign material to the superficial deposits of the escarpment is negligible and true drift of this age is not found above 1250' O.D. The deposits on the escarpment are very similar to solifluxion deposits with boulders of a given stratum only being found at or below their outcrop and the whole was certainly intensively reworked in the two further cold periods which followed.

During the three glacial phases the upper Tees valley would almost certainly act as a collecting ground for ice, especially Tees head which would appear to be an ideal site. Drift is common on the eastern slopes up to 2000 ft. O.D. and retreat phenomena are found in the Tees valley ; the valley of Troutbeck shows evidence of glacial straightening. Glacial striae on Whin Sill in the Tees valley indicate that ice movement was in general down valley and the overall effect is a redistribution of local material with little, if any, introduction of external material. As on the escarpment the superficial material would be intensively reworked by solifluxion activity during the two cold phases which followed the Main Lake District glaciation.

As mentioned earlier the Main glaciation is of Weichsel (= Wurm) age but the exact correlation within the Weichsel is still problematic (Penny 1964). The retreat of the main ice sheet in Britain was interrupted three times, i.e. the Scottish Readvance (Zone I), the Perth-Aberdeen Readvance (Zone I) and the Highland Readvance (Zone III), and corrie glaciers were re-established in the Lake District and in the Cross Fell Range at the time of the last readvance. If corrie glaciers were not re-established in the two earlier readvances intense solifluxion activity would certainly affect the Pennine area and in the Zone III corrie glaciation the ice free areas would suffer intense freeze-thaw phenomena. The fresh morain material at 1250ft, 1900ft and 2250ft. O.D. in Knock Ore Gill and at 1500ft. in Middle Tongue Beck are attributed to the corrie glaciation (Johnson and Dunham 1963). Solifluxion phenomena are widespread on the Reserve, e.g. the solifluxion layer found near the upper surface of much of the drift deposits in which stones have been brought to angles near the vertical and the near vertical boulders protruding through the surface on Hard Hill, Currick Hill and Great and Little Dun Fell.

The most important point about the superficial deposits as parent material is that the material of which they are composed has been derived from the immediate vicinity. The drift and solifluxion deposits are therefore composed of the pre-glacial soil and weathered crust plus material picked up by the ice, i.e. fresh bedrock, and mixed in with the pre-glacial weathered material. Glaciation would not tend to alter the drift material chemically but would grind it down, i.e. weather it physically. Pre-glacial weathering may well have altered the superficial material but it is doubtful whether this would be detectable after this material had been mixed up during glaciation. Some indication of the make up of the drift and solifluxion deposits can be gained from the preceding examination of the solid geology and from the fact that the nearby bedrock tends to dominate any superficial deposits. The texture of the drift varies greatly from place to place, e.g. it is very stony on the eastern slopes of Burnt Hill and extremely clayey on Cottage Hill. Sandstone boulders are the commonest boulders in the drift and in particular the ganisteroid sandstones, the more arkosic sandstones seem to be broken down far more quickly. Large shale cobbles are very rare in the drift except within close proximity of a shale outcrop but small shale fragments are extremely persistant and are an important constituent of the 2 mm - 2 cm. fraction of the drift and soils, although sandstone fragments are by far the most common. Limestone boulders are uncommon but may be found but small limestone fragments are absent presumably due to attack by acid waters. Some larger limestone cobbles and boulder are preserved inside an iron rich rim and sometimes the iron rich outer rim has been broken through and the limestone inside removed by solution leaving a boxstone (Plates 1-3). X-ray diffraction work on

Plate 1. 'Boxstone' with the limestone core removed by solution.

Plate 2. 'Boxstone' with part of the limestone core still remaining.

boxstones and limestone boulders with an iron rich rim has shown the boxstones and the rims to be composed of iron carbonate, siderite, and iron hyroxides. It is suggested that these iron minerals are formed by the reaction of iron rich acid waters with the surface of limestone boulders. The siderite produced by this reaction would be resistant to further attack by acid waters but if the rim were incomplete the internal limestone may be dissolved by less iron rich acid water. An alternative suggestion is that the iron is derived from within the limestone itself but a very high iron content would be required to produce a rim as thick as is usually present. Below the Whin Sill outcrop quartz dolerite boulders are a very important constituent of the superficial deposits, especially on the escarpment. The quartz dolerite boulders almost always have a weathered rim due to attack by acid waters ; small fragments of the rock are not as common as one would expect, presumably because theyrare readily broken down in acid conditions.

The detailed mineralogy of the superficial deposits reflects that of the sandstones, shales, Whin Sill and the insoluble residue of the limestones, together with the large suiteof minerals introduced by mineralisation. The mineralogy, therefore, is potentially very variable.

The potential of the drift as a medium for plant growth will vary considerably depending upon the relative contribution to the drift of the various rock types. The Whin Sill and the shales give a base rich soil but the shales also yield a very heavy soil, whereas the sandstones would give a base poor, sandy soil.

Plate 3. Part of a 'boxstone' with the limestone core showing up black.

CHAPTER 4

Topography

4.1. Introduction.

Topography can affect soil formation in several ways. It can cause variations in micro climate which will be reflected in soil developments, thus precipitation increases with increasing altitude and temperature decreases. As temperature decreases and precipitation increases the effect of the precipitation is accentuated because evaporation is reduced. The increased amount of cloud in upland areas also help to give an increased dampness.

In deeply dissected areas aspect can become very important in soil formation. On south facing slopes soils receive more solar radiation than on north facing slopes. As a result the soils on the slopes with a southern aspect are much warmer. In extreme cases soils are found to vary on the different slopes : the most detailed work on variation of soils with aspect has been carried out in Switzerland where different soil types are found on north and south facing slopes of sharp peaks.

Soil drainage is greatly affected by variations in topography and this is refered to as the "action indirecte" by Duchaufour (1965). This effect is very important on the Moor House area. On the steeper slopes soil drainage will be much better than on level or gently sloping sites. As a result freely drained soil types are commonest on sloping sites and soils with impeded drainage are commoner on level sites. In areas with heavy precipitation, such as Moor House, freely drained soil types are often restricted to sloping sites or sandy parent materials. Glentworth and Dion (1949) have shown the variation of soil type with slope within the podzol zone and have described the variation as a 'hydrological sequence;' Crampton (1965) has described a fairly similar type of sequence from south Wales. In both cases gleyed soils are found on the level sites, podzolic soils on the moderate slopes and brown earths on steep slopes.

The direct action of topography on soil development is found on very steep slopes where soils fail to reach maturity because of the instability due to the steep slope. The movements of material downslope due to soil creep leads to a thinning of the soils at the top of slopes and an accumulation and thickening at the base of slopes. Duchaufour (1960) describes a soil catena in limestone terrain controlled by this kind of downslope movement in which brown calcareous soils are found on the plateaus, a skeletal rendzina on the very steep slopes, a true rendzina near the base of the slope and a brown calcareous soil in the depressions. In addition to mass movement downslope movement of soil water carries clay grade material and nutrients down slope. Lessivage, movement of clay material down the profile, is commoner on sloping sites. ?

4.2. Structural and bedrock control of topography.

The Moor House Reserve straddles the summit ridge of the Pennines and in particular part of the Cross Fell massif. The morphology of this part of the Pennine chain is a reflection of the dominant structural unit of the area, the Alston Block. Trotter (1929) has said that, "In brief the Alston Block is topographically a 'desk structure' with a fault scarp trending between north west and north north west and a dip slope facing north east and east north east," (Fig 6). Later in the same paper he adds that the desk structure has an, "arched slope". This 'arched slope' of the dip slope is because the block has an anticline, the Teesdale anticline, superimposed onto it. It is because of this anticline that we do not find a series of streams flowing straight down the dip slope of the block; instead the Tees flows south eastwards and the South Tyne north, roughly parallel to the escarpment.

The final uplift of the Alston Block took place in Tertiary times and the westward facing escarpment had its origins in this uplift. The scarp is the remains of the fault scarp of the Inner Pennine Fault. The Block itself has been in existance as a structural unit since Devonian times and as such has had an important influence upon the post-Devonian geological history of the region. Trotter (1929) is of the opinion that a Tertiary peneplain was developed prior to the final uplift and the dip slope of the Alston Block is cut into this peneplain. Cross Fell, Great and Little Dun Fell and Mickle Fell rose above the peneplain as monadnocks.

The lowest point on the Reserve, approximately 1000 feet, is found at the foot of the escarpment at the western edge of the Reserve. In a distance of some two miles the scarp climbs to the highest point, 2780 feet, on Great Dun Fell (Fig 7). From the summit ridge, of which Great Dun Fell forms a part, the land falls away down the dip slope to the River Tees. The gradient on the dip slope is much gentler than on the escarpment dropping from 2780 feet to 1625 feet, in the south east corner of the Reserve, in just over five miles. On both the escarpment and the dip slope the gradient is far from constant and below the actual summit ridge forms a series of steps. The stepped nature of the slopes is due to the variable nature of the carboniferous rocks which underlie almost the whole of the Reserve (Chapter 3). The Yoredale rocks, as this part of the Carboniferous succession is often refered to, is made up from a series of alternations of limestone, shale and sandstone and these produce the stepped topography with the limestones forming the steep faces of the steps and the sandstones and shales the flat benches between. This stepped topography is superimposed onto the scarp and dip slope of the block but is much better developed on the scarp slope as the steeper slope produces a quicker variation of the rocks at outcrop.

Plate 4. 'Solifluxion layer' of sandstone blocks exposed by erosion of peat.

4.3. Influence of glaciation on topography.

The area has been influenced by both glacial erosion and deposition. Goodchild (1875) is of the opinion that the stepped topography, although having as its ultimate cause the variable lithology, is due to ice erosion by a glacier flowing parallel to the strike of the rocks. A study of the topography of all the areas where Yoredale rocks are found at outcrop may show whether Goodchild is correct but his theory requires actively eroding ice at above 2000 feet in the Pennines which would seem unlikely. Glacial deposition on a large scale tends to mask the existing topography. In the stepped topography it is likely to even out the steps by depositing a thicker layer of drift at the back of the steps than at the front. Fairly large areas of the lower parts of the dip slope, mainly below 2000 feet, has a masking cover of drift and many of the minor hills and stream valleys are cut into this drift. On the scarp slope the effect of the drift is less obvious probably because the steep slopes have increased instability and resulted in the drift being redistributed. Small terminal moraines, laid down by small valley glaciers in the Allerod (Johnson and Dunham 1963) are found in the valleys of Knock Ore Gill and Middle Tongue Beck.

In the late glacial the area must have been subject to severe periglacial conditions. Frost action would redistribute, or disturb, much of the superficial material. A widespread solifluxion layer is found below the peat cover. Bare rock faces would also be subject to frost action and the coarse sandstone screes, e.g. High Raised Band, and High and Low Carle Band, may date from this period.

4.4. Influence of peat development on topography.

The onset of blanket peat development in the Atlantic period would only have small effect on the topography but many small

Plate 4a. Knock Ridge from Great Dun Fell.

Plate 5. Great and Little Dun Fell with Hard Ridge extending eastwards from Great Dun Fell. Dun Fell Hush can be seen on the slopes of Great Dun Fell.

scale features may have been masked by it. In general it would tend to round off existing features. Valley bog development has affected one small area and has infilled a small depression near the Moor House Field Station. The most important role of the peat would be in sealing off the pre-existing superficial material and slowing down normal erosion.

4.5. Topographical Regions of the Moor House Reserve.

The area can be divided into three topographical regions :-

a) The summit ridge

b) The scarp slope

c) The dip slope

The summit ridge is formed on a platform of the Great Limestone at 2500 feet north of Knock Fell and on the Four Fathom Limestone at about 2300 feet on Knock Fell and Knock Ridge. Great and Little Dun Fell are steep sided rounded summits (Plate 5) which rise some 200 to 300 feet above the Great Limestone. Both summits are elongated in the general direction of trend of this section of the ridge, i.e. north north west - south south east, and lack the stepped nature of the slopes below the Great Limestone, Knock Fell is rather the highest part of a broad, flat topped ridge, Knock Ridge, (Plate 4a), which forms the summit ridge south of Great Dun Fell. The summit ridge trends in different directions along its length (Fig 7); the section on which Great and Little Dun Fell are found trends north north west south south east, the northern half of Knock Ridge trends west south west to east north east and the southern half north west - south east. These changes in direction alter the length and, as a result, the gradient of the scarp and dip slope.

Plate 6a. The eastern slopes from the summit ridge.

Plate 6b. The eastern slopes dropping away from Knock Ridge.

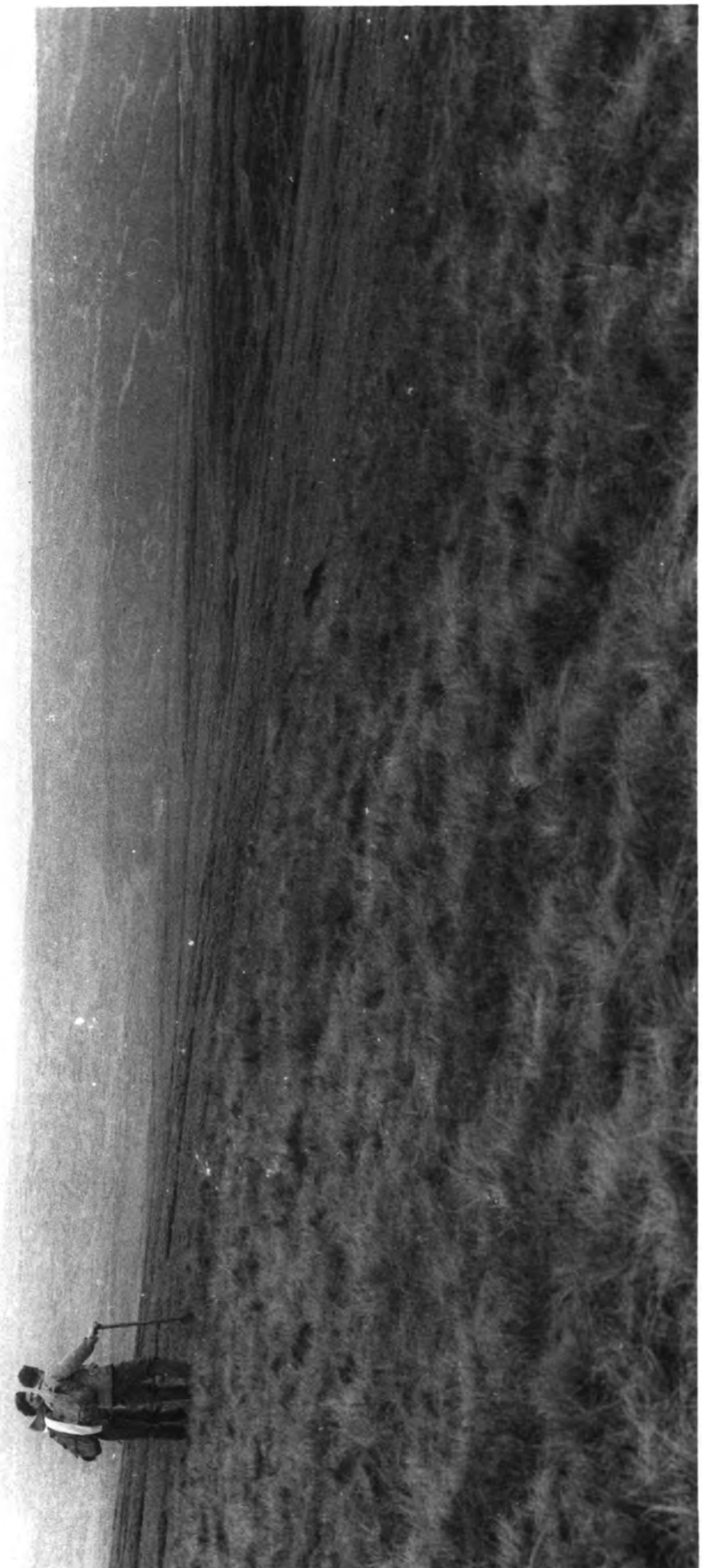
Plate 7. Looking up Knock Ore Gill to Green Castle and Knock Fell and showing the steep valley sides. The limestone outcrops in the foreground are the Melmerby Scar Limestone.

The escarpment is always much steeper than the dip slope and the stepped topography is more marked. The scarp is cut by four main stream valleys and several small ones. The main stream valleys, e.g. Knock Ore Gill, are very steep sided and show a V-shaped profile (Plate 7); the valleys are almost straight and cut at right angles to the trend of the summit ridge. In places the slopes of the valleys form large free to excessively drained sites but elsewhere they are so steep that instability is present. The features due to the various limestones, sandstones and the Whin Sill vary greatly along the escarpment. The Great Limestone, the Melmerby Scar Limestone and the Whin Sill always produce features but they vary in size from place to place. The Melmerby Scar Limestone feature, at around 1400 to 1500 feet, is most marked north of Knock Ore Gill and south of this it is only a small change of slope. The same is true of the Whin Sill feature, at around 1800 to 1900 feet. The Great Limestone feature, at 2400 to 2500 feet, is always very marked and at Green Castle it gives rise to cliffs which are the highest limestone cliffs in England. Small, discontinuous features are given by the Four Fathom Limestone, between 2300 and 2400 feet, the Scar Limestone, between 2000 and 2100 feet and the Six Fathom Hazle, between 2200 and 2300 feet.

The north part of the dip slope within the Reserve takes the form of a large ridge, Hard Ridge (Plate 8) running out at right angles to the summit ridge. The River Tees lies to the north of Hard Ridge and Troutbeck to the south and the ridge is terminated by the confluence of these two streams. Hard Ridge has a fairly uniform slope from 2400 feet down to 1800 feet at the confluence : the distance is some three miles. The gradient slackens briefly at 2275 to 2225 feet due to a bench formed by the Quarry Hazle and the Four Fathom Limestone forms a distinct feature on the north and east faces of the ridge at 2200 feet. The valleys of Troutbeck and the Tees are in marked contrast

Plate 8. Hard Ridge extending out from the summit ridge. The Moor House Field Station can be seen in the foreground.

Plate 9. Looking across the head of Troutbeck valley to Hard Ridge and showing the gradual slopes east of the summit ridge.



to the valleys of the escarpment and are relatively wide, shallow and flat bottomed (Plates 9 and 9a).

South of Troutbeck the lands drop fairly steeply from the Knock Ridge to 2200 feet and then below this the gradient slackens appreciably (Plates 6a and 6b). The streams draining this area are tributaries of the Tees or Troutbeck and have shallow, open meandering valleys which are often cut into drift. The Scar Limestone gives a discontinuous feature at between 2000 and 2100 feet. The general aspect is of low, flat topped, peat covered hills with meandering, open valleys between. A large amount of the surface topography seems to be cut into a drift cover below 1900 feet.

4.6. Morphology of the Smaller Valleys on the Dip Slope.

Having noted the distribution of the streams on the dip slope a short mention will be made of some characters of the valleys of the tributary streams of the Tees and Troutbeck which have some bearing on the erosion of the superificial material. When the streams are flowing in peat, erosion is very rapid once the vegetation cover is broken and down-cutting proceeds quickly producing very steep sided channels through the peat. At this stage the peat being removed is essentially that from the channel floor and a little from the walls as its widened but downcutting greatly predominates over widening. Eventually the channel is cut down to the level of the peat - drift interface and at this level the rate of downcutting is reduced and widening of the channels becomes much more important. The peat is removed by back cutting at the interface and this will expose the drift to soil forming processes again. As backcutting 'into' the peat is taking place downcutting, but at a reduced rate, into the drift is taking place;

Plate 9a. The confluence of Troutbeck and Netherhearth Sike showing the open valleys of the dip slope.

the channels cut into the drift are more open than those cut into peat but steeper sided than those cut into bedrock. At the drift - bedrock interface the rate of down-cutting is once again reduced and back cutting of the drift at the interface takes place. Most of the streams being discussed flow across the three different substrates, i.e. peat, drift and bedrock, somewhere along their courses and so show the differing valley forms. It is impossible to lay down a rigid zonal distribution of the sections of streams on the differing types of substrate but many rise on peat, then flow across drift and when they are more powerful on bedrock. Where the streams are near the peat - drift interface the soils near the streams will tend to be in drift but where they are at the drift - bedrock interface some of the soils may be developed on bedrock (Assuming that the bedrock is not being re-covered by alluvial material).

4.7. Changes in the Topographic Effect with Time.

The effect of topography as a soil forming factor would be most applicable in the pre-blanket peat period on the Reserve. At this time the variations in slope would be a factor in determining the distribution of the soil types of the area and the type of hydrological sequence described by Glentworth and Dion (1949) might have been developed. The sequence would be shown best on the stepped topography of the scarp slope but a difference would be expected between the soils of the steeper and less steep slopes of the eastern side of the summit ridge. In the period of birch forest brown earths would probably be found over much of the area but as humidity increased podzols and gleyed soils would tend to replace the brown earths. The podzols would dominate the better drained sites and the gleys the poorer drained ones. The steepest slopes of all, e.g. the valley sides of the western slopes, would limit soil development then as now. The exposed sites such as the summits of Great and Little Dun Fell would probably have extremely slow soil development as a result of their exposure and this will have applied throughout the evolution of the soils of these sites.

When peat development began topography would be important in that initially it would form on the level sites or at best on slight slopes. As the peat spread the steeper slopes would gradually be covered as the pace of expansion overcame the inherent instability of the peat on steeper slopes. The effect of peat erosion would almost certainly operate in a reverse sequence with the peat being removed from the steepest slopes first and remaining longest on the gentle slopes and flat sites. Thus topography will have had some effect on the age of the soils. Once the soils were exposed from the peat cover the normal effects of topography on drainage would become important again and influence the types of mineral soils formed.

The drainage system is also extremely important in the removal of peat from the surface and the subsequent exposure of the mineral material beneath. Directly the streams only affect a very narrow strip of land along their courses but as they cut down they cause renewed erosion of the peat adjacent to them by their tributaries which rise in the peat. Where the streams are very dense then the likelihood of the area between them being stripped of peat is increased.

Plate 10. 'Islands' of blanket peat showing an advanced stage of erosion.

CHAPTER 5

Climate

5.1. Introduction

The one factor in soil formation which has received far more attention than any other is the climatic factor. This great emphasis on climate probably dates from the period when the zonal distribution of soils was first recognised and led to the series of soil classifications based on climate. Crocker (1952) states that the zonal concept dates from Sibertzev.

Temperature is significant as it controls the rate of the chemical reactions which take place in the soil and which are responsible for the breakdown of parent materials, with subsequent release of plant nutrients, and the formation of authigenic clay minerals. The reactions concerned proceed much quicker at higher temperatures. Rainfall determines, to some extent, the amount of leaching which a soil undergoes so that excessive leaching will only be found in wet climates. 'Lessivage', the down washing of clay minerals, will only take place in a wet climate; plus a free draining soil. Soil texture and site topography become very important in wet conditions as a heavy soil or a badly drained site will lead to gleying. Temperature and rainfall must be considered together as a low temperature will increase the effectiveness of a given amount of rainfall because it will reduce evapo-transpiration.

The regional climate can be taken as a background when considering soil evolution in a given area but the micro-climate of a given site must also be considered, e.g. the variation in climate on the two sides of a conical mountain peak can give completely different soil types.

5.2. Present Day Climatic Conditions.

Continuous climatological records have been kept at the Moor House Field Station since the Nature Conservancy took over the area in 1952. Prior to that Professor Manley had taken meteorological readings for several short periods at the house, now the Field Station, and from a small hut on the slopes of Great Dun Fell. Since 1958 meteorological records have been kept at the Ministry of Aviation, Dun Fell Radio Station. As a result a reasonably detailed picture has been built up of this stretch of the Pennines. Manley has published several papers on the subject of the climate (Manley 1936, '38, '39, '42, '43) and others have been published by Green (1953, '56, '59a, '59b, '59c, 65) and Millar (1964); these papers should be consulted for detailed observations.

A general impression of the climate of the area can be gained from an examination of Tables 1 and 2 and the following comments are based on these readings. The average annual temperature at Moor House is 5.1°C and the range is from -0.7°C in January to 11.0°C in July. The growing season (Months with average temperatures above 6°C) is five and a half months, from early May until late October. In three months the average temperature is below freezing (December, January and February) and air frosts are known in every month. The Dun Fell temperatures are fairly similar to those of Moor House during the winter but during the rest of the year Dun Fell is several degrees colder (Table 2). At these temperatures most chemical weathering will be at a minimum and although the soil temperatures at one foot are always above freezing, 1.3°C in February to 11.7°C in August, soil reactions will be slowed down. It should be pointed out here that solution of limestone due to carbon dioxide in solution in water will be greater at temperatures near 0°C as more carbon dioxide can be dissolved at these temperatures than at higher ones. Most limestone solution will be accomplished by humic acids beneath soil cover so that the above effect will not be a major factor, although it will be a contributary one, in solution of limestone. The fact that the temperature is often at or close to zero, there are ground frosts on 169 days per year at Moor House, will mean that physical weathering due to frost action will be important.

The mean annual rainfall at Moor House is 73.6 inches and ranges from 4.3 inches in March to 8.7 inches in December. Given this amount of rainfall and 248 rain days per annum most of the soils will be in a damp condition, if not permanently saturated. The very shallow, excessively drained soils over limestone are still liable to dry out in dry spells. The high rainfall means that the soils will be heavily leached and that lessivage, movement of the clay fraction down the profile, is to be expected. The low temperatures reduce evapo-transpiration (Although the frequent winds offset this) and increase the effectiveness of the rainfall.

There is a snow cover at Moor House on an average of 63 days per year and this increases to about 100 days on Dun Fell. The snow generally collects in the valleys and hollows where it lies for long periods, but on the ridges and hill tops the cover is generally thin, and removed rapidly, owing to the persistant winds. Snow patches often persist in the vicinity of the Moor House Field Station until late April and in sheltered sites they often last until May or June. Snow patches will have a severe effect on the vegetation beneath them and they will, like any snow cover, maintain the soil below them in a saturated condition although most soil reactions will be slowed down. Snow cover on limestone will increase the rate of solution of the limestone as snow can contain more carbon dioxide in solution than water, especially warm water.

The low amount of sunshine, 1192 hours per year at Moor House and about 750 hours on Dun Fell, is evidence of the high amount of cloud cover. The number of days with fog at 9 a.m. on Dun Fell, 250 days per annum, are an indication of the dampness. The high cloud cover and high humidity will help maintain the soils in a damp, or even saturated condition, by reducing evapo-transpiration.

Mention has been made above of the persistent winds at Moor House. The number of calm days is very small but east of the summit ridge very high winds are also relative infrequent. On the higher ground high winds are much more common and may well have an effect on the rate of colonisation of bare ground. During drier periods the wind lifts the surface of bare peat faces and greatly facilitates erosion by later rainfall.

The present climate might be summarised as wet and windy with cool to warm summers and cold winters but also one with great day to day variability. The early climatically based soil classifications would probably have placed the area in the zone of podzolic soils but this would be a very dangerous generalisation. The high rainfall and humidity make podzolisation, leaching and 'lessivage' important processes but the rapid variations of slope, vegetation and parent material, added to the great day to day variability of the climate, are such that the micro-conditions of a particular site become vitally important.

5.3. Late and Post Glacial Climatic History (Fig.8)

In considering the evolution of the soils of the Moor House area the past as well as the present climate has to be considered. If the end of the last glacial episode is taken as a starting point then the climatic variations since that time must be considered. Pollen studies and studies of present day variations in the size of glaciers have given much information on the late and post glacial climate.

As the glaciers retreated at the end of the Ice Age a landscape of unsorted, hummocky drift, bare of vegetation would be left. Periglacial conditions would exist for a long time after the retreat and intense solifluxion would affect the superficial surface deposits ; the bare rock faces would suffer intense physical weathering. Redistribution of the superficial material would almost certainly take place during this period and would tend to remove the material from topographic highs and accumulate it in lower areas. This period immediately after the retreat of the main glaciers has been designated the Lower Dryas period or zone I. As zone I continued the climate ameliorated and a tundra vegetation would spread into the area and slowly form a continuous carpet on the lower slopes. Physical weathering would still be at a maximum and would greatly predominate over chemical weathering. Soil development, or rather modification of the bare rock or drift, would be at an absolute minimum although organic material would begin to be introduced into the surface layer of the drift.

Zone I lasted until 10,000 B.C. and the following zone II (the Allerod) until 8800 B.C. During zone II the climatic amelioration continued and Walker (1966) working in the Cumberland lowland suggests that by the latter half of this zone summer temperatures commonly exceeded 12°C but winters were cold enough for most of the precipitation to fall as snow. Walker (ibid) also finds a complete herbaceous cover in the lowlands at this time thus indicating a lack of permafrost development. In the Pennines conditions would be colder than in the Cumberland lowland but almost all the permafrost would be gone and birch forest may have spread into the more favourable areas.

Soil development would still be minimal.

In Zone III (the Upper Dryas, 8800-8200 B.C.) a climatic recession took place during which corrie glaciers formed again and intense solifluxion would be prevalent. Manley (1959) refers to the climate of this period as sub-arctic and equates it with the Perth readvance in Scotland. In the Cumberland lowland (Walker 1966) a slight climatic deterioration took place and the small fall in winter temperature was enough to cause solifluxion movements. Morainic deposits from the corrie glaciation of this period have been identified in the Lake District (Manley 1959) in the Upper Eden Valley (Rowell and Turner 1952) and on the Moor House Reserve itself (Johnson and Dunham 1963). The moraines on the Reserve have been mentioned previously, p. 25. The corrie glaciers plus intense solifluxion (or permafrost) would tend to negate any soil development which took place in Zones I and II. The existing periglacial phenomena, e.g. the sub-peat solifluxion layer (Plate 4) and the heavy sandstone scree, may well date from this period as any pre-existing phenomena would tend to be destroyed or reworked in Zone III.

The climate ameliorated again in Zone IV (Pre-Boreal, 8300-7700 B.C.) with a consequent spread of, first a tundra vegetation and then birch forest. Soil development would begin once again. Walker (1966) thinks there was a substantial rise in summer and winter temperature at about 7000 B.C. and an increase in the precipitation - evaporation ratio so that the climate became "markedly oceanic". He is of the opinion that this oceanic climate was "clearly adequate then to allow the development of 'mor' soils". The climate continued to improve in Zones V and VI (The Boreal, 7700-5500 B.C.) and with the increasing warmth there was a rapid spread of forest cover; the tree line was probably at about 2500 feet and hence the summit would be clear of forest. Soil evolution would now proceed more rapidly and under the birch forest an acid brown earth or a brown podzolic soil would most likely develop. In Zone VI pine and hazel would replace the birch to some extent and, pine especially, would increase the tendency towards podzol development.

During Zone V the first peat began to develop on the area under study but it was limited in extent. Pollen studies on the Valley Bog (Johnson and Dunham 1963) and from the eroding peat complex on Hard Hill (ibid) show that peat development began at these two sites at this time. Both these sites are natural depressions. The Valley Bog area is badly drained and the Hard Hill site, although not so badly drained, is a water receiving site. At this time peat development was limited to rather badly drained depressions.

The latter half of Zone VI and the whole of VIIa (The Atlantic Period) are known as the "climatic optimum" as the climate reaches its warmest (In post-glacial time) during this period. In most of Britain the "climatic optimum" is marked by a spread of alder-mixed oak forest but in the Pennines it is more important as the beginning of widespread blanket peat development. Most of the cover of blanket peat on the Moor House Reserve dates from this time. Godwin (1956) says of the spread of blanket peat that the Pennine chain, "... hitherto forest clad to high altitudes, passed by way of wet Molinetum to a continuous cover of acidic oligotrophic bog." Later he adds, "... we may note that those climatic factors which caused extensive mire formation led, in less extreme conditions of altitude, slope,parent material and local climate, to more or less pronounced podzolisation". In the Atlantic Period, therefore, not only did blanket peat formation begin but podzolisation would tend to become the dominant pedological process where soil drainage conditions and parent material permited. On the areas where blanket peat did form the mineral soil beneath it would be sealed off once the peat reached a reasonable thickness. The soils under deep peat are, therefore, fossil soils dating from the Sub-Boreal or Atlantic periods.

In Zone VIIb (the Sub-Boreal, 3000-500 B.C.) blanket peat continued to form, although the rate of build may have declined towards the end of the zone. As the Sub-Boreal gave way to the Sub-Atlantic (Zone VIII, 500 B.C. to present) there was a rapid deterioration in the climate. This deterioration gave rise to renewed growth of blanket bog and renewed podzolisation; the increased rainfall would also cause instability in deep peat. Climatic variations since the beginning of Zone VIII have been relatively small and so, from a climatic point of view, soil conditions have been relatively stable since that time.

Despite the climatic variations outlined above it would seem that the climate has been an oceanic one since about 7000 B.C. In the areas where mineral soils existed, as opposed to blanket peat, leaching, podzolisation, gleying and lessivage are likely to have been dominant processes since 7000 B.C. The processes would probably become more marked after 500 B.C. as the deterioration of the climate would reduce evapo-transpiration and give an apparent increase in rainfall. As mentioned earlier (p. 48) any generalisation, such as the above, is likely to be negated by local micro-conditions.

CHAPTER 6

Vegetation

6.1. Introduction

Crocker (1952) is of the opinion that vegetation is the most important soil forming factor and gives a very complete review of the influences vegetation has on soil formation and evolution. Muckenhausen (1962) reminds us that soil formation would be impossible without the macro and micro flora as they are the source of the humic materials which are essential constituents of soil. The ways in which vegetation is effective as a soil forming factor are listed by Duchaufour (1960) as follows :

a) By the microclimate which it favours.

b) By the depth of rooting

e) By the type of humus it produces

d) By its protection, more or less effective, against soil erosion

The microclimate is affected because the plant cover reduces the amount of solar radiation reaching the soil, but it also reduces heat loss due to radiation. The nett result will be to reduce temperature changes in the soil. A cover of vegetation will tend to increase water losses from the soil because of transpiration but it will keep the atmosphere damp near the soil surface.

Plant roots have several kinds of effect upon the soil. Roots from large plants, especially trees, will help to break down the parent material. They will do this physically by fragmenting material and also chemically due to the organic acids secreted by the roots. The roots nearer the surface will also break up the soil and are extremely important in the creation of structural units in the upper soil. The dense root mat under some grasslands is one factor in the formation of a crumb structure. The 'channels' through the soil which are created by roots are available for movement of water and air through the soil and this water carries with it clay material, in suspension, and various elements in solution.

Muller (1878 and 1884), in his classic works, demonstrated the importance of humus type in soil development with mull humus below deciduous forest associated with a brown earth and mor humus beneath a coniferous forest associated with a podzol. A change in the vegetation, and hence a change in humus type, could alter the soil type. Dimbleby (1962) has shown the same effect of a change of vegetation on the North Yorkshire Moors. The classic example of vegetation controlling soil evolution is the "kauri effect" in which the kauri tree (Agathis australis) in New Zealand causes podzolisation in a very restricted area around the individual tree during its lifetime. Carbon and nitrogen, fixed from the atmosphere by plants, are added to the soil as plant remains be they dead roots, leaves or stems. The humic material at or near the soil surface is also the source of humic acids which, when carried down the soil, facilitate such processes as podzolisation and solution of iron in gleyed soils (Bloomfield 1952, 1953, 1955).

6.2. The Vegetation of the Moor House Reserve.

A vegetation map of the Moor House Reserve, based on phytosocialogical communities, has been constructed by Eddy (1962), with additions by Welch (1965) Fig.9. Where-ever possible the associations recognised correspond to those of McVean and Ratcliffe (1962) who worked in the Scottish Highlands. The following details of the vegetation at Moor House are based on the written analyses of Eddy, Welch and Rawes (1968).

Botanical work carried out on the Reserve to date has recognised about 260 flowering plants, 250 mosses, 75 liverworts, 110 lichens, 40 fungi, and 30 algae. During the construction of the vegetation map some 30 communities were recognised although these were later regrouped into sixteen mapping units. Two of the communities recognised cover about one third of the total area of the Reserve. The two communities, Callunet - Eriophoretum (Calluna vulgaris and Eriophorum vaginatum Co-dominant) and Eriophoretum, (Eriophorum vaginatum dominant), dominate the vegetation of the blanket peat. McVean and Ratcliffe (ibid) refer to Calluneto - Eriophoretum as, "Pennine blanket bog" and as identifiable remains of the two dominants are found within the bog they are growing on these authors add that, "There is thus evidence that the present association has been in uninterrupted possession of the ground in many places from Atlantic times." The Calluneto - Eriophoretum has a carpet of mosses, chiefly Sphagnum spp. through which the dominants grow : Eriphorum angustifolum, Empetrum nigrum and Rubus chamaemorus are constants. The relative proportions of Calluna, Eriophorum and Sphagnum spp. varies with the degree of moisture, altitude, grazing pressure and length of time since the area was burnt. Sphagnum spp. increases in the wetter areas and grazing and burning both reduce the amount of Calluna; some areas of Eriophoretum may be anthropogenic in origin. The effect of higher grazing pressure can be seen by comparing the vegetation of the blanket peat on the escarpment (Higher sheep density) with that on the dip slope : in the former the Calluna has been removed and Sphagnum sp. reduced so that Eriophorum is now dominant. On the dip slope Calluneto - Eriophoretum gives way to an Eriophoretum in which the Sphagnum carpet is lacking with increasing altitude and Eddy, Welch and Rawes (1968) designate this as a high altitude phase of

Eriophoretum. Trichophoreto-Eriophoretum occupies small areas of blanket bog which has a high water table plus the two valley bogs.

Large areas of blanket bog has been mapped as "Eroding bog" which is defined as blanket bog "in which more than about 30% of the original surface has been removed by erosion, and in which recolonisation has occurred in less than half of the newly exposed surface," (Eddy, Welch and Rawes 1968). Areas of this are found within all the blanket bog associations. The areas of recolonised peat complexes and peat edge vegetation are areas in which the recolonisation has gone further than the level mentioned above. These areas are important because they are transitional between an organic soil and a mineral soil.

Two soligenous mire associations were mapped by Eddy (1962) and Welch (1965). The first, Sphagneto-Caricetum alpinum, has Carices, Eriophorum angustifolium, and sometimes Nardus stricta, growing through an almost continuous carpet of Sphagnum spp. This association is mainly found between 2200 and 2400 feet on moderately sloping ground around Great and Little Dun Fell where organic soils are flushed with acid water. The Sphagneto-Juncetum effusi is typically found along stream and river valleys associated with alluvial soils with impeded drainage. Juncus effusus grows through a dense carpet of mosses.

Two grassland associations, plus intergrades between them, cover the vast bulk of the mineral soils on the Reserve: they are Juncetum squarrosi sub-alpinum and Nardetum sub-alpinum. The associations are found on peaty gleys and peaty gleyed podzols with the Juncetum commonest on the former and the Nardetum on the latter; the Nardetum is also sometimes found on an acid brown earth or brown podzolic soil. The associations have a similar altitudinal range, 1500-2600 feet, but the Nardetum gives way to the Juncetum as soil moisture increases and so the Nardetum is commonest on steeper slopes than the Juncetum. Festuca ovina, Deschampsia flexuosa and Galium saxatile are constants in the Juncetum. Ratcliffe (1959) working in north Wales was of the opinion that the climax vegetation of the soils on which he found a Juncetum should be a Callunetum, grazing having eradicated the Calluna. Agrostis tenuis, Anthoxanthum odoratum and Carex pilulifera are usually present in the Nardetum : stands with Juncus squarrosus as co-dominant are assigned to a Juncus facies. The largest areas of both associations are to be found on the western escarpment and the summit ridge ; they often occupy sites kept free of blanket peat because of their instability. Smaller areas of both are found on the dip slope : the Nardetum is commonly on alluvial terraces, especially along the Tees and Troutbeck. Both associations often grade into Festuca grasslands and can occur as mosaics with it.

The grassland association, Agrosto-Festucetum is found as variously sized, though generally small, patches scattered over the Reserve. It is found on well drained alluvial flats near the larger streams, on steep, often flushed, slopes (e.g. the sides of the V-shaped valleys on the escarpment) or, most commonly, associated with limestone outcrops. The soils are freely drained but vary from a rendzina or brown calcareous soils to acid brown earths or brown podzolic soils. McVean and Ratcliffe (1962) distinguish a Species - rich and a Species - poor facies with the Species - rich facies associated with soils with a mull humus and the Species - poor facies a mor humus. The association mapped on the Reserve is equivalent to the species - rich facies. It is rich in basiphilous herbs some of the commonest of which are Cerastium holosteoides, Euphrasia borealis, Prunella vulgaris, Thymus drucei and Trifoluim repens. A facies of the association found on rendzinas has Seslaria coerulea as an important constituent and is designated as a Seslaria facies.

The Festucetum association mapped on the Reserve has no exact parallel in McVean and Ratcliffe's work. (ibid) Welch and Rawes (1964) consider it to be closely related to the Cladineto-Vaccinetum and Festuceto-Vaccinetum of McVean and Ratcliffe (1962), and suggest that it has been derived, by grazing, from a community dominated by Vaccinium spp. and lichens. The association is found on extremely acid, heavily leached humus - iron podzols on the tops of Great and Little Dun Fell, Hard Hill, and Knock Fell, and on a Brown Ranker in Middle Tongue. Deschampsia flexuosa, Agrostis tenuis, and Anthoxanthum oderatum are constants : Carex bigelowii becomes important at higher levels.

An association dominated by Pteridium aquilinum and designated as Pteriditum by Eddy, Welch and Rawes, is found on the lowest slopes of the escarpment below the scars formed by the Melmerby Scar Limestone. The soils are acid brown earths or brown podzolic soil. In places the association has recolonised scree and two facies are recognised depending on whether or not this is the case. The facies not derived from scree may be derived from woodland or a Festuca grassland: Festuca ovina is dominant in the grassy sward below the Pteriduim and Agrostis tenuis and Anthoxanthum oderatum are important.

Two groups of flushes were mapped, Calcareous Springs and Flushes and Flushed Gleys. The former are associated with the limestones, especially the Great Limestone, and are found below the outcrops where lime rich water emerges. The Calcareous Flushes have been divided into five zones by Eddy, Welch and Rawes (1968), and exhibit a great variation. The soils are organic. The Flushed Gleys are on moderate slopes and have a surface humic horizon; they have a scattered distribution. Some of the constants are Carex panicea, Ctenidium molluscum, Agrostis canina, Festuca ovina and Thymus drucei.

Large areas of heavy scree with discontinuous plant and soil cover are found on the Reserve and have been mapped as Sandstone Scree, although some of the included scree is of Whin Sill. Eddy, Welch and Rawes (1968) define this mapping unit as areas in which, "rock, naked or lichen covered, forms 70% or more of the cover in the plane parallel to the surface." The mapping unit is not a single association. Bryophytes and lichens outnumber flowering plants but the latter are found in crevices.

The mapping unit, Made Ground, covers the various areas on the Reserve which have been disturbed by mining and quarrying activity; it includes spoil heaps, quarries, hushes, trackways and collapsed mine workings. The vegetation on these sites depends on the rock type involved, e.g. that on limestone tips is more species rich than that on sandstone.

6.3. Significance of Vegetation in the Evolution of the Moor House Soils.

The vegetation of the Moor House Reserve will have influenced soil development and evolution in the manner outlined at the start of this chapter. Vegetation cover on the steep sides of the valleys of the escarpment undoubtably prevents soil erosion on what would be an unstable site. The various associations outlined earlier will all produce their own characteristic microclimate, humus and soil structure.

The Agrosto-Festucetum produces a mull humus and the dense root mat it gives produces a crumb structure. The Nardetum and Juncetum squarrosi sub-alpinum give a much less dense root mat and the soil structure is characteristically weaker and coarse. The mor humus of these two associations also tends to give a podzolised soil, if the soil is freely enough drained. In a large number of sites the vegetation seems intermediate between an _Agrosto-Festucetum_ and a _Nardetum_ or _Juncetum squarrosi_ and which ever becomes dominant could determine soil evolution. This transition is one of the most important vegetational influences on the soils.

Post-glacial variations in climate have caused variations in vegetation and thus soil type. Most of the vegetation and soil changes have been outlined in Chapter 5. More recent changes, caused mainly by man, will be considered in Chapter 8. Both types of variation must be remembered as a background to the present conditions. One change not considered elsewhere is the deforestation which has undoubtedly taken place on the lower slopes of the escarpment. The woodland was probably oak and alder away from the limestones and ash on limestone (The rowan trees still found on limestone indicates that it was probably important in the past). Brown earths would be dominant under both types of woodland but after deforestation the soil type would depend on the invading grassland or heath.

CHAPTER 7

Time

7.1. Introduction

Early systems of soil classification recognised the importance of the time factor and very young soils were designated azonal as intra-zonal. Alternatively, very young soils were designated as immature and this indicates the main consideration when discussing the age of soils, i.e. whether or not the soils have reached maturity, or the climax state. Lyon et al (1952) suggests that a young, or immature, soil is still in the "process of adjustment to its environment" whereas the mature soil is "in dynamic equilibrium with climatic and vegetative influences and the profile horizons are not appreciably changing either physically or chemically." For the soils of an area to reach maturity necessitates relatively constant conditions in the other soil forming factors, e.g. climate and vegetation. A large scale alteration in one of the other factors will bring about changes in any existing soils, be they immature or mature. In considering the age of a soil one must refer back to the last large scale variation in one of the other soil forming factors.

It must also be remembered that in some sites soils can be prevented from reaching maturity because of local factors. Thus on steep slopes the soils remain immature because of continual movement downslope. Duchaufour (1966) refers to the equilibrium, or climax, soil on these sites as "being a 'site climax' whereas the regional, climatically determined equilibrium, or climax, soil type he calls a 'climatic climax'." A site climax can be due to relief, exposure or parent material, e.g. the calcareous soils over limestones will be site climaxes.

Only in a relatively few instances can one date the last large scale variation in local environment and so put an age, in years, on the soils being examined. Most of the examples where it has been possible have been on sand dunes, recent glacial moraines, river terraces and raised beaches where one can date the laying down of the parent material. Tamm (1919) worked on podzols of the north Swedish forest region and was able to date the commencement of soil formation as the sites studied had emerged from beneath a glacial lake and the soils were in drift or glacio-fluvial deposits. The rate at which the podzols formed varied with the vegetation cover, e.g. it was quickest beneath a moss-rich forest, and the texture of the parent material, e.g. it was quickest on the fine sand or loamy drift. In 100 year old podzols an A_2 horizon of 1-2 cm. had developed but chemically the horizon was virtually unchanged except for the removal of iron. Tamm (ibid) comes to the conclusion that under "Myrtillus type" forest at least 1000-1500 years are needed to develop a normal A_2 and ortstein as all the podzols of a greater age than this are very similar chemically. Podzolisation was found to proceed much more slowly under a Calluna heath.

Burges and Drover (1953) and Hamblock (1958) also worked on the rate of formation of podzols. Burges and Drover (1953) worked on sand ridges in New South Wales and found that in 250 years or so "appreciable stratification in iron had occurred and at least part of the transported iron was deposited in the form of a B horizon at about 20-30 inches below the surface." The A_2 became distinct after 300 years and the B horizon after 1000 years. In 1000 years the profile had "all the characteristics of an iron podzol". The texture of the parent material would aid podzolisation but the lime rich nature of the sands would retard it. Hambloch (ibid) worked on sand dunes of the upper Ems, Germany. He calculated that a buried iron humus podzol had evolved in a maximum of 2500 years. The profile had an A_2 of 15 cm. of bleached sand, a B_1 of 10 cm. of hard humus ortstein and a B_2 of 50 cm. of rust coloured ortstein bands.

Dimbleby (1952) has shown that a peaty podzol with thin iron pan can be changed to a brown forest soil with mull humus after some 60 years under birch. Traces of the podzol were still visible. The rate of development of soils on calcareous parent materials has been studied by Scheffer et al (1962) in the central German mountains. They concluded that on hard, pure limestones the rendzina was a stable soil type but on impure limestones the soil evolved from a skeletal rendzina to a brown calcareous soil. After 4000 years a brown calcareous soil with 2% of calcium carbonate is reached whereas after 10,000 years the brown calcareous soil is completely decarbonated to a depth of 50-60 cm. In a humid climate they suggest that decarbonation is much more rapid and needs 2-3000 years.

Most other work on the rate of soil development has been concerned with the rate of build up of organic matter, carbon or nitrogen in the soil, e.g. Salisbury (1925), and Crocker and Major (1955).

7.2. The Age of the Moor House Soils.

The soils of the area which have drift as the parent material must post-date the last ice advance. Further, as these soils are developed in the upper layers of the drift which have been reworked by solifluxion, they must post date the last phase of solifluxion activity.

The soils which are not directly derived from drift may vary in age. If the site where they have formed was covered by ice during the last ice advance then the soils must have formed since that ice advance and probably since the last period of solifluxion. If the sites were not covered by ice, as may be the case with the summits (p.24), then the soils may be much older. Soil formation would be minimal during the last ice advance and any material on unstable sites would be highly disturbed even if clear of thick ice.

It was pointed out in Chapter 5 that the initial climatic amelioration was very short lived after the retreat of the main ice sheets at the end of the last glacial episode (Fig.8). After this brief improvement the climate became sub-artic again, small valley glaciers formed and solifluxion took place. Except on flat, stable sites any superficial material would be redistributed by this solifluxion. Over much of the area, therefore, soil development must post date this climatic recession which ended in 8200 B.C. and so these soils have had a maximum of 10,000 years in which to develop.

Since the Allerod climatic recession which ended 10,000 years ago other climatic variations have taken place (Chapter 5) and the start of the present pedogenic cycle will only date from the time when the present type of climate became established. Although the last change in climate dates from about 500 B.C. it is likely that, from the point of view of soil formation, it has been reasonably stable for the last 7000 years. Thus although 10,000 years, and in some cases longer, is available for soil formation most of the soils will only have evolved in the present direction for some 7000 years.

If we examine the position closer we find that in many cases this 7000 years is a maximum. On a small area of Hard Hill and in the Valley Bog, peat formation began in the Boreal (p.53) and the mineral soil below would be sealed off. The mineral material beneath Valley Bog is still sealed off but that below the peat on Hard Hill is now being exposed by erosion and soil development will begin from the time it is exposed. During the Atlantic period the large scale development of blanket peat began and many more areas of mineral soil would be sealed off. At its greatest extent the blanket peat is thought to have covered all but the steepest slopes. Large areas of mineral soil would be sealed off and cease to evolve at this time.

Over large areas soil development would cease in the Atlantic and would only commence again when the peat cover was subsequently removed. Tallis (1965) working in the southern Pennines proposed two main phases of peat erosion. The first is a headword extension of streams beginning about 3000 B.C. ; this would only affect small areas but would allow a long period of soil development. The second is a very rapid extension of gulleying since 1770 A.D. ; this would affect much larger areas but would only allow a very short time for soil development. Removal of peat has also taken place by mass movement, e.g. bog bursts, and this type of removal is still active. Moss movement would be commonest on steep slopes.

The period of time available for soil development would seem to vary from a minimum of 2200 B.C. to a maximum of 10,000 years depending on whether the site was covered by peat and, if it was covered, when the peat was removed. If one only considers the present pedogenic cycle, i.e. since the climate became reasonably stable the range becomes 0 to 8000 years.

Further interruptions to soil evolution have taken place on some sites. Clearance of woodland by man would drastically alter the vegetation and could change the course of soil development, thus initiating a new pedogenic cycle. Sheep grazing may have the same effect.

7.3. Relative Maturity of the Soils of the Moor House Reserve.

It is impossible to generalise about the soils of Moor House when trying to decide whether or not they have reached maturity. A site that was not covered by ice during the last glacial episode may have reached maturity providing that it is not on a very steep slope and depending upon the parent material. The soils of the unstable, very steep slopes will be permanently immature or will give a 'site climax'. On sandstone, shales or unconsolidated material, on a stable site which was ice free, and subsequently peat free, the soils will most probably have reached maturity; providing the vegetation has not been drastically changed by grazing or mans activities. This is always assuming that the estimates of the time needed for podzol formation given in part one of this chapter are correct. The same may not be true of the soils over limestone. Scheffer et al (1962) suggests that a rendzina is a stable soil type on hard pure limestone. If they are correct then the soils on such limestones would have reached maturity. The writer does not think the rendzina will be stable under the climatic conditions obtaining at Moor House (Chapter 14). In this situation the rendzina would be a site climax, as used by Duchaufour (1966), whereas the writer believes that the soil would evolve towards the climatic climax, i.e. a podzolic or gley soil (Chapter 14).

Drift covered sites may also have had time to reach maturity provided they were not covered by peat and the sites are reasonably stable. If the sites were covered by peat then it will depend upon when the peat cover was removed and whether the soil exposed after peat removal is in equilibrium with the conditions obtaining at the time. If one looks upon the various types of podzol as a climatic climax then some fossil soils would be in equilibrium when re-exposed. The same would be true of many peaty gleys as these are a site climax.

The areas which have suffered a fairly recent change of vegetation, e.g. by deforestation or grazing, are unlikely to be in an equilibrium condition. Each site at Moor House must be considered separately and its post-glacial history determined, then one must determine whether a site or climatic climax would form : one can then decide whether the soil present is likely to be a climax type.

CHAPTER 8

Man and Animals.

8.1. Introduction.

The role of man as a factor in soil formation and evolution was given scant attention in early pedogenic work. Today the influence of man's various activities is fully realised and Muckenhausen (1962) says that man is the most intensive soil forming factor in central Europe today. As Muckenhausen (ibid) goes on to point out, the major difference between man and the other soil forming factors is the speed with which man can affect the soil, i.e. the changes associated with his activities can be extremely rapid. Kowalinski (1965) is of the opinion that, "There are no virgin soils in central and western Europe. All the land there is cultivated to a lesser or greater degree." He proposes a new classification of the soils of Europe which, "... will reflect not only natural factors but also soil changes accompanying the modification of the natural environments by man".

The more drastic effects man has upon the soil are obvious, e.g. ploughing, addition of fertilizers and drainage. Ploughing will destroy all horizon differentiation within the plough depth and can cause hardpan formation : deep ploughing can increase the depth of very shallow soils. Lime and fertilizers will alter the base status and fertility of the soil. Drainage can also modify soils, e.g. changing a gleyed soil into a free draining one. Perhaps the most drastic effect man has had on an area is the large scale soil erosion of parts of the United States caused by intensive farming in areas of marginal rainfall.

The changes of the soil caused by the processes mentioned above take place fairly rapidly, many more take place slowly and are caused indirectly by man's activities. The clearance of the deciduous forests in parts of Britain by Neolithic man allowed heath to invade the sites with a subsequent change from a brown earth to a podzol (Dimbleby 1952). The even more widespread clearances of the middle ages undoubtably had similar results in some areas. On a larger scale, some areas of the savannahs of Africa and the prairies of the United States are thought to be anthropogenic in origin, having been derived from forest. This kind of change would undoubtable cause subsequent changes in the soil.

The effect of mans animals can also be important. In the mediterranean region grazing by flocks of goats has completely stripped quite large areas of vegetation and exposed them to erosion. Ratcliffe (1959) described the effect of sheep grazing in the Carneddau in north Wales. He came to the conclusion that many of the vegetational communities, and their associated soil types, are determined by the anthroprogenic factor. Selective grazing by sheep has allowed acidophilous species to invade sites from which they would normally be excluded ; a change in soil type would parallel the change in vegetation.

8.2. Man's Activities on the Moor House Reserve.

The first evidence of human activity in the area is given by the flint blade microliths found near the base of the peat on Hard Hill summit and various other sites (Johnson and Dunham 1963, Chapter 17). Further specimens have been found during the present survey; again on the Hard Hill site. The microliths are assigned to the Mesolithic and are of Atlantic age (Johnson and Dunham, ibid). The people who fashioned the microliths may have formed temporary settlements in the area as they made some of their stone tools of local chert. Several horn sheaths of Bos, the indigenous wild cattle, have also been found on the Reserve and they are sometimes associated with microliths and are of the same age. Johnson (Johnson and Dunham, ibid) suggests that the people who fashioned the microliths may have hunted the Bos. The effect of these early peoples and the Bos may have been small but it does show that from very early times one has to take man's activities, and those of animals, into consideration.

Various Roman remains have been discovered in the area, e.g. the Roman alter found in Knock Ore Gill, but no permanent settlement took place and permanent effects on the vegetation and soils are unlikely. The Romans may well have visited the fells for hunting and various references to herds of deer in this part of the Pennines can be found. Ramsden (1947) states that in 1673 there were 400 deer in Teesdale forest but only 40 to 50 were left after the snows of the winter. Although fairly large herds of deer may once have existed they would seem to have virtually died out, or been killed by the end of the seventeenth century. The effect of the grazing of these animals on the vegetation, and hence the soils, would be minimal as they would tend to move about and graze lightly. The same is true of the other wild animals, e.g. rabbits, foxes and hares found in the area.

Prior to the Nature Conservancy aquiring the Moor House Reserve it was managed as a grouse moor and grouse have probably been hunted in the area since fairly early times. Welch (MS 1967) suggests that large scale shooting dates from the invention of the breech loading gun in the nineteenth century. The grouse would have little, or no, effect on the fells but the management of the fell for grouse shooting may have had quite marked effects. Keepers lived at Moor House, which was formerly a mine shop and was enlarged and converted to a shooting lodge in 1842 by the Earl of Thanet; the keepers kept down predators, e.g. foxes and hawks, and encouraged the growth of young heather by draining wetter areas and burning small strips. The burning would change the vegetation of the blanket bog by encouraging the growth of Eriophorum vaginatum which recovers better than Calluna after burning, The vegetation of mineral soils alongside the burnt strips of blanket bog could easily have been affected during the burning. It is also worth recording that the keepers at Moor House kept fowls, pigs and a cow in a pasture around the House and the pasture has also been dug, manured and limed. This small area around the House is, therefore, highly disturbed when compared to the rest of the area.

Sheep have been grazed on the Reserve from early times and this is the most important use of the fells today. Welch (1967) suggests that the sheep grazing dates from Norse times as they introduced the coarse-woolled, black faced mountain sheep into the area and many of the terms applied to the sheep and their markings today are Norse in origin. All the farms adjacent to the Pennines have common rights and in the past, as now, most of the sheep belonged to commoners because monastic buildings are few in the area, although Shap Abbey held Milburn Grange. Welch (ibid) says that documentary evidence exists from the fourteenth century of sheep and other animals grazing on the fells and, using Hutchinson's (1794) figures, he is of the opinion that the number of sheep had risen to one-third its present level by 1794. Today (1963-65) some 8500 sheep are estimated to be summered on the Reserve and these belong to twenty two commoners of Milburn, Knock and Dufton.

The management of the sheep seems to have changed little in hundreds of years, e.g. practices described as ancient in 1863 (Powley 1876) are still carried on today. One year old unmated females are put on the fell in April and ewes with their lambs at the end of May. During the summer the sheep are visited very little except when rounded up for shearing and dipping. The lambs are gathered for the sales in September and the rest of the sheep are usually off the fells by the end of October. While on the fells the sheep are heafed, i.e. they occupy the same ground year after year due to instinct and sheepherding.

There are also records of cattle and horses being grazed on the fells but it is unlikely that the number was very large. At present a few fell ponies are kept on the escarpment. Geese also appear to have been kept on the fells in considerable numbers from medieval times until the end of last century. The 1862 "Cross-fell District Goose Shepherds Guide" lists the markings of 62 owners in Milburn, Kirkland, Skirwith and Ousby parishes.

The area of the Reserve has been intensively exploited by mining and quarrying. The mining exploited veins and flats produced by mineralisation in the Carboniferous strata (Johnson and Dunham 1963, Chapter 13). The chief mineral mined was galena, lead, sulphide, and it was this mineral that prompted almost all of the mining activity in the area. Mining activity on Alston Moor may date from Roman times but the earliest reference to any working on the Reserve area is in a charter of 1580 quoted by Welch (ibid). Robinson writing in 1709, says of Dufton Fell that "... lead, of which there is such a plenty got as keeps a Lead-Mill for the most part smelting the Ore". The production was clearly quite considerable by this time but mining on the Reserve probably reached its peak in the early years of the nineteenth century and then declined due to the decline in the price of lead after 1829.

The lead mines were entered by drifts and addits driven into the fell side, rather than by vertical shafts. The number of addits which can be located on the Reserve is some indication of the extent of mining (fig.10). A spoil heap is usually located close to the mouth of the addit and is often the most obvious evidence of mining. In connection with the mining hushing was carried out and has produced the most noticeable man made features on the Reserve, e.g. Dun Fell Hush (Plate 5) and Hard Hill Hush (fig.10). The hushes were produced by ponding up water in small reservoirs, often fed by leets, and, when the reservoir was full, releasing the water so that it rushed down the hillside and excavated a channel so removing the blanket of superficial material and exposing the bedrock. The object was to allow the bedrock to be examined for mineral veins.

Other minerals apart from galena were also mined within the Reserve area. Coal was mined prior to 1823 at Knock Coal Shop, which is marked on maps of the area. Iron was being worked on Milburn Fell in the fifteenth century as an Elizabethan rememberance lists a payment of 26s.8d. in 1420 and mentions the rent paid for the mine in various years between 1429 and 1529 (Welch 1967). The last mine worked on the Reserve was Silverband mine; it was first worked as a lead mine (The name is due to the high silver content of the lead) but was latterly worked for barytes by B.Laporte and Co. (Now Laporte Industries Ltd). Laporte's closed the mine in 1962.

Limestone has been quarried on both sides of Knock Ore Gill, the larger workings being to the south of the stream, and four lime kilns are located on the Reserve (fig.10).

8.3. Man's Influence on the Soils of the Moor House Reserve.

The influence due to mining and quarrying has some very obvious effects and some 'hidden' ones. The tip heaps at the entrances to addits are an obvious effect and soil formation on these tips is only just beginning. These obviously despoiled areas are mapped as made ground on the vegetation and soil maps (fig.10). There must have been many more trial diggings which are not so obvious today but which could have an important, though restricted, effect on the soil. The hushes, hydraulic opencuts used by early lead miners, not only completely alter the area which is now their channel and in which immature soils are found, but they spread material on the surface, at their lower end, in the form of an alluvial fan and here again very young soils are found. The hushing undoubtably caused peat erosion in the near vicinity and also locally improved the soil drainage. Mine trackways, drainage channels and leets would also cause peat erosion and locally alter the soil drainage.

Sheep grazing will have had the kind of effect mentioned by Ratcliffe (1959) and pointed out in part one of this chapter. Selective grazing has undoutably allowed acidophyllous species to invade some areas and as the sheep preferentially graze the Agrosto-Festucetum they may well have allowed areas of this to be invaded. As noted in Chapter 6 the change from an Agrosto-Festucetum to a Nardetum sub-alpinum or a Juncetum squarrosi sub-alpinum could cause a change in soil type from a brown earth to a podzol. It was also noted in Chapter 6 that Eddy, Welch and Rawes (1968) suggest that the Festucetum is derived by grazing. Further reference to the effect of sheep grazing will be made in Chapters 14 and 15.

CHAPTER 9

Peat Erosion.

Removal of blanket peat is extremely important in the Moor House Region as it exposes the underlying mineral material to soil forming processes and the time and manner of removal of the peat will have an important bearing on subsequent soil development. A brief consideration of the processes involved in peat removal will be made. Bower (1960a, 1960b, 1961 and 1962) has made a study of this subject, part of it at Moor House, and a brief summary of her conclusions will indicate the processes involved.

Bower (1960a) considers that there are two main groups of processes, water erosion and mass movement. The water erosion takes place by dissection of the peat by running water, sheet erosion of the peat surface, and by back cutting at marginal faces developed at the edge of the peat blanket. Mass movement of peat takes place on slopes and involves movement of the whole peat layer. Bower (ibid) also says that mass movement can occur in peat overlying drift-covered limestone outcrops. This occurs when sink holes develop through the opening up of an underground drainage system. Many examples of shake holes through drift to the underlying limestone are to be found on the Reserve : if Bower (ibid) is correct then they will be a very important factor in removal of peat from limestone and the subsequent development of mineral soils.

A large scale example of mass movement on a slope was provided by the bog bursts on Meldon Hill in 1963. On this occasion two separate slides occured which caused the removal downslope of some 835 tons of peat (dry weight) from an area of some 8600 sq.m. The slides took place after a thunderstorm when the solifluxion clay-peat interface failed under the weight of the fully saturated peat. The slope was 10^{o} near the top, to 14^{o} - 17^{o} near the bottom, of the scars. These slides showed the large areas that can be rapidly stripped of peat by this process and also that the process is continuing today. The old slides marked on old geological and topographical maps of the northern Pennines show that the 1963 slides are not isolated examples.

Dissection is the most important kind of peat erosion in the Pennines and Bower (ibid) distinguishes two types. The first is found in deep peat (At least 5-7 feet) and on slopes of less than 5^{o}. This dissection is very intense and due to an intricate network of closely spaced gullies. Most of the large eroding complexes on the Reserve are of this type. The second type of dissection has no depth or slope limits and is much more open with individual gullies rarely branching. It is commonest on slopes exceeding 5^{o} and in higher areas.

Three main stages in gully development are envisaged by Bower (ibid). In the "early stages" the gullies are contained within the peat, in the "advanced stage" they have cut to the base of the peat and in the "late stage" the gullies are wide and the islands of peat between them are small and widely scattered. The "advanced" and "late" stages will be important in exposing the underlying mineral material to soil development. Many of the eroding peat complexes on the Reserve have reached the 'advanced' or 'late' stages (Plate 10).

It is extremely difficult to determine when peat erosion began and which process of removal has been dominant at any time. Conway (1954) envisages a kind of inbuilt instability in peat. When a certain thickness is reached lines of weakness develop within the peat mass along which mass movement or water erosion will take place. The critical thickness is thought (Conway ibid) to decrease as the angle of slope increases. Crisp et al (1964), in their paper on the Meldon Hill slides, suggest that the primary cause of the instability has been the lack of water courses on the slope. Nearby areas with more water-courses have not suffered spectacular erosion. Bower (1962) would seem to agree with the view that erosion is due to inherent instability. If these views are correct then one would expect erosion to begin very early and, if Crisp et al (1964) are correct, one might expect mass movement to be commonest in the early period of erosion before water-courses were established. Conway (1954) concludes that erosion had been liable to occur in areas above 1500 feet at any time since the onset of wetter conditions in about 500 B.C. She is also of the opinion that clearance of forest from the margins of blanket bog and burning with clearance of sphagnum from the bog surface would accelerate erosion.

Tallis (1965) working in the southern Pennines puts the start of dissection at about 3000 B.C., early Zone VIIb. He says that it took place by headward extension of streams along pre-established lines of weakness, the pre-glacial stream channels. This dissection continued into historic times and even by 1300 A.D. had not reached the limits of the pre-glacial stream channels in many areas. Tallis (ibid) proposes a second, very rapid, extension of gullying after c. 1770. It will be seen that he is of the opinion that erosion started much earlier than the date suggested by Conway (1954). At present it would seem impossible to be any more definite about the onset of erosion but perhaps one can say that it has been continuing for at least 2500 years and perhaps as long as 5000 years.

The suggestions that peat erosion begun because the climate became drier and prevented continued bog growth, e.g. Lewis 1906, do not seem to have any bearing on the Moor House situation. The theory may well apply in some areas but the Moor House area has considerably more rainfall than the 55 inches which Pearsall (1950) says is required to maintain growth of peat bogs.

Man's activities have undoubtably caused an acceleration of peat erosion in the last few hundred years. The most obvious erosion caused by man is the hushes, which date from the eighteenth and nineteenth centuries (p.76). Sheep grazing and burning of areas of the fell will also have caused accelerated erosion.

CHAPTER 10

Soil Classification

10.1. Introduction

The philosophical considerations and the basic problems of classification are not discussed as they are considered to be outside the scope of the present study. A grouping of the various soils found on the Moor House Reserve is shown in Table 3 and is based mainly on the systems used by Avery (1956) and Glentworth (1966). In the rest of the chapter sections are devoted to each of the soil groups described in parts II and III and in these the origin of the soil name is considered along with the usual sub-groups which are recognised plus their european equivalents. The North American equivalents of the various sub-groups are mentioned by Glentworth (ibid).

10.2. Brown Ranker

The 'ranker-like soils' of Kubiena (1953) are "AC soils on parent material low in lime" and he explains that the name is dervied from "rank" = steep mountain slope with the name originally applied to soils on steep slopes but later to all AC soils on lime defficient parent materials. The term has gained wide acceptance in Europe, e.g. Muckenhausen (1962) and Duchaufour (1965), and is in general use. The rankers are sub-divided on the basis of humus type, e.g. mull ranker, Alpine mull-like ranker, region where developed, e.g. Tundra ranker, the major soil group towards which the soil is evolving e.g. podzol ranker, braunerde ranker, syrosem ranker, or colour, e.g. brown ranker or grey ranker.

Kubiena (ibid) says of the brown ranker that it has "... extensive browning of the humus, frequently underneath the humus horizon already showing a brown humus deficient seam, indicating a transition form from ranker to braunerde". The brown ranker is equated with a 'skeletal brown earth by Avery (1956).

10.3. Calcareous Soils.

The calcareous soil found on the area of study are rendzinas and brown calcareous soils. The name 'rendzina' is generally said to have been first used in the literature by Sibirtzev in 1898, e.g. Kubiena 1953, and he says the name is of Polish origin. Since this first appearance in the literature the name has received international recognition and use although its position varies in the various types of classification.

Most writers today distinguish several types of rendzina this Kubiena (1953) recognises sixteen, Muckenhausen (1963) nine and Duchaufour (1965) seven, but the basic properties remain fairly constant. The soils are always said to be associated with calcareous parent materials and the AC profile is generally looked upon as being characteristic, although some of the sub-types of Kubiena (1953) and Duchaufour have a (B) horizon. The colour is a black, dark brown or dark grey, but Duchaufour (1965) has sub types of his "rendzines typiques" distinguished by variations in colour, e.g. "rendzine rouge". The dark colour of the soil may be due to the high organic matter content but Kubiena (ibid) suggests that the calcium in the soil combines with the organic colloids and prevents dispersion of these colloids. Other writers suggest that the clay-humus bond is very strong, e.g. Singh (1954).

The rendzinas of Poland and those described by Sibirtzev (1898) are plastic, sticky clay soils but the rendzinas of Kubiena (ibid) and Duchaufour (ibid) characteristically have a crumb structure and are friable. High faunal activity is also characteristic and the p.H. is close to neutral and often alkaline (Stace, 1956); (Duchaufour, 1960). Some authors consider the presence of a high content of calcium carbonate as diagnostic, e.g. Duchaufour (1960) but Kotzmann (1935) does not think this important. The cation exchange complex is usually saturated and is dominated by calcium.

In Great Britain some of the earliest detailed work on calcareous soils was done by Low (1934) when he compared soils developed on limestone in the Chilterns with those on limestone in Derbyshire. The shallowest soils he compared to the continental rendzinas and they are similar in properties to those mentioned above. Although the shallowest soils examined in the Chilterns were rendzinas they were still up to 16" deep. The calcium carbonate content was also fairly high, although variable, e.g. 21% - 2%. Robinson (1949) has the rendzinas as one of his two major calcareous soil types and describes them as shallow, dark coloured, neutral to alkaline soils with free calcium carbonate. Bunting (1967) also stresses the "higher than neutral pH, with carbonates throughout the profile". The detailed characteristics of the rendzina as defined by the Soil Survey of England and Wales have varied somewhat but the basic features remain constant, e.g. association with limestone, black, dark brown or grey black, crumb structure, high faunal activity, shallow and containing limestone fragments. Ball (1963) defines calcareous soils as those with 5% calcium carbonate throughout their profile but the other Memoirs are not as rigid although several consider finely divivded calcium carbonate to be present throughout the profile, (Avery 1955; Ball 1960; Findlay 1965).

Most of the published work on rendzinas in Great Britain has been on low lying areas. Low (1934) when examining the soils in Derbyshire noted that they were much shallower than in the

Chilterns. Barratt (1960), Bullock (1963), Fadlalla (1963) and Syers (1963) all examined soils developed on limestone in the north of England as part of Ph.D. or M.Sc. work. They all describe black to dark grey, shallow soils with high organic matter contents and crumb structures and refer them to the rendzinas. These soils though, are leached and may be slightly acid, do not necessarily have a saturated exchange complex and may not have free calcium carbonate throughout the profile.

Brown calcareous soils are similar to the calcareous braunerde of Kubiena (1953), sol brun calcimoph of Duchaufour (1965) and the pararendzina of Muckenhausen (ibid). They are again associated with calcareous parent material but a (B) is far more commonly developed than in the rendzinas. Low (1934) described such soils and said that the organic material was well integrated and in the surface horizon masks the colour of the mineral soil. Robinson (1949) included these soils as red and brown limestone soils and thought that they may be the mature phase on limestone and other calcareous materials in temperate regions. In Great Britain they have generally been described as rather deeper soils than the rendzinas, this is not necessarily so with the continental authors. The calcium carbonate content is lower than in the rendzinas and is considered to be present as hard pieces rather than finely divided (Ball, 1960; Avery, 1955). Avery (ibid) also adds that leaching may cause the surface to be decalcified and slightly acid. Faunal activity is still considered to be high, percentage base saturation high and structure a good crumb or polyhedral.

The continental authors tend to view rendzinas and brown calcareous soils as being derived from different parent materials rather than as members of the same evolutionary sequence. Some reference has been made to this in Part II (p.219) and mention has been made of the work carried out in this country by Khan (1957) on the effect of difference in limestone type on soil type.

Bullock (1963) and Fadlalla (1963) working in Northern England recognise a brown calcareous soil which is rather deeper than the rendzina. The surface is decalcified and acid but the humus is still of the mull type and well integrated.

10.4. Brown Earths.

The brown earths are equivalent to the braunerde of Ramann (1905). The term 'brown forest soil' has also been applied to these soils by many authors. The literature on this group of soils must be the most extensive on any group of soils and it would be impossible to cover it at this point. Tavernier and Smith (1957) are of the opinion that the concept of the brown earth has been much confused and Travernier et al (1954) lists the general characteristics of the group in an attempt to clarify the classification. Many authors consider the soils as incipient podzols, Glinka (1914) Tiurin (1930) and many authors as immature podzols.

Kubiena (1953) distinguished ten types of brown earth and two of these the oligotrophic and eutrophic braunerde are equivalent to the brown earths of (high and low base status-respectively) the Soil Survey of England and Wales (Crompton and Osmond 1954, Roberts 1958) and the Brown Forest Soils of low and high base status of the Soil Survey of Scotland (Glentworth 1954). In both cases the soils differed in the degree of leaching and the major aspects of the morphology remained constant. There is very little, if any, accumulation of plant debris on the surface and the A_1 horizon is fairly thick, has a moderate humus content and a strong crumb structure. There is no development of an A_2. The (B) horizon has a much lower organic matter content and the structure is usually polyhedral. The colour of the (B) may have a reddish tinge but the horizon is always browner than the A_1 in which the colour of the mineral soil is masked by the humus. The p.H. is slightly acid. In the low base status sub-group the percentage base saturation is much lower than in the high base status sub-group in which the exchange complex is generally saturated.

In his classification of British Soils of 1956 Avery has a sub-group of leached brown earths which he later equates with the sol lessivé of Duchaufour (1960) (Avery 1964). The sol lessivé of Duchaufour (1960) have a B horizon which is enriched with clay grade material translocated from the overlying illuvial horizon but this clay movement is envisaged as taking place with only slight movement of iron. The concept of sol lessive seems to be generally accepted in the Soil Survey of England and Wales (e.g. Burnham and Mackney, 1966; Bridges, 1966), and so gives a new division of the brown earths into those with eluviation of clay and those without. A further acceptance of the continental classification of soils within the brown earth major soil group has taken place. The acid brown earth of Findlay is equivalent to the sol brun acide of Duchaufour (1960) and Mackney and Burnham (1964) use the term podzolised sol brun acides. Inclusion of the equivalent french language name used by french and belgian workers has also become increasingly common in the english literature, e.g. Findlay (ibid), Bridges (1967).

The increasing incorporation of continental concepts has followed recent more detailed studies of the soils within the Brown Earth Major Soil Group and particularly a re-examination of the soils which are transition between the Brown Earth and Podzolic Major Soil Groups. Further reference is made to this particular point on page 90 .

10.5 Podzols.

The name podzol is said by Muckenhausen (1962) to be very old and he says that the characteristic profile, a bleached horizon under a humic horizon, has been known as long. Kubiena (1953) says the name is a russian peasant one first used in the literature by Dokuchaev (1879). Muir (1961) points out that Dokuchaev's purpose in using the term 'podzol' was to limit it to an 'ashen' surface layer but with time this has been broadened to include the whole profile. This agrees with Muckenhausen (1962) who states that 'podzol' means, freely translated, soil under ash.

Podzols have an ABC profile and are very acid, nutrient deficient soils. They usually have a surface mat of acid, mor, humus and Duchaufour (1965) says this acid humus conditions their evolution. More or less intense eluviation of iron and, sometimes, humus takes place producing the bleached surface, A_2 horizon of the mineral soil. This eluvial horizon is underlain by one or more illuvial horizons, B_1, B_2, B_{PAN}, or B_H, which may be enriched in iron or humus, or both. The intense alteration of the A_2 and the subsequent liberation and translocation of iron which is then immobilised in the illuvial B horizon is termed podzolisation.

The podzols have been sub-divided on the basis of the humus type, degree of development of the various horizons, the presence or absence of a humus enriched illuvial horizon, the presence or absence of gleyed horizons, the presence or absence of a cemented horizon and other characters. Thus a humus-podzol has a marked illuvial humus, B_H, horizon. Kubiena (ibid) distinguishes seven types of podzol, as does Duchaufour (ibid) and Muckenhausen (ibid) ten.

The humus iron podzol distinguished in the present work has similarities with the humus podzol and the iron humus podzol of the above authors. The term humus iron podzol is used because illuvial horizons enriched in humus and iron are both present, as opposed to only an illuvial humus horizon, with no iron enrichment, as in the humus podzol. Humus iron, as opposed to iron humus, is used because the illuvial humus horizon is visibly more striking than the illuvial iron horizon. This sub-group is used by the Soil Survey of Great Britain to designated soils similar to those being discussed in the present study (Glentworth 1966, Burnham and Mackney 1966) and Glentworth (ibid) equates them with the iron humus podzols of european classifications.

The peaty gleyed podzols as used here include a variety of soils from a peaty podzol to a peaty gleyed podzol to peaty podzolic gley soils. The profile has the essential characteristics of a podzol but the surface humus layer is peaty. When the peaty humus is the only feature distinguishing these soils from normal podzols then they are refered to as peaty podzols. The eluvial horizon of these soils often has impeded drainage and is gleyed and as a result has grey or blue-grey, or even greenish, colours. The presence of this gleyed, A_{2G}, horizon led to the soils being described as peaty gleyed podzols. This term was probably first used in the english literature by Muir (1934) who says that it is a Russian term. Since this date it has been used frequently and soils of this type have been described from many localities in the British Isles, e.g. Muir 1934, Dimbleby 1954 and Ball 1960, as well as from Newfoundland (McKeague et al 1967), Denmark (Jonassen 1950), and New Zealand (Gibbs et al 1950). A thin iron pan is frequently found in these soils and those with such a pan present are often refered to as peaty gleyed podzols with thin iron pan. Fitzpatrick (1964) distinguished a group of Thin Iron Pan Soils.

Soils of this general type but with a gleyed B or C horizon are classified as gleyed soils by Avery (1956), peaty podzolic gley and Glentworth (1966), podzolic gley soils. In the chapter devoted to 'peaty gleyed podzols' in part III of this study the peaty podzols and podzolic gley soils are included to bring out their close similarity. Avery (1956) also includes the peaty gleyed podzols in the class of 'gleyed soils' and Crompton also considered this as the soils have a continuous gleyed horizon. Glentworth (ibid) includes them in the podzols and most memoirs of the Soil Surveys of both England and Wales (e.g. Findlay 1965) and Scotland (e.g. Muir 1956) classify them as podzols. They are recognised as podzols here although the problems in this classification are noted.

Kubiena (ibid) distinguishes a peat podzol, which is clearly a similar soil to those being discussed here, and he attributes the name to Frosterus (1912). Duchaufour (ibid) and Muckenhausen (ibid) have no direct parallel to the peaty podzol and peaty gleyed podzol. Alternative names for these soils are to be found in the english literature, e.g. heath podzol (Dimbleby 1950) due to the common association with heath vegetation, or heather podzol (Jacks 1957) because of the close association with *Calluna*.

10.6. Podzolic Soils.

In recent years it has been increasingly realised that soils intermediate between the brown earths and the podzols are much more widespread than previously thought. This is due to the greater area covered by soil surveys and also to more detailed studies of the soils in question. In this country soils of this type have been variously described as podzolised acid brown earths (Burnham and Macknay 1964) and brown podzolic soils (Ball 1966).

In his 'Podzol Class' Kubiena (ibid) distinguishes a 'Semipodzol' type of soil, which he subsequently breaks down into four sub-types; he says that these soils have an illuvial horizon but no distinct, uniform eluvial horizon. The concept of the cryptopodzol dates from Nikiforoff (1937) and he distinguishes these soils are those in which translocation of substances is only detected by chemical analysis : this is true of most brown podzolic soils. The concept was applied in early work in Wales by Roberts (1958) who referred the Manod series of Anglesey to the cryptopodzols.

Duchaufour (ibid) in discussing soils evolving with acid humus, distinguishes 'three groups, depending on their degree of evolution'. One of these groups is the podzols and the others are ochreous podzolic soils and podzolic soils. The ochreous podzolic soils have no A_2 horizon and the podzolic soils have a pale coloured, but not ashy, A_2. In both cases a brightly coloured B horizon is present which has a high content of free iron. The 'parabraunerde' of Muckenhausen (ibid) includes most of the soils intermediate between brown earths and podzols and he distinguishes nine types with a basic profile of $A_1 - A_3 - B - C$ and the A_2 almost always absent; if present the A_2 is thin and discontinuous. In Belgium Pectot and Avril (1954) and Manil and Pecrot (1954) recognised a Sol Brun Podzolique and a Sol Bruns Ocreux respectively, as intermediate between a Sol Brun Acide and a podzol. Avril (1957) suggests that in some cases the Sol Podzolique Brun is a climax soil.

It is clear that this intermediate group of soils is widely recognised. They have moder humus and the A_2 of the podzols is absent, or thin and discontinuous. The B horizon is bright coloured and often a reddish brown, and is usually a thick horizon. The free iron content of the B horizon is high and of the A_1 or A_3 low. The soils are acid and the surface horizons often leached of bases.

The soils of this group in Great Britain have been variously named, as mentioned above, and the problem would seem to be whether or not they are more closely allied to the podzols or the brown earths. It would seem that some indication of incipient podzolisation should be included in the name to distinguish them from acid brown earths. Although they can visibly resemble acid brown earths the high free iron content of the B horizon and the leaching of cations seems to distinguish them.

It is interesting that Duchaufour (ibid) says of the 'sols ocre podzolique', that they result, 'from a slow process of podzolisation, an ecological factor playing, at least, the role of a brake on the translocation of iron'. It may well be that further detailed work will show several transition soils some close to brown earths and others closer to podzols and thus necessitate the use of both the terms being used in Britain but for different soils.

In the Epilogue to his "The Soils of Europe" Kubiena (ibid) has the following to say, "Several new soil concepts which originated in the U.S.A. have found considerable application in Europe in the meantime, in the first place those of the 'graybrown podzolic' and the 'brown podzolic soil'. They have not been treated in this book since their exact definition, and most of their delimitation against already existant European soil concepts are not yet fully established". The last sentence seems to be still largely true.

The term brown podzolic soils is here used for the soils with moder or mull like moder humus and a bright, usually reddish brown B horizon but no visibly apparent A_2 horizon. Other soils here included in the podzolic soils are closely related to the peaty gleyed podzols. They have a mull-like moder humus and a discontinuous A_2 horizons. They would seem to be similar to the 'podzols with gleying' described by Crampton (1963) from South Wales. The term applied to these soils here is podzolic soils with gleying. The naming is very difficult as it is thought important to indicate the incipient podzolisation and, preferably, to indicate the close connection with the peaty gleyed podzols. The name used by Crampton gives no indication of either of these factors and is hence thought unsatisfactory for the present work. The terms gley podzolic soils and peaty podzolic soils are used by Avery (1956) and Glentworth (1966) for soils other than those being considered here and so one had to be careful not to cause any confusion with these soils. The term podzolic soils with gleying is unsatisfactory but further work may clarify the position of these soils and enable a better designation to be made.

10.7. Gleyed Soils.

Gleys are soils which have developed under conditions of intermittent or permanent waterlogging. This waterlogging results in anaerobic conditions in the soil and this, in turn, leads to a reduction of iron present from the ferric to the ferrous state. The dull grey or bluish colours associated with gleyed soils are due to the iron being in the ferrous state. Horizons suffering seasonal waterlogging may dry out in part of the year and become aerobic with a resultant reoxydation of some of the ferrous iron and this gives mottled horizons with brownish mottles on a greyish background.

Kubiena (1953) says that the term gley is a russian folk name first used in the literature by Wyssotzki (1900). The name first referred to horizons with ground-water precipitations but now refers to strongly water-logged, reduction horizons in general (Kubiena, ibid). Other classes of waterlogged, or partially waterlogged, soils are warp soils, i.e. alluvial soils with waterlogging, and anmoor soils, humus rich soils with waterlogging but in which the humus is active as opposed to the humus in blanket peat. The term anmoor is rarely used in Britain and the soils included within this class, as used by Kubiena (ibid), are classified as peaty gleys or flushed gleys (Avery 1956, Glentworth 1966). Warp soils are recognised.

Gley soils with a high content of calcium or magnesium are classified as calcareous or magnesian gleys; the calcareous gleys sometimes have calcareous concretions at depth. These would both be classified as mull gleys by Kubiena (ibid), gley eutrophe, or mesotrophe by (Duchaufour 1965). Gleyed soils with mull humus, but a low, or normal, calcium or magnesium content, are sub-divided on whether or not they are surface water, or ground water gleys. In the surface water gleys the gleying is due to surface water draining away slowly : these are equivalent to the pseudogleys of Kubiena (ibid), Duchafour (ibid) and Muckenhausen (ibid).

Gley soils with mor, or peaty humus are designated peaty gleys in Britain. They are usually considered as a separate and distinct sub-group but sometimes they are treated with other non-calcareous gleys and in this case they are placed amongst the ground water gleys. In the continental classifications gleys with mull or mor humus and in which the water table is at, or very close to, the surface are classified as stagnogleys. This sub-group has no equivalent in the British classifications. The use of mull gleys, moder gleys and peaty gleys essentially follows Kubiena's (ibid) sub-division of gleys with terrestial humus forms but which are not completely waterlogged.

A further sub-group of the gley soils which is usually recognised is one which includes podzols which are gleyed in the B and C horizons. Avery (ibid) refers to these soils as gley-podzolic soils, a major soil group, and recognises three sub-groups i.e. gley-podzol, peaty gleyed podzol and peaty podzolic gley. Glentworth (ibid) has one group of podzolic gleyed soils. It should be noted that the peaty gleyed podzols are included with the podzols in the present study and not with the gleys as Avery (1956) does. The peaty gleyed podzols as considered in this work undoubtedly include some podzolic gley soils or peaty podzolic gley soils (p. 89 and 90); these soils were considered together to show their close relationship but the alternative naming must be considered when a specific soil is under discussion.

10.8. Organic Soils.

Soils with more than 12 to 15 inches of organic material overlying the minderal soil are designated as organic soils. These soils form under the waterlogged conditions resulting from high rainfall and impeded drainage. Blanket peat is developed in upland regions with high rainfall and low temperatures. It generally covers large areas on covex and concave slopes. Basin peat owes its origin to the existance of badly drained depressions or basins in which ground water accumulates.

Although the organic soils cover by far the largest area of any of the soils on the Reserve they are not considered further in the present work as they were dealt with in detail by Johnson and Dunham (1963).

PART II

THE LIMESTONE GRASSLANDS EAST OF THE SUMMIT RIDGE.

CHAPTER 11

The Limestone Grassland Sites

11.1. Introduction.

The areas described in this section are those which were mapped by Johnson (Johnson and Dunham 1963) as "brown limestone soils" (fig 11). The use of this term to designate the soils of these areas is misleading as it infers that the areas have a uniform soil cover. As will be shown later they are in fact a very rapidly varying soil complex one member of which is a brown calcareous soil. A term to describe the soils of these areas will be discussed later (p.177). A useful term to designate these areas is, "limestone grassland" a term frequently used by other workers. This term implies the common features of these sites: they are all associated with outcrops of limestone and they are grassland areas. It is because of their distinctive vegetation that they have received considerable attention in the past: it also distinguishes them readily from the surrounding slopes.

East of the summit ridge the gradual slopes down to the River Tees are, for the most part, covered in blanket peat with an associated Calluneto-Eriophetum (p. 58). This peat cover is broken along the larger stream valleys where a Juncus squarrosus or Nardus stricta dominated community (p. 59) is found. Other breaks in the blanket peat cover are provided by areas of limestone grassland. These stand out very clearly as patches of bright green vegetation contrasting with the dull olive greens of the vegetation on the blanket peat. The vegetation of the limestone grasslands is a species-rich Agrosto-Festucetum (p. 60) with areas of Juncetum squarrosi sub-alpinum or Nardetum sub-alpinum near the grassland-blanket peat junction. It was the sharp contrast of the

Agrosto-Festucetum with the surrounding vegetation which prompted the first warden of the Moor House Reserve, the late Mr.K.F.Park, to refer to the areas as "oases" within the general blanket peat cover. The image created by this description is very useful. It conveys the impression of a small patch of grassland surrounded by peat which is, indeed, often the case. This aspect of the sites has, in itself, aroused a great deal of interest amongst botanists who, in particular, have queried whether or not these areas were formerly peat covered.

The areas are all small and a one-inch soil map of the eastern slopes would omit them and show a spread of blanket peat broken only by the largest stream valleys. They vary in size from approximately one tenth of an acre up to some two acres. The soil map of the Reserve (fig.11) tends to make them appear larger than they actually are. As most soil boundaries are gradational a problem arises as to how to delimit the areas. Most of them are surrounded by peat and so the problem was where to draw the line between an organic soil and a mineral soil: a depth of 15 inches of peat was eventually used. The outer limit of the areas was taken as the line beyond which the depth of blanket peat was greater than 15 inches. If a hummock of peat deeper than 15 inches was completely surrounded by grassland then the whole of the hummock was considered to be within the area of study.

Twelve areas are considered in detail in the following pages and these are located and identified in fig.12. In order to facilitate description of the sites a map has been constructed of most of them and diagrams of the rest (figs.12 to 26). The maps and diagrams show the soils present and the changes in slope: the symbols for the changes in slope are after Curtis, Doornkamp and Gregory, 1965. The maps were constructed by dividing the sites into a grid of five or ten yard squares and marking these off with canes. The maps were drawn on squared paper with a fixed number of squares equalling the

Plate 11. The Moss Burn - Sheep Fold Site.
The upstanding block of limestone in the south east of the site : the vertical sided channel is shown in the foreground with bare limestone.

squares of the grid. A grid of numbers and letters has been put on each map and diagram to facilitate the pin-pointing of certain features.

Each area of limestone grassland has been named by the writer and these names are used in the following descriptions. In most cases the name refers to the nearest stream to the site, or the hill slope on which the site is located. In some cases a further feature is added to distinguish between areas close to the same stream, e.g. Moss Burn - Sheep Fold Site. The descriptions are intended as a commentary on the maps and diagrams and are intended to be used together.

11.2. Moss Burn - Sheep Fold Site.

Figs. 13 and 14. Plates 11 to 14 Site no. 1 in fig.12. Nat.Grid Ref. 745317 Height, 2050 ft O.D. Grid references used in the following description, e.g. A.12, apply to fig.13.

The area straddles Moss Burn and is associated with the Scar Limestone; good outcrops of the limestone are found in the south east quarter (e.g. C.7). The complex is surrounded by blanket peat except where the stream enters (F.1.) and leaves the area (F.9.) This stream is intimately associated with the complex. Two branches of the stream are found within the area. The main part of Moss Burn enters on the west (F.1) and flows in a wide flat area at first before entering a more confined channel and going underground (F.3). The channel continues east beyond the point at which the stream goes underground. The presence of a great deal of fresh peat on the surface of this dry section of the channel is evidence that the stream continues on the surface in times of flood. The dry channel may have been the normal channel prior to the establishment, or re-establishment of underground drainage. In the eastern half of the area two streams

Plate 12. The Sheep Fold Site. Plates 12 to 14 from a panoramic view, from east to west of the site. The limestone block (C 7.5) is the centre of this plate.

emerge from underground and these unite near the eastern boundary (F.9). One of these streams is presumably the one mentioned above as going underground, the other may be one which goes underground just outside the south-west corner of the area. A channel in the south west of the area (A.1.5) may well be the former channel of this latter stream, it contains alluvial material.

A line of shake holes forms the southern limit of the area. On the other boundaries the grassland grades into blanket peat. One large 'island' of peat (C.2. to C.6) is found within the area and surrounded by grassland. This island of peat and the blanket peat which surrounds the site stand higher than most of the grassland. Much of the grassland takes the form of a series of channels cut into the peat blanket: the channels are also cut into the superficial material and limestone bedrock which underlies the peat. The result is that not only do the blanket peat surfaces stand above the level of the channel bottoms but also mesa like blocks of limestone stand above them. The largest mesa like limestone block is in the south east of the area (B 7.5 to D 7.5) and the top surface of this block is probably the true upper surface of this limestone bed (Plate 11). To the north, east and west the block is terminated by channels: the eastern edge is also the edge of limestone outcrop. The southern edge of the block is the southern edge of the site and the surface of the block slopes in this direction (Plate 12). The block surface has a hummock and hollow surface superimposed onto it (Plate 11) and this reflects the underlying clints and grykes. The soil cover is thin on the top of the block, although highly variable due to the clints and grykes. The dominant soil is a rendzina with brown calcareous soils in the hollows, i.e. the grykes. On the more gradual slopes away from the block, i.e. to the north, east and south, the soil cover thickens and a brown calcareous soil becomes dominant with subordinate rendzina.

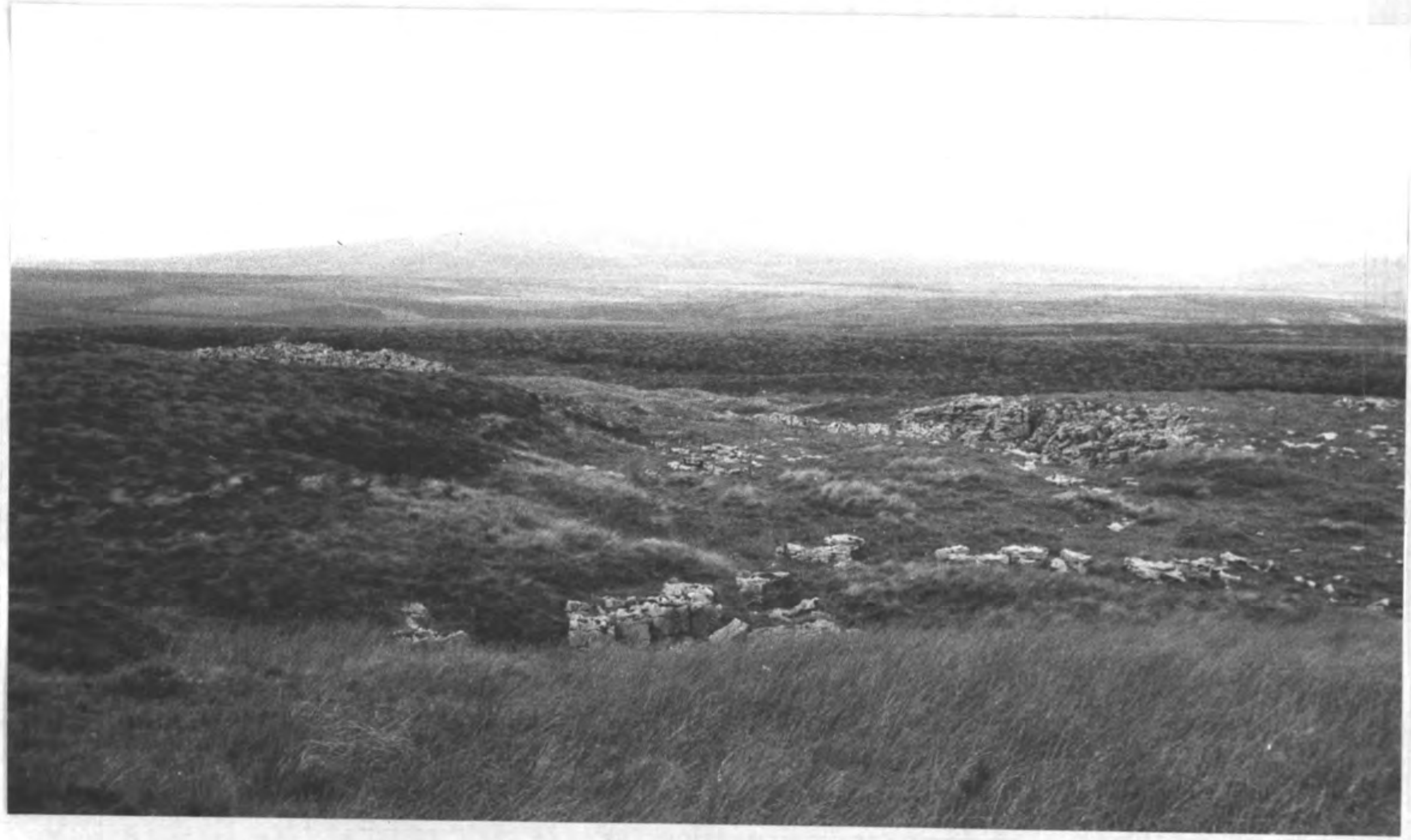


Plate 13. The Sheep Fold Site. The area C 6 to C 8.

The north and east slopes are more a series of steps: the west edge of the block is a vertical drop of some ten feet (Plate 11).

The large island of peat within the area (C2 to C6) rests on a layer of superficial material which rests on a limestone surface at a similar level to the surface of the block discussed above (Plates 13 and 14). A peaty gleyed podzol is developed in the superficial material which is up to three feet thick: the blanket peat is some eight feet deep in the centre of the 'island'. To the north, west and south the peat extends to the edge of the limestone block on which it rests. To the east the limestone projects out from below the peat (Plate 13) as a small bench (C6.5 to D6.5). This bench is at a similar level to that of the block mentioned above (B7.5 to D7.5) but is separated from it by a steep sided channel (C7 to E7). The channel has an abrupt southern end but is open to the north. On the bench of limestone (C6.5) a brown calcareous soil is dominant. In places the superficial material below the peat projects out from the peat to give a small bench: in these cases a peaty gleyed podzol or a peaty gley is developed in this superficial material.

The channels cut into the limestone are of various depths and are almost always floored with superficial material. This material is sometimes recent alluvium but limestone boulders often protrude through it. The recent alluvium always contains abundant redistributed peat. Soils developed in obvious alluvial material have been designated alluvial soils. In some cases the superficial material in the channels is more like drift or colluvium and contains abundant sandstone and shale fragments.

If the above is summarised we can see that a number of surfaces can be distinguished. The first is the general level of the blanket peat surface, including the 'island' of peat within the area: this surface has an easterly slope. Secondly there

Plate 14. The Sheep Fold Site. The island of peat C2 to C6, is in the centre of the plate.

is the upper surface of the limestone, i.e. the top of the mesa-like blocks (D 7.5). Thirdly there are the floors of the channels, which, although varying somewhat in level, are all below the level of the limestone surface. This is a generalisation but it is thought to be a useful and valid one.

One final component of the micro-topography remains to be described. Superimposed on the limestone surface, the floors of the channels and the slopes between these two surfaces are a series of mounds, e.g. B7 and E6. These mounds have smooth, rounded outlines and stand about eighteen inches to two feet above the surface on which they stand. The mounds are completely distinct from the hummock and hollow surface found on the top of limestone block. An acid brown earth, or, more rarely, a peaty gleyed podzol is developed in these mounds.

The various segments of the micro-topography are best seen in the southern half of this site. This is because the dissection is rather simpler giving large units. In the northern half of the site the more intricate dissection gives smaller units and hence a rapid variation of surfaces and soil types. A small swallow hole into the limestone is found in the northern half (D4) and this is evidence that a sub-surface drainage system was established prior to the last glacial episode. Insufficient time will have elapsed since this glacial episode for such a feature to develop.

It is important, when studying these limestone grassland sites, to determine whether or not the areas have been affected or contaminated by human interference, e.g. mining. The Sheep Fold Site has suffered some interference as two sheep folds, both now collapsed and disused, are now found within it. The folds were constructed from limestone blocks which were used in dry stone walling. The limestone would, almost certainly, be derived from within the area. An important point is whether the limestone was loose blocks on the surface or whether it was quarried. This question cannot be answered with certainty but it would seem likely that loose blocks would be used first and then any further limestone obtained by quarrying. An obvious site to postulate such quarrying would be the vertical sided channel (C 7). This would explain the rather un-natural abrupt southern end to this channel.

There is no evidence of mining on the area. Grazing will certainly have had an effect and is probably the most important interference in the ecosystem. The effect of grazing will be discussed later (p.217).

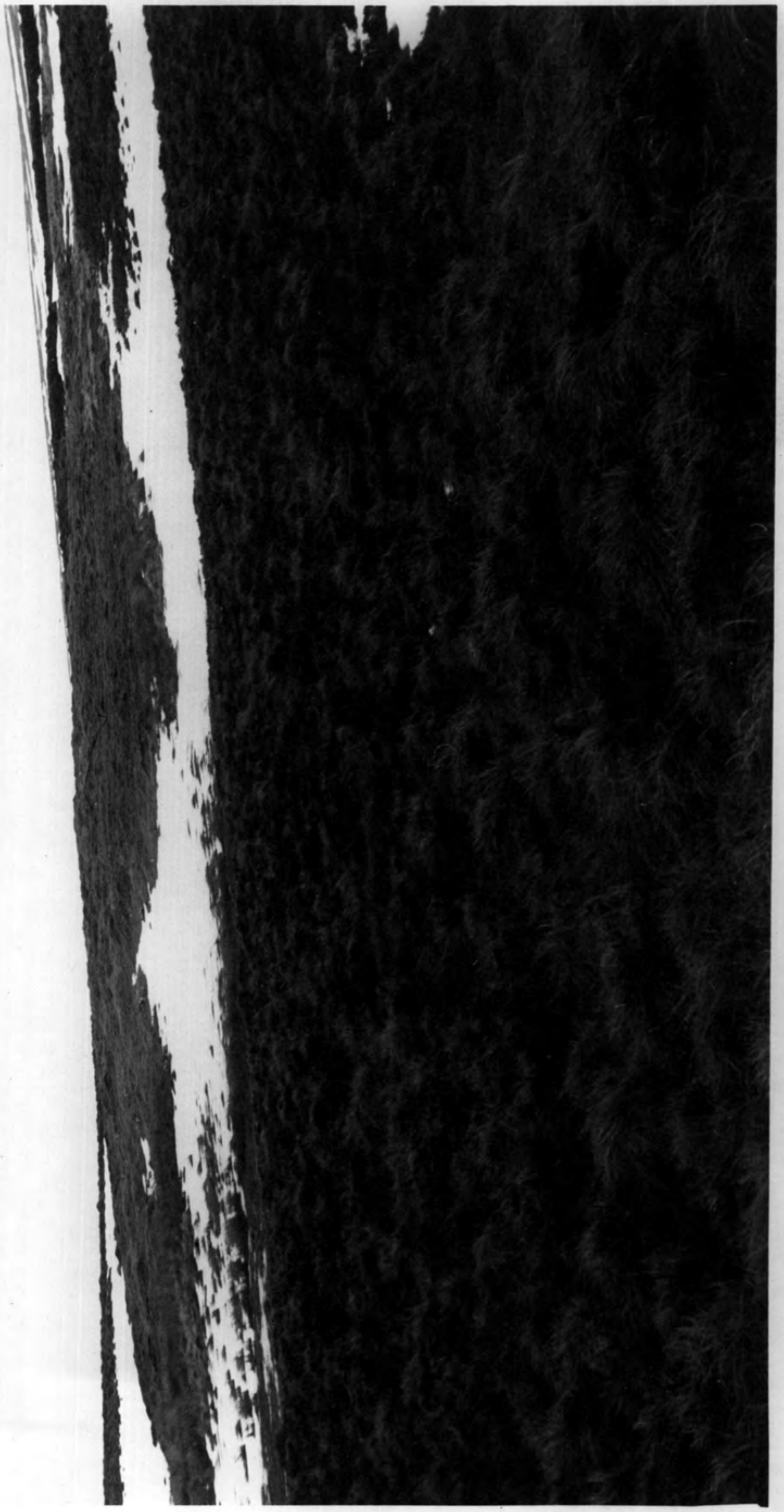
11.3. Moss Burn - Flush Site.

Figs. 15 and 16. Plate 15. Site no.2 in fig.12. Nat.Grid Ref. 745314. Height 2100 ft O.D.

This particular area is not sited on the banks of Moss Burn itself but a short distance from it. On three sides the site is surrounded by blanket bog but to the north east, i.e. downslope, it gives way to a flushed gley. This flush stretches downslope to Moss Burn, reaching the stream near the Sheep Fold Site. The site is roughly circular in outline and in cross-section it forms a low dome superimposed onto the general easterly slope of this part of the fell. The distance across the site is some 25 yards and it is on an outcrop of the Scar Limestone.

At the upslope edge of the Flush Site, i.e. to the west, the grassland gives way to topographically higher blanket bog. Between the blanket bog and the Agrosto-Festucetum of the site is a narrow zone of Nardus dominated vegetation. A similar junction is found at the northern and southern margins. A number of shake holes are also found at the western margin. On the area itself limestone bedrock projects through the soil cover in places. In situ limestone can also be seen in some of the marginal swallow holes. The dome shaped

Plate 15. The Moss Burn - Flush Site.
The low domes shape of the site can be seen.



cross-section is almost certainly structural in origin reflecting a dome in the limestone bedrock.

A hummock-hollow surface is superimposed onto the dome but does not reflect a near surface clint and gryke system. The hummocks seem to be small versions of the rounded mounds found on the Sheep Fold Site and represent an irregular surface developed on a layer of superficial material. Areas of the very shallow rendzinas are of limited extent and the soil pattern is a rapid alternation of brown calcareous soils and acid brown earths.

Two factors about this site are particularly noteworthy. Firstly if the surface of the surrounding blanket peat is continued over the area the peat has to be thinned considerably over the dome (fig.15). Secondly a number of springs rise near the downslope boundary of the dome. Further reference to these two points will be made later.

11.4. Moss Burn - The Currick Site.

Fig.17. Plates 16 and 17. Site no.3 in fig.12. Nat.Grid Ref. 742316. Height 2100 ft O.D. Grid references used in the following description refer to fig.17.

This area is another one associated with an outcrop of the Scar Limestone and across which Moss Burn flows. The northern limit is the edge of the limestone outcrop which, in this case, is terminated by the fault with which the Dun Fell Vein is associated. Blanket peat surrounds the Currick Site except where the stream channels enter or leave the area. One stream enters the area in the south (E 10) and flows in a fairly wide, flat bottomed channel before going underground at the edge of an upstanding, mesa-like limestone block (C.12). This stream channel is floored with alluvium

Plate 16. The Currick Site.
The eastern block of limestone : a shake hole is seen in the foreground.

through which limestone boulders project. Two streams, probably two branches of the one which goes underground emerge from underground near the northern edge of the Currick Site (B.13 and C.13) and unite just outside the area.

The Currick Site can be divided up on the basis of the micro-topographical units which were applied in the description of the Sheep Fold Site. An upstanding mass of limestone (C11.5 to C.13) in situ is found in the north east of this site (Plate 16). The upper surface of this mass probably represents the top of the limestone. The north eastern edge of this limestone mass is the edge of the limestone outcrop, which is here terminated by the fault mentioned above, and forms a steep slope (C13 to C14) with a drop of some 25 feet. The two streams mentioned above emerge from underground at the top of this steep slope and flow down it to unite in a flat bottomed valley below. The limestone outcrop has a very shallow soil cover with a rendzina dominant: limestone projects through the soil in places. A hummock and hollow surface is developed and reflects the underlying clints and grykes. The top of this limestone mass continues diagonally across the area (C13 to G16) in a westerly direction and has a rendzina of brown calcareous soil developed on it. At its western limit the surface has been broken by a series of channels leaving irregular fragments or the limestone surface standing above the floor of the channels. In the north west of the area two narrow topped ridges of limestone are found (G18 and F18): limestone blocks are found along the ridges and the ridges have an un-natural appearance. Further reference to these ridges will be made later (p. 113).

Except for the block at its eastern end, i.e. C12 , the limestone surface disappears to the south under a thickening cover of superficial material. This, in turn, passes under the cover of blanket peat which surrounds the site. In the thickening superficial

Plate 17. Shake holes associated with the Currick Site.

material a peaty gleyed podzol or a peaty gley is developed (F14 and F15): sometimes an acid brown earth is developed at the edge nearest the limestone outcrop. The same series of surfaces as identified on the Sheep Fold Site is produced once again, i.e. the blanket peat surface, the limestone surface and the channel floors. The channels commonly contain a flooring of fresh alluvium. A further surface is produced by the superficial material resting on the limestone surface. This surface was present at the Sheep Fold Site but was not well developed.

The rounded mounds are again found superimposed on the limestone and the channels at all levels. At one point on the limestone surface (D14.5) a number of small, closely grouped mounds are found: they are not differentiated on fig. 17 but an acid brown earth is developed in them. Two large mounds are found on a channel surface (E16 and G17), in the west of the area. The floor of the channel on which they rest is very damp and this impeded drainage results in a peaty gley in one mound and a peaty gleyed podzol in the other.

Within the blanket peat a short distance south of the limestone surface a series of shake holes are developed, e.g. (Plate 17). Limestone is exposed in the base of some of these, i.e. some are swallow holes (p.247). The occurrence of these shake holes will be noted at other sites and their significance will be discussed later (p.247).

There are no obvious signs of human activity on the site, e.g. mine tip heaps or mine entrances, so that large scale mining has not taken place and the soils have not been affected by this kind of interference. The two narrow ridges of limestone, mentioned earlier, look very un-natural, especially the large number of relatively fresh looking limestone block found on them. The sides of the ridges have a brown calcareous soil on them but the top carries a rendzina with a very high humus content. It is difficult to decide whether or not some exploratory diggings, for example, have taken place at this spot but a question mark must hang over the soils. The area has been heavily grassed as have the other grassland sites.

Some eighty yards east of the eastern edge of the Currick Site a roughly circular area of limestone grassland is found which is approximately 25 yards in diameter. The surface is a gentle dome superimposed on the general easterly slope and limestone outcrops are found projecting through the soil cover. Along the upslope edge of the area a number of swallow holes are found just within the blanket peat cover which abuts with this edge of the grassland. To the west of the grassland is an area which shows a great deal of alluvial addition and the effects of flushing. In the east the area drops away to a channel which carries a stream and beyond this is thick blanket peat. The soils of the grassland show a rapid variation from brown calcareous soil to acid brown earth with no regular pattern. The area seems to be a fragment of the limestone surface found nearby, which is projecting above wide channels, and it is a structural high in the limestone.

11.5. The Currick Hill Site.

Figs. 18 and 19. Plate 18. Site no.4 in fig.12. Nat.Grid Ref. 737316. Height 2075 ft O.D. Grid references used in the following description refer to fig 18.

The area of limestone grassland under consideration in this case is one of a series of similar areas found on the southern slopes of Troutbeck valley and associated with its tributaries. The tributary associated with the Currick Hill Site rises on the slopes of Currick Hill and then flows north to its confluence with Troutbeck. The grassland is situated where the stream crosses the edge of the outcrop of the Scar Limestone. The grassland is also at a confluence

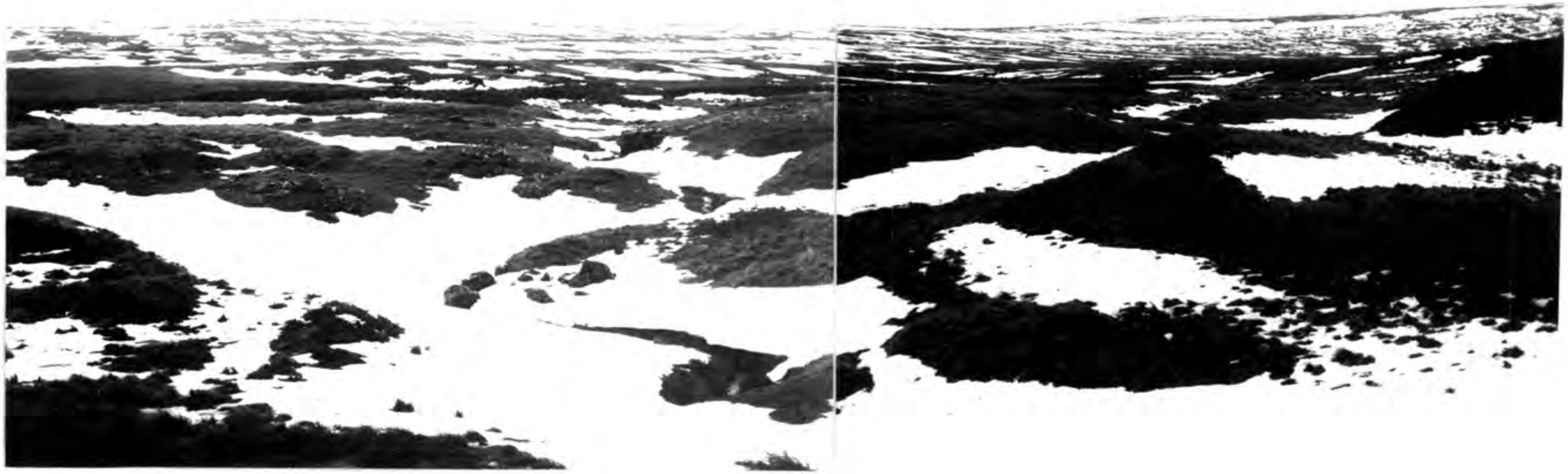


Plate 18. The Currick Hill Grassland Site.

of two small side streams; one rises as a spring in the west (E22) of the area and the other enters the area in the east (D27) and flows underground for a short distance before joining with the other stream (C22.5). After the confluence the resulting stream occupies a deep steep sided valley cut in a thick layer of superficial material. The sides of this deep valley carry a much richer vegetation than the moor edge complex which is usually found in such valleys. This is almost certainly due to flushing by lime rich waters and is not reflected in the underlying soils although Johnson (Johnson and Dunham 1963) included it within the brown limestone soil area of the grassland area under discussion (fig 11).

To the south, east and west the grassland gives way to blanket peat and the steep sided valley below the confluence has blanket peat to either side of it. The stream channels within the area show the strong alluvial addition mentioned at the previous sites. A dry channel stretching back from the point at which the western stream now normally rises (E22) also shows alluvial addition (G22) indicating it was a former stream course. Once again the area is made up of a number of surfaces at various levels. The limestone surface is represented by two upstanding outcrops; one is situated in the angle formed by the confluence of the two streams (E22.5) and the second is west of this (C25). The block between the confluence (E22.5) drops away steeply at its northern and eastern edge, the northern edge is at the edge of the outcrop. To the south the limestone disappears under a cover of superficial material and this in turn under the cover of blanket peat. A complex of rendzinas and brown calcareous soil is found on the limestone and of peaty gleyed podzols and peaty gleys on the superficial material. The podzol is commonest at the edge of the superficial material nearest the limestone and the gley nearer the blanket peat. The westerly limestone outcrop (C25) is rather more

<u>Plate 19.</u> Site 5 on fig 12.

complex. In places it passes directly underneath the blanket peat (B26) and in other places the intermediate stage of a layer of superficial material is found (E25). Both limestone outcrops show a hummock and hollow appearance over at least part of their surface and both have the rounded mounds on them in which an acid brown earth is developed, e.g. There is also one larger than normal mound (D25) on the westerly limestone block and a peaty podzol is found in this. Rendzinas and brown calcareous soils again cover the surface of this limestone.

A number of sink holes are found within the blanket peat a short distance back from the limestone surface.

As has already been mentioned this site is one of a number of very similar sites associated with tributaries of Troutbeck. The three tributaries to the west of the Currick Hill Site have similar areas on them (Sites 5,6 and 7 on fig 12): only the most westerly of these tributaries, Ninewells Sike, is named. On each of these sites the grassland is found where the stream crosses the edge of the limestone and also it is at the confluence of two smaller streams (Fig 20, Plate 19). A block of limestone is found in the angle formed by the confluence and a roughly triangular area of grassland is produced in these cases only 50 yards across at the widest point. Again the areas are surrounded by blanket peat and to the south the limestone surface disappears under a cover of superficial material and this under a cover of blanket peat. The stream channels show considerable alluvial addition and channels at present day have re-distributed peat at the surface showing they are used in times of flood. The soil types and their distribution is very similar to that found at the Currick Hill Site and these are in all ways small versions of that site.

11.6. Hard Hill - Eastern Unit

Fig.21. Plate 20. Site no.8 in fig 12.
Nat.Grid.Ref. 732332. Height 2200 ft. O.D.

The eastern unit is a crescentic area of grassland around the summit of Hard Hill on which the trig. point (731332) is built plus a few small patches of grassland on the southern slopes of Hard Hill near the head of Hard Hill Hush. The crescentic band of grassland is very narrow, some 30 yards at the widest, and follows the contour of the hill top. The band widens considerably at the head of Hard Hill Hush but this is entirely a result of the hushing activities and the expansion of the vegetational zone is a response to flushing and is not reflected in the underlying soils. At its upper and lower boundaries the grassland gives way to blanket peat with the normal Calluna-Eriophoretum community. It strikes one that it would be highly unlikely that such a narrow peat free band, entirely surrounded by blanket peat, could have remained free of peat cover during the maximum peat expansion.

The upper limit of the grassland is the very marked break of slope which is present around this section of the summit of Hard Hill. This break of slope is due to the Four Fathom Limestone capping this section of the summit and giving the usual steep face that is produced by the limestone beds in the Yoredale type of succession (p. 17). The lower limit corresponds approximately to the base of the limestone and here again there is a break of slope although it is much less marked than the one at the upper limit of the grassland. It is worth noting at this point that these breaks of slope, especially the sharp upper break, would provide a line of weakness at which

Plate 20. Part of the Hard Hill - Eastern Unit.

erosion would take place very easily and thus facilitate the removal of any previous peat cover.

Within the zone of grassland there is often a rough zonation apparent with the zones running parallel to the boundaries of the belt. A zone of Agrosto-Festucetum grassland often occupies the centre of the belt with zones of a Nardus stricta or Juncus squarrosus dominated community on either side which in turn give way to blanket peat. In places the Festuca-Agrostis zone ceases to be continuous and becomes a series of disconnected patches. Very little limestone is exposed within the grassland but a number of boulders project through the soil cover in the Agrosto-Festucetum areas. In the Agrosto-Festucetum zone a hummock - hollow surface is sometimes developed but it is impossible to determine whether this reflects an underlying system of clints and grykes or is a product of some kind of soil creep on the slope; the latter is probably most likely, The soils in this zone vary rapidly from a brown calcareous soil to an acid brown earth but there are only very small areas of the rendzina like soil found at the other areas. The Nardus sub-alpinum zone is usually on a peaty gleyed podzol.

11.7. Hard Hill - Northern Unit

Fig.22. Site no.9 in fig.12. Nat.Grid.Ref. 725333. Height 2175ft O.D. Grid references used in the following description refer to fig.22.

The second group of small areas of limestone grassland on Hard Hill is found north of the summit on the slopes which drop down to the river Tees. The group form a series of disconnected patches of grassland which lie in a line along the outcrop of the limestone and hence follow the contours. The limestone, the Four Fathom, is downfaulted with respect to the east end of Hard Hill on which the trig. point is built and this part of the hill is capped by the sandstone above the Four Fathom Limestone. A distinct terrace is produced on this north side of the hill by the limestone, although very little limestone is exposed at the surface. The bench or terrace which is underlain by the limestone has been smoothed out to some extent by the blanket peat and superficial material both of which thicken to the back of the bench. The peat layer would be at its thinnest at the downslope edge of the bench and this plus the break of slope at the downslope edge would make removal of any peat layer relatively easy. This downslope edge would also be the actual line of outcrop of the limestone. The bench is terminated in the east by a deep gulley which continues onto the summit of Hard Hill and marks the line of the fault mentioned above; the limestone is exposed in the gulley.

The actual limestone grassland areas lie near the downslope edge of the bench mentioned above. The areas have very irregular outlines and the surface is also highly irregular. The actual Agrosto-Festucetum grassland is usually associated with upstanding dome shaped areas (E.32, E31, E29.5) which seem to be underlain by small upstanding masses of limestone. A hummock - hollow surface is often found on these dome shaped areas but the very shallow rendzina like soils found associated with this type of surface on most other sites is not present and the soil is a brown calcareous soil. The depth of soil on these domes not only varies with the hummock and hollow surface, added to these variations in depth are ones caused by areas of decalcified

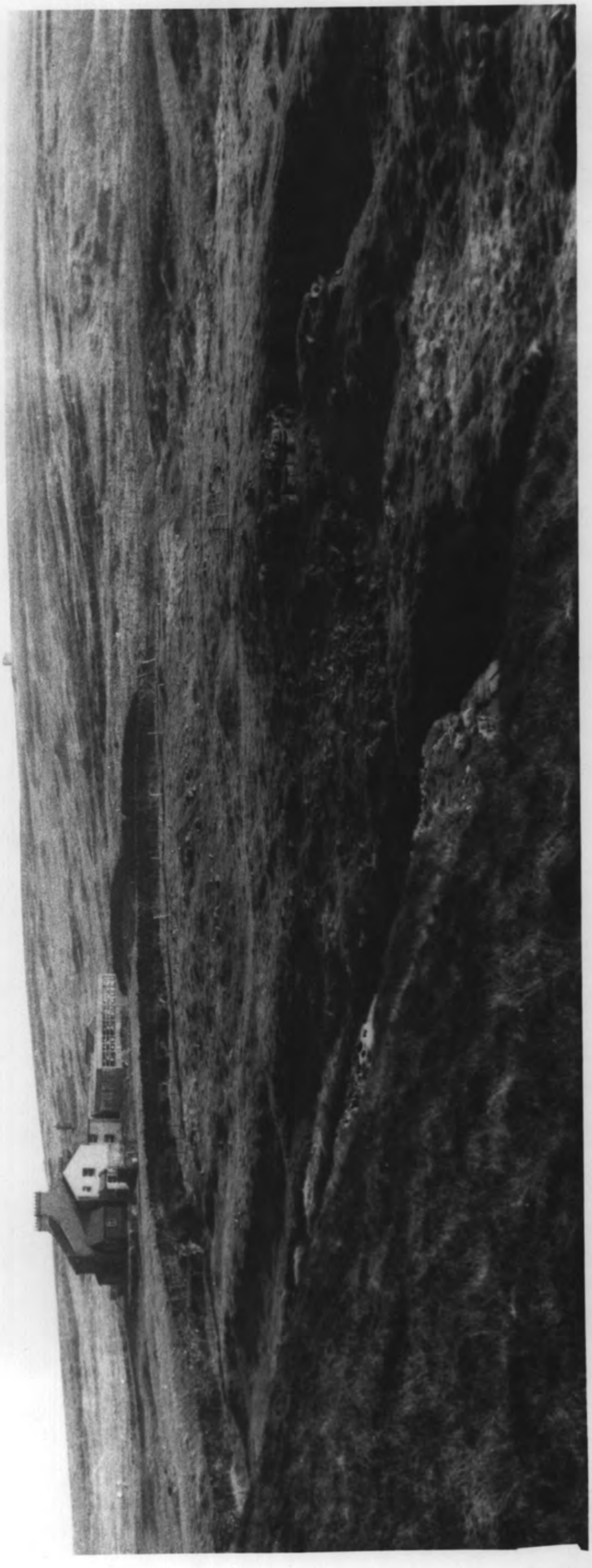
Plate 20a. Part of the Hard Hill - Northern Unit.

impure limestone which increase soil depth. A similar effect is found on the Rough Sike Site and will be discussed in detail later. Over these deeper areas an acid brown earth is produced.

The Agrosto-Festucetum grassland gives way on all sides to a community in which Juncus squarrosus and Nardus stricta are important or, one intermediate between this and the Agrosto-Festucetum. Upslope, i.e. to the south, the domed areas seem to give way to the Nardus stricta community (E30) and downslope to the intermediate community (D30); this is probably because of flushing downslope. Rounded mounds of superficial material are also found on the slopes of the domes and these often carry a high proportion of Polytricum spp (D32.5), a deep gleyed acid brown earth is associated with these. The Juncus squarrosus - Nardus stricta dominated community is associated with a peaty gley podzol and the intermediate community with a peaty podzol or an acid brown earth.

The most obvious effect of human interference on any of the Hard Hill grassland areas is around the head of Hard Hill hush where there has been much alluvial addition in the reservoir area and also some digging of leets. The other areas show no obvious signs of human activity but the presence of the hush means that the possibility cannot be ruled out. It can safely be said that no mining or quarrying of any importance took place.

Plate 21. The Rough Sike Site.



11.8. Rough Sike Site.

Fig.23. Plates 21 to 26. Site no.10 in fig.12. Nat.Grid.Reference 756327. Height 1850ft O.D. Grid references used in the following description refer to fig.23.

Moor House itself is built on this area of limestone grassland (Plate 21); the House itself is at 1830feet. This is one of the larger limestone grassland areas and it straddles Rough Sike and the stream formed by the confluence of Netherhearth Sike and Moss Burn. The limestone with which the grassland is associated is the Tyne Bottom Limestone.

The area of the grassland can really be divided into four parts, a western, unenclosed part (Plate 21), the narrow gorge of Rough Sike itself, the part enclosed by a dry stone wall in which the House stands (Plate 22) and the eastern part which is enclosed within a fenced area. Although all four parts belong within the area the western, unenclosed portion has been studied in greatest detail : a great deal of what is said about the western part can be applied to the whole.

The main area of grassland is on the south side of the stream formed by the confluence of Netherhearth Sike and Moss Burn (called Netherhearth Sike from here onwards) but a few small isolated areas occur on the north bank. The southern limit of the area is the blanket peat and the areas to the north of the stream are also enclosed by deep blanket peat. The eastern limit of the area as a whole, as opposed to the western section, is also blanket peat. The western edge is very vague as the limestone grassland gives way to a complex of made ground and Moor Edge complex but ultimately the area is pinched out as the blanket peat gets closer to the stream.

The Limestone projects out from below the blanket peat and superficial cover as a level bench (G38-G36) which then drops away northwards to the stream. The surface of the blanket peat has a northerly slope also. Between the true limestone grassland and the blanket peat is a zone of moor-edge vegetation in which Juncus squarrosus and Nardus stricta are important species. This is associated with a thick, 12" plus, layer of superficial material in which a peaty gleyed podzol is developed. Much of the limestone bench has a hummock and hollow surface (Plate 26), reflecting the underlying clints and grykes, and this has a very thin soil cover of the rendzina or brown calcareous soil type. Frequent limestone boulders project through the soil surface on this part of the bench. Resting on the limestone surface are a number of rounded mounds, e.g. H38 and H40, which carry various communities intermediate between an Agrosto-Festucetum community and a Nardetum sub-alpinum (Plates 26 and 23 to 25). These mounds usually rise about 9"-12" above the surrounding hummock hollow surface and are usually associated with an acid brown earth but in places this shows signs of podzolisation. Soil deepening is also found associated with decalcification of very impure limestone, as on Hard Hill, and these zones of decalcified material commonly underlie these mounds. Some of these mounds are continuous with superficial material on which the moor edge vegetation is developed (I40). It is worth noting that one large mound on the bench is actually a mass of bedrock and not of superficial material (F41).

The drop from the main limestone bench down to stream level takes the form of a series of steps in part of the area (F40 to D40) and a gradual slope in another (E43). The slope to the stream is embayed at one point (E42) and this embayment is in line with a flushed area in the peat (I43.5) and the area

Plate 22. A panoramic view of most of the Rough Sike Site is provided by Plates 22-25. The Moor House Field Station is to the right of this plate, which also shows the walled 'pasture'.

Plate 23. Rough Sike gorge is at the right hand edge of this plate. The depression in the foreground is a 'trial digging'.

between this flush and embayment shows a great amount of alluvial addition and may formerly have been the line of surface drainage. Where the drop to the stream is a gradual slope a brown calcareous soil is dominant with a few patches of acid brown earth where the soil cover deepens. Rounded mounds such as found on the limestone bench are also found on the slope down to the stream: again they are associated with an acid brown earth. Where the drop to the stream is via a series of steps the backs of the steps are usually bare limestone and the steps themselves have a shallow rendzina.

At stream level is a narrow flat area composed of alluvium which is the flood plain of the stream at the present time (D41).

If one examines the site in an attempt to identify a series of surfaces, as has been done on other sites, the pattern found elsewhere emerges. The upper surface of the blanket peat is found to the south, this slopes gently northwards to the stream, the superficial material between the peat and the limestone gives a narrow surface on which the moor edge vegetation is developed (J41), and the limestone bench is the upper surface of the limestone found elsewhere. The channels cut down into the limestone are here occupied by streams and are deeper than those found on other sites. It is notable that these channels are almost certainly too deep to have been excavated in post-glacial times and are most likely to date from the pre-glacial or inter-glacial.

The Rough Sike grassland has been greatly influenced by man's activities in the past and is still being influenced today. The enclosed gorge of Rough Sike itself has been used in botanical experiments involving the introduction of exotic species. The area around the House itself has been kept as a hay meadow for

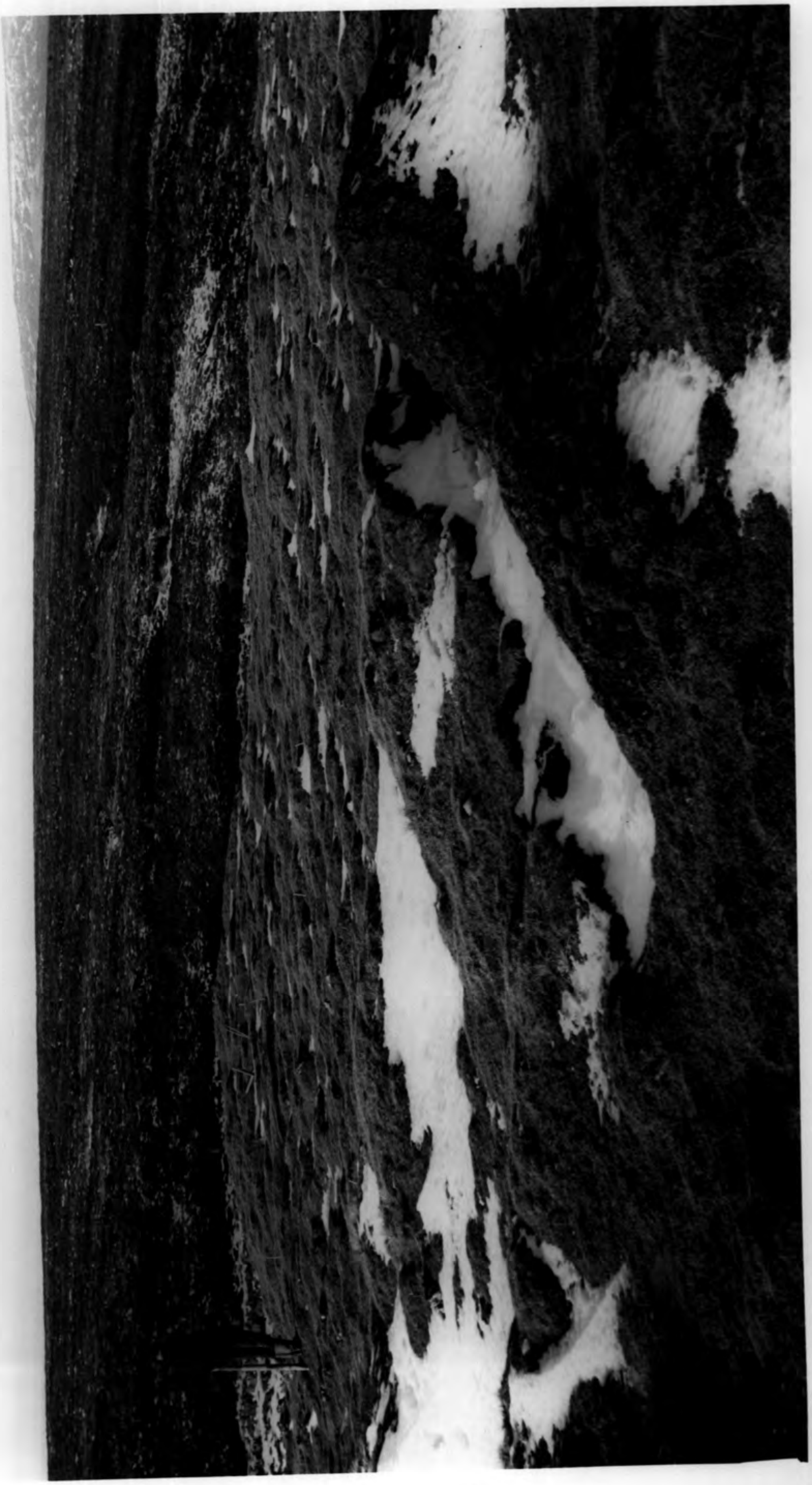
Plate 24. The limestone bench with hummock and hollow surface. The Rough Sike Trench is near the centre of the plate.

<u>Plate 25.</u> Some of the mounds of superficial material on the Rough Sike Site - the mounds have <u>Nardus</u> on them.

periods but part of it has been used as a garden and a number of animals have been grazed in the meadow during the period that the House has been used as a mine shop and subsequently as a shooting lodge and gamekeepers residence (See p. 74 for past history of Moor House itself). The area to the east of the House has been used for keeping various kinds of animals but it has been most drastically effected by mining and numerous mine tips are the most obvious result. The western, unenclosed, part of the area, to which the greatest attention has been paid in the present study, has also been greatly affected by the mining activity which lead to the building of the first house on the site of Moor House. A mine level enters the limestone from stream level to the west of this part of the area (F47) and several mine tips are to be found at the western limit : these mine tips have been mapped as made ground and no appreciable soil formation has taken place on them. A trial digging was also made running west from Rough Sike near the edge of the blanket peat (I 39) and this has to be differentiated from the 'natural' channels on the area. When considering any erosion which has taken place on this site one has to consider any removal of peat, superficial material or bedrock which took place as a consequence of mining activity. The drainage system of the site will almost certainly have been affected by the mine level which is found on the area and a stream now emerges from the level. The level would provide an underground drainage system and may have resulted in some surface drainage going underground and hence surface erosion being reduced.

It is comparatively easy to list the evidence for mining activity at the site but it is extremely difficult to fully assess the effects. The more obvious effects, e.g. mine

Plate 26. The Rough Sike Site.
The limestone bench on the Rough Sike Site showing the hummock and hollow surface and, in the foreground, the mounds of superficial material. Rough Sike Trench cuts one of the mounds.



tips, levels and shafts are readily visible but other effects, such as those on drainage, can only be hinted at and the effects on soil evolution are extremely difficult to assess. The important fact is that on a site such as this one the influence of man must be taken into account when considering any changes which have taken place. Although considerable human activity has taken place a pattern of surfaces and soil types emerges which is very similar to other sites where there is no evidence of interference and this must indicate the fairly limited effect of man apart from such things as tips.

11.9. Green Hole Site.

Figs. 24 and 25. Site no.11 in fig 12. Nat.Grid. Reference 764326. Height 1800ft O.D. Grid reference in the following description refers to fig 24.

The name used for this site is one commonly in use amongst workers on the Reserve. This area of grassland is associated with the southernmost of the tributaries of Great Dodgen Pot Sike. The Tyne Bottom Limestone underlies the area. Only very general remarks can be made about the site as the main area of grassland (D62 and north) has been enclosed and used in a tree planting experiment and the enclosure and plantings have lead to changes in the site. Prior to the tree planting a soil map of the area which is now enclosed was constructed and a copy of this is included, fig.25. The whole of the surrounding area has a thick cover of glacial drift into which the streams have cut their valleys and in places the streams have exposed the bedrock below the drift.

In the case of this particular site it is more rewarding to describe the immediately surrounding area and fit the patches of grassland into it than to concentrate on the details of the grassland. The area is dominated by a large north-south trending depression (C53 to I62) which has fairly steep sides and is rather like an oval bowl. The western rim of the bowl is broken by a steep sided valley (L61) in which a stream flows but this goes underground at the edge of the depression. A line of swallow holes runs east (H62) from where the stream goes underground and may mark a subsurface channel. A peaty podzol is found in these swallow holes below deep peat and must indicate better drainage than the surrounding areas where gleys are found. In the north west of the depression a stream rises (fig.25) and has cut a valley along the north west edge and leaves the depression through a steep sided valley cut through the centre of the southern rim of the depression (B62.5). This stream valley has cut through the drift to expose the underlying limestone and brown calcareous soils and acid brown earths are found associated with the outcrops. The actual outcrops are spurs projecting into the steep sided valley, i.e. and within the enclosed area north of C62 (fig.25).

Further small outcrops of limestone (D60) are found on the south side of the exit valley at the point where it cuts the rim of the depression. A series of swallow holes runs away from this outcrop (e.g. D61) along the base of the south east rim and peaty gley podzols are found around the edges of these (E59). Limestone is associated with a brown calcareous soil and a zone of peaty gleyed podzol is found around the outcrop (E60).

Plate 26a A small area of limestone grassland at the Green Hole Site. The area is at D.60 on fig. 24

Plate 27. Part of the limestone grassland, now enclosed, at the Green Hole Site.

Apart from the areas mentioned the rest of the depression, and the sides of it, are covered with blanket peat which, therefore, completely surrounds these small areas of mineral soil.

This area is another one in which mining has taken place. A level entrance formerly existed immediately to the east of the area used in the experimental tree plants. The tip heaps from this level are found, a little downstream. Once again we are left knowing that man has influenced the area but not really being able to assess the total effects. It seems highly unlikely that mining activity could take place with its related diggings and alteration of drainage, without causing peat erosion and removal.

11.10. Little Dodgen Pot Sike Sites.

Fig.26. Site no.12 in fig 12.

Nat.Grid.Reference 764318, 764317 and 765316. Height 1850-1875ft O.D.

The sites which have been described so far are the larger sites of limestone grassland found east of the summit ridge but there remain a few small patches, usually a few square yards each, to be considered.

The first group of these small areas is found at the head of Little Dodgen Pot Sike (764318). The Sike rises from springs at the base of the Tyne Bottom Limestone which forms a slight feature running north-south across its head of the valley. The sides of the valley are covered in glacial drift and blanket peat. The patches of grassland are associated with the feature caused by the limestone at the head of the valley and are a series of large pot holes and swallow holes into the limestone, and surrounded entirely by blanket peat. In situ limestone is exposed in the floor and sides of the large pot holes but in the sink holes limestone is not exposed. The largest of the pot holes have a shallow soil developed on the limestone within the pot but this has a great deal of added alluvial material due to drainage into the pot. The sink holes usually have an area of Sphagnum dominated vegetation in the base and water from the surrounding blanket peat drains into them.

Around the swallow holes and sink holes a peaty gleyed podzol is found below the blanket peat. In some places a small zone of moor edge vegetation surrounds the pot holes and this again has a peaty gleyed podzol below it. This zone of moor edge vegetation in turn gives way to blanket peat.

The majority of the pot holes are much too large to have been formed in post-glacial times and must, therefore, be pre-glacial or interglacial. Assuming this kind of age they would almost certainly be filled with glacial drift in the last glacial episode and must have been subsequently re-excavated.

A second group of small patches of limestone grassland (764317 and 765316) are found in a valley which runs south from near the head of Little Dodgen Pot Sike to Green Burn. The grassland patches are on the east side of the valley which is covered with drift and blanket peat. A small stream runs in the valley at present and the grassland is some distance above the level of the stream. It is associated with two kinds of features, the first is the sink holes commonly associated with these areas of limestone grassland the second is small mounds which stand above the surrounding blanket peat. These mounds are found to be underlain by upstanding limestone bedrock: a brown calcareous is developed on the mound and this gives way to a surrounding zone of moor edge vegetation with a peaty gleyed podzol and this in turn gives way to the surrounding blanket peat. The sink holes have a soil with much alluvial addition in the centre then the zone of peaty gleyed podzol and then blanket peat. All these patches are no more than a few yards across.

The series of patches of grassland just mentioned are in line along a slight bench like feature on the east side of the valley which may well be a feature caused by the limestone.

CHAPTER 12

The Soils of the Limestone Grassland Areas.

12.1. Introduction

During early reconnaisance work on the limestone grassland sites it became clear that a definite recurring pattern of soil sub-groups was emerging. The maps and diagrams of the sites helped in showing the soils present and their distribution pattern. Subsequently the various soils were sampled, usually from soil pits but sometimes from short trenches. Analyses were carried out on the samples both to amplify the profile descriptions and also to shed some light on the genesis of the various sub-groups. The recurring sub-groups are rendzina, brown calcareous soil, acid brown earth, peaty gleyed podzol and peaty gley : they will be described in this order.

12.2. Rendzina. (Plates 28 and 29).

Rendzinas are found associated with the top surface of the upstanding outcrops of limestone which are horizontal, or nearly so. They are much less common on the gradual slopes which surround these outcrops. A small scale hummock and hollow surface is often associated with these soils (Plates 11 and 25) but not every hummock and hollow surface indicates a rendzina. The hummock-and-hollow surface associated with the rendzinas was found to reflect an underlying system of true clints and grykes. On other sites the hummock - hollow surface may be caused by soil creep and here a deeper soil than the rendzinas is found, e.g. Moss Burn - Flush Site.

<u>Plate 28.</u> Rendzina. South end of the Rough Sike Trench.

In the hummock hollow surface associated with the rendzinas the hummocks represent the clints and the hollows, the grykes. A very rapid variation in soil depth results with very shallow, 0 - 4", soils on the hummocks over the clints and deeper soils, up to two feet, in the grykes. The rendzinas are the very shallow soils found on the clint surfaces.

As has been mentioned earlier the vegetation associated with the rendzinas is an Agrosto-Festucetum (p.60) : this is very species rich when compared to the surrounding blanket bog vegetation. It contains species requiring a base rich soil and also a number of calcicoles. The rendzinas are often associated with a Sesleria facies of the Agrosto-Festucetum and the presence of this facies along with a hummock-hollow surface is a good indication of the presence of this very shallow soil.

The soils in question have an AC profile and have fragments of limestone throughout the profile. They are a very dark brown or black colour and show little, or no, variation in colour with depth. The colour indicates the high humus content. The loss on ignition varies from 25% to 12% and the organic carbon from 5% to 10%. The organic matter is well mixed with the mineral skeleton of the soils. Difficulties met with in dispersing the soils and removing the organic carbon would infer a well developed clay-humus complex. The soils are generally loamy (Chapter 13) and have a fine to medium granular or crumb structure, which is very stable.

The overall soil depth to the first continuous bed of limestone is usually some nine inches. The A horizon is up to four inches and usually varies between two and four inches. This upper layer of soil can be stripped back like a layer of turf and commonly comes away with a few limestone fragments embedded in the base. Between this A horizon and the first unbroken bed of limestone is

Plate 29. Rendzina, Rough Sike Site.

three to five inches of shattered limestone - the C horizon. The shattered rock is commonly present as thin irregular slabs with soil material and plant roots penetrating between the slabs. At the base of the A horizon a root mat is found on the top of the broken limestone. The whole of the A horizon has a dense root mat and earthworms are commonly found. There is no evidence of a Cca horizon.

Despite the close proximity of the limestone bedrock and the presence of limestone fragments throughout the profile the calcium content of the fine earth is low. The total calcium oxide content rarely reaches above 1.75% and if the whole of this were present in calcium carbonate it would only give a carbonate content of about 3.25%. In fact some calcium is present on the clay complex and few carbonate contents reached more than 3.0%. This shows the leaching of these shallow soils under the high rainfall prevailing. The pH also gives some indication of this and varies between 6.0 and 6.5. The cation exchange complex is rarely saturated and the base saturation varies between 70 and 95% with the usual values being between 70 and 80%. Calcium is the dominant cation of the exchange complex.

Although generally loamy the soils can be divided texturally into two groups. Those over the Scar Limestone (e.g. The Currick Site and the Sheep Fold Site) are usually a sandy loam but those over the Tyne Bottom Limestone (e.g. Rough Sike Site) are clay loams or silty clay loams. The reason for this difference is considered in Chapter 13.

The soils detailed above contain less free carbonate then many other soils which are classified as rendzinas (Chapter 10) but free carbonate is present and the soil colour and humus type are similar to those detailed elsewhere. The writer believes that the same can be said of these soils as Roberts (1958) says of the Gower series which are a mixture of drift and limestone, i.e. "The influence of the limestone remains dominant ..."

Rendzina

Profile number : 1 R   Sample numbers : R.S. 1 and R.S. 2

Location : Rough Sike Site.

Site map reference : Fig.23. H.39.

Nat. Grid Reference: 756327

Altitude : 1850ft. O.D.

Relief and aspect: Level, north facing, limestone terrace forming a brake in a north facing slope.

Geological data : The underlying limestone is the Tyne Bottom.

Vegetation : Agrosto-Festucetum.

Horizons:
ins.

0 - 4 A	Very dark brown (10YR 2/2), slightly stony, friable clay loam; strong medium crumb; limestone fragments; dense root mat; earthworms, high organic matter content; irregular clear boundary.
4+ CD.	Dark grey limestone eroded in clints and grykes with many horizontal partings along which soil is found; the upper limestone surface is stained black. Dark brown (10YR 3/2), very stony, firm clay loam; moderate medium granular; roots.

Profile no. IR.

Sample no.	Depth(ins)	p.H.	$CaCO_3$%
RS 1	0 - 2	6.5	0.9
RS 2	4 - 6	6.9	1.8

	U.S.Sand	I.Sand	I Silt.	Clay	U.S.Silt %
RS 1	21.7	35.6	32.2	32.2	45.06
RS 2	18.7	34.9	38.4	27.1	54.17

		Extractable							
	% B.S.	Ca	Mg	Na	K	L.O.I.%	C%	N%	C/N
RS 1	87	12.8	1.62	0.59	0.27	15.01	4.92	1.12	4.39
RS 2	Sat	15.2	0.81	0.52	0.16	13.80	4.35	0.95	4.58
		meq./100g.							

	Si	Al	Fe	Mg	Ca	Na	Ti	Mn	H_2O%
RS 1	54.8	13.9	7.8	6.2	0.8	0.6	0.8	0.4	9.3
Rs 2	55.9	14.1	7.7	6.0	1.1	0.6	0.9	0.4	8.5

Rendzina

Profile number : 2 R   Sample numbers MH 3 and MH 4.

Location : Moss Burn ; Sheep Fold Site.

Site map reference : Fig.13. C 7.5

Nat. Grid Reference : 745318

Altitude : 2100ft. O.D.

Relief and aspect : The profile is on the almost level surface of an upstanding outcrop of limestone some 80 yards by 40 yards. The general slope has a north north easterly aspect.

Geological data : The underlying limestone is the Scar.

Vegetation : Sesleria facies of an Agrosto-Festucetum.

Horizons:

ins	
0 - 3 A	Dark brown (10YR 3/4), stony, friable loam; strong, medium to fine crumb; roots very numerous; limestone fragments; earthworms; high organic matter content; merging boundary
3 - 6 C	Very dark brown (10YR 3/3), very stony, firm, loam; strong, medium crumb; frequent roots; fragmented upper surface of limestone with soil between limestone slabs; sharp, irregular boundary.
D	First unbroken bedding plane of limestone between six and twelve inches.

Profile no. 2R

Sample no.	Depth (ins)	p.H.	$CaCO_3$%
MH 3	0 - 2	6.6	1.3
MH 4	4 - 6	7.6	1.8

	U.S.Sand	I.Sand	I.Silt	Clay	U.S.Silt %
MH 3	42.5	63.51	16.0	20.4	37.1
MH 4	52.5	87.1	14.7	14.7	32.8

	% B.S	Extractable Ca	Mg	Na	K	L.O.I.%	C%	N%	C/ N
MH 3	84	11.2	1.72	0.49	0.31	24.71	9.89	1.00	9.89
MH 4	Sat.	14.4	1.13	0.43	0.20	23.31	9.23	1.05	8.79
		meq./100g.							

	Si	Al	Fe	Mg	Ca	Na	K	Ti	Mn	H_2O
MH 3	n.d.	4.9	5.9	0.19	1.22	0.16	1.17	n.d.	0.56	10.91
MH 4	n.d.	5.6	5.9	0.21	1.72	0.15	1.27	n.d.	0.53	11.60

	P %
MH 3	0.195
MH 4	0.221

12.3. Brown Calcareous Soils. (Plates 30 and 31).

The brown calcareous soils are found in close association with the rendzinas, but are also found on sites which have no very shallow, rendzina phase present. As has been previously mentioned the hummock and hollow surface on which the rendzinas are found represents a very rapid variation in soil depth due to the rapid alternation of the small clints of limestone and the intervening grykes. Although the soil is rarely more than 4" deep on the clints it may reach as much as 2 feet in the grykes and in these grykes the soil present is a brown calcareous soil. On some of the limestone grassland sites the thinnest soil present is a brown calcareous soil, e.g. the northern slopes of Hard Hill, the rendzina being absent. In the sites where these soils are the shallowest they are associated with an upstanding mass of limestone, e.g. on the northern slopes of Hard Hill they are found on the top of the dome shaped masses of limestone which stand up above the surrounding area. These soils are also found associated with the smoothed and rounded mounds of superficial material which are found on the limestone surfaces. The acid brown earth found on top of these mounds gives way to a brown calcareous soil around the edges as the layer of superficial material thins. The final position in which they are commonly found is on the slopes away from the large upstanding blocks of limestone, e.g. at Moss Burn - Sheep Fold Site they are found on the slopes dropping away from the outcrop in the south east of the area.

The vegetation associated with this soil type is an Agrosto-Festucetum but in areas with a cover of brown calcareous soil, as opposed to the rapid alternation on the hummock-hollow surfaces, the Sesleria facies of this association is not found. Overall soil depth is usually between six and nine inches, although much greater depths are found in some of the grykes and will be

Plate 30. Brown calcareous soil, Green Hole Site.

discussed later (p.216). An A (B) C profile is developed and although the soil penetrates some fractures in the limestone bedrock the soil - limestone junction is rather sharper than is the case with the rendzina and the zone of shattered limestone may be missing. The horizon boundaries, especially the A/(B) one are extremely vague and the colour change is gradual from the very dark brown of the A horizon to a brown (B) horizon; the colours vary somewhat from site to site. The A horizon colour is fairly constant but the (B) varies from a dark brown to a brown to a reddish brown; this is partly parallel with an increase in depth with the slightly deeper profiles having the lighter colours. The colour variation is also a reflection of the iron content of the parent material (p.215). The A horizon has a well developed mull humus and a moderate, fine to medium granular structure: it is between three and six inches deep. Although live roots are usually present throughout the profile they are concentrated in the A horizon and give a dense root mat. The concentration of organic material in the surface horizon is reflected in the loss on ignition as well as the colour. The loss on ignition of the A horizon is between 9 and 18%, with a carbon content of between 5 and 10%, and the loss on ignition of the (B) horizon is between 5 and 14%, with a carbon content of between 3 and 7%. The (B) horizon has a moderate blocky structure.

The soils are acid despite the close proximity of the limestones. At the surface the pH is approximately 5.5 - 5.8 and rises to 6.0 - 6.5 nearer the limestone bedrock. The total calcium oxide contents are generally between 0.75 and 0.95% at the surface and 1.0 - 1.15% near the limestone. The carbonate content are around 1.5% near the surface and 1.9% in the (B) horizon. The percentage base saturation is generally between 50 and 70% and increases with depth. Calcium is the dominant cation.

Plate 31. Brown calcareous soil; Moss Burn - Sheep Fold Site, Profile 12 B.C.S.

The texture of the soils varies fairly widely but all contain a moderate to high content of clay. They vary from clay loams to silty clays or even clays. A marked textural change down the profile can sometimes be detected and hence there may be a textural B horizon in some of the profiles but only micromorphological studies could confirm the downward movement of fines.

Brown Calcareous Soil.

Profile number : 3 B.C.S.   Sample numbers: H.H.6 and H.H.7.

Location : Northern slopes of Hard Hill.

Nat. Grid Reference : 725333

Altitude : 2200ft. O.D.

Relief and aspect : A small level area which is part of a bench on a generally north facing slope.

Geological data : The underlying limestone is the Four Fathom.

Vegetation : An <u>Agrosto-Festucetum</u>

Horizon. ins	
0 - 3 A	Dark brown (7.5YR 4/4), stony, friable silty loam; strong, medium granular; abundant roots; limestone fragments; earthworms; irregular merging boundary.
3 - 6 (B) C	Dark yellowish brown (10YR 4/4), very stony, firm silty loam; moderate medium granular; frequent roots; earthworms; irregular clear boundary.
6+ CD	Limestone blocks with silty clay along the junction between boulders.

Profile no. 3 B.C.S.

Sample no.	Depth (ins)	p H	$CaCO_3$ %
HH 6.	0 - 3	5.7	0.5
HH 7	4 - 7	6.6	0.9

	U.S.Sand	I.Sand	I.Silt	Clay	U.S.Silt %
HH 6.	-	18.6	54.9	26.3	73.6
HH 7.	8.5	25.6	48.9	25.5	66.0

		Extractable							
	% B.S.	Ca	Mg	Na	K	L.O.I.%	%C	%N	C/N
HH 6.	69	7.8	0.82	0.41	0.30	10.77	3.25	0.55	5.91
HH 7.	78	10.6	0.39	0.45	0.21	10.44	3.10	0.43	7.21
		meq./100g.							

	Si	Al	Fe	Mg	Ca	Na	K	Ti	Mn	H_2O	P%
HH 6	n.d.	3.9	4.4	0.17	0.64	0.08	0.55	n.d.	0.38	n.d.	0.157
HH 7	n.d.	3.5	4.1	0.16	0.93	0.08	0.55	n.d.	0.32	n.d.	0.178

Brown Calcareous Soil.

Profile no : 4 B.C.S.   Sample numbers: MH 1 and MH 2.

Location : Fenced area east of the Moor House Field Station.

Nat. Grid Reference : 758327

Altitude : 1850ft. O.D.

Relief and aspect : Level, north facing limestone bench.

Geological data : The underlying limestone is the Tyne Bottom.

Vegetation : An Agrosto-Festucetum.

Horizon. ins.	
A 0 - 4	Dark reddish brown (5YR 4/3), stony, friable clay loam; strong medium to coarse granular; abundant roots; limestone fragments; earthworms; merging, irregular boundary.
(B)C 4 - 8	Dark reddish brown (5YR 4/4), very stony, firm clay loam; moderate medium granular; roots; irregular boundary.
CD.	Limestone bedrock with soil along cracks. First complete limestone surface at 12".

Profile no. 4 B.C.S.

Sample no.	Depth (ins)	p.H.	$CaCO_3$%
MH 1	2 - 6	6.35	0.7
MH 2	8 - 12	6.00	1.1

	U.S.Sand	I. Sand	I.Silt	Clay	U.S.Silt %
MH 1	21.6	36.5	31.7	31.8	46.6
MH 2	18.6	20.8	33.0	46.2	35.2

	% B.S.	Extractable Ca	Mg	Na	K	L.O.I.%	%C	%N	C/N
MH 1	49	4.2	0.83	0.31	0.30	18.30	7.98	0.52	15.35
MH 2	56	7.9	0.46	0.27	0.13	14.59	6.28	0.45	13.96

meq./100g.

Total

	Si	Al	Fe	Mg	Ca	Na	K	Ti	Mn	H_2O	P%
MH 1	n.d.	8.0	9.7	0.44	0.84	0.34	1.90	n.d.	1.30	n.d.	0.183
MH 2	n.d.	8.2	10.9	0.44	1.60	0.28	1.67	n.d.	0.74	n.d.	0.163

12.4. Acid Brown Earths. (Plates 32 and 33).

The acid brown earths are found in two types of site which are closely related. The first is on rounded mounds of material found resting on the limestone surfaces and in the channels cut into the limestone. The acid brown earths are usually found in the top of mounds where the superficial cover is deepest, although in a few very large mounds a peaty gleyed podzol occurs in the centre. The second type of site is also connected with the superficial material resting on the limestone but in this case it is the continuous cover of this material found around the edges of the grassland sites where they give way to blanket peat. In some cases the transition from limestone grassland to blanket peat is very rapid but in other cases there is a fairly wide zone of peat free superficial material between the grassland and the blanket peat. In the latter type of site a thin belt of acid brown earth is found at the edge of the peat free superficial material nearest to the limestone surface, e.g. at the Currick Hill Site (fig.18).

The soils are associated with a facies of the Agrosto-Festucetum in which Nardus stricta is important. The association would seem to be transitional between the Agrosto-Festucetum and the Nardetum sub-alpinum. In some cases Polytricum spp. become important and this is usually associated with a vegetation closer to the Nardetum than the Agrosto-Festucetum.

Morphologically the soils are unlike most other acid brown earths which can be found described in the literature, e.g. Findlay 1965, but they are extremely similar to those described from the Malham area by Bullock (1963). Two different types of acid brown earth are found on these areas of limestone grassland, but they have similar general characteristics. The overall soil depth is between 12" and 24 inches and an A (B) C horizon is developed. The most

Plate 32. Acid brown earth; Rough Sike Site, Profile 10 A.B.E.

striking features of the profile are the humus horizon and the (B) horizon. There is a thin mat of acid humus formed at the surface and only a limited amount of intermixing of humus and mineral material. There is no visually apparent movement of iron below this acid humus, or of clay minerals. Below the thin A, which is formed, never more than two inches, there is generally a very even coloured freely drained (B) horizon. This (B) horizon is a reddish-brown colour and it is extremely difficult to sub-divide because of the even colour and texture. There is usually a very gradual change in structure down the profile from granular to polyhedral and this is accompanied by a change from friable to firm. The pH near the surface of these soils is around 5 and increases with depth to about 6 near the limestone surface. The calcium oxide content of them is low, 0.5% near the surface to 1.0% at depth and also indicates the acidity. No free carbonate is present near the surface but a little may be present near the limestone. The base saturation is very variable ranging from 12% to 30%; the dominant cation is calcium. The loss on ignition of the A horizon is between 8 and 12% and of the (B) between 3 and 5% with organic carbon contents of 3 to 5% and 1 to 2%.

As has been mentioned above two different types of acid brown earth are found on the limestone grassland sites. They have similar overall depths and the features described above are common to both; the differences between the types will now be discussed. The most striking difference is the increase with depth of the content of fragments of gingerbread limestone in one type while in the other type no such fragments are found. In the type with gingerbread limestone fragments, (Plate 32) i.e. fragments of decalcified impure limestone, the first fragments are usually found between 4" and 6" below the surface and they increase until, at a depth of approximately 18 inches, the gingerbread limestone is virtually in situ, usually as small blocks, with soil material between. This arrangement infers

Plate 33. Acid brown earth; Moss Burn - Flus h Site, Profile 5 A.B.E.

that the soils over the gingerbread material have developed in situ and this will be examined further (p.191). This type of soil is found associated with the Tyne Bottom and Four Fathom Limestones but not with the Scar, because the Scar is much purer and does not produce a gingerbread on decalcification. The soil near the base of this type of acid brown earth over the Tyne Bottom Limestone is often stained black and the topmost continuous layer of limestone i.e. not yet fragmented, always has a black, greasy deposit on the upper surface. This is not found over the Four Fathom Limestone and the difference is due to the difference in insoluble residues of the limestone.

The limestone - soil junction in the soils associated with gingerbread limestone is gradational but in the other type of acid brown earth it is much sharper and the base of the soil layer can be peeled away from the underlying bedrock. In this second type a change in structure takes place in the profile from granular to moderately coarse blocky. The accompanying change from friable to very firm is not always reflected in a textural change. At the base of the soil layer, in contact with the underlying limestone, a skin, a few millimetres thick, of very dark brown material is obviously distinct from the rest of the profile.

Texturally, the most striking fact about these soils is the consistantly high clay content although the actual textural class of the soils varies, e.g. clay loam, silty clay, or clay. There is also a marked increase in clay content down the profile : the increase usually takes place fairly rapidly but at varying depths from the surface. It is also significant that the increase is most marked in the soils developed over the gingerbread material.

Within this sub-group, as used here, there are undoubtably, soils which may be better considered as brown podzolic soils. It was decided to consider one sub-group intermediate between a brown calcareous soil and a peaty gleyed podzol (Chapter 14) as the sites were so small and to collect enough samples to adequately sub-divide the soils further would have caused unacceptable disturbance. The problem of soils intermediate to a podzolic soil is considered further in part III.

Acid Brown Earth

Profile number : 5 A.B.E. Sample numbers : MBF 1, MBF 2, MBF 3, and MBF 4.

Location : Moss Burn - Flush Site.

Nat. Grid Reference : 745314.

Altitude : 2100ft. O.D.

Relief and aspect : Slight slope to the north north east.

Geological data : The soil is developed in a layer of superficial material overlying the Scar Limestone.

Vegetation : An intergrade between an Agrosto-Festucetum and a Nardetum sub-alpinum.

Horizon ins	
A_1 0 - 1½"	Dark brown (7.5YR 3/2) friable clay loam; moderate, medium granular; high organic matter content; dense root mat; sharp regular boundary.
(B) 1½- 7"	Brown (7.5YR 4/2) friable to firm clay loam; moderate coarse prismatic which breaks down to strong, medium granular; even coloured; few stones; frequent roots; few earthworms; merging regular boundary.
(B)C 7"-11"(19")	Very dark brown (10YR 3/2) firm clay loam; moderate coarse blocky which breaks down to moderate medium blocky; very uneven coloured, black and ochreous areas (Rotting rock fragments); few stones; few roots; sharp, highly irregular boundary.
D	Limestone bedrock.

Profile no. 5 A.B.E.

Sample no.	Depth (ins)	p.H.	$CaCO_3$%
MBF 1	0 - 2	4.2	0
MBF 2	6 - 8	4.7	0
MBF 3	11 - 13	5.2	0
MBF 4	17 - 19	5.8	0

	U.S.Sand	I.Sand	I.Silt	Clay	U.S.Silt %
MBF 1	11.8	19.00	23.8	57.2	31.00
MBF 2	22.6	25.9	25.4	48.7	29.6
MBF 3	-	7.5	30.1	62.4	37.5
MBF 4	11.2	19.2	30.3	50.5	38.3

		Extractable							
	% B.S.	Ca	Mg	Na	K	L.O.I.%	%C	%N	C/N
MBF 1	12.2	1.71	0.39	0.05	0.06	10.31	3.04	0.31	9.8
MBF 2	31.8	4.26	0.31	0.08	0.075	7.89	1.89	0.23	8.2
MBF 3	40.7	4.82	0.30	0.07	0.092	6.45	1.20	0.18	67
MBF 4	56.0	5.1	0.41	0.71	0.10	6.68	1.31	0.09	14.6
		meq./100g.							

				Total						
	Si	Al	Fe	Mg	Ca	Na	K	Ti	Mn	H_2O%
MBF 1	53.04	19.44	9.12	0.58	0.46	0.65	1.48	1.03	0.66	10.10
MBF 2	56.54	16.50	10.29	0.59	0.48	0.70	1.49	1.17	0.85	9.65
MBF 3	58.97	19.25	5.76	0.59	0.56	0.77	4.47	0.71	0.11	8.87
MBF 4	59.36	19.55	6.17	0.69	1.02	0.80	2.05	0.64	0.16	8.36

Acid Brown Earth

Profile number : 6 A.B.E   Sample numbers H.H.8, H.H.9 and H.H.10.

Location : Northern slopes of Hard Hill.

Nat. Grid Reference : 726333

Altutude : 2200ft. O.D.

Relief and aspect : Almost level bench on a north facing slope.

Geological data : The underlying limestone is the Four Fathom.

Vegetation: An association related to an *Agrosto-Festucetum* but with an unusually high content of *Polytricum* spp.

Horizon. ins	
A_1 0 - 1	Dark brown (10YR 4/4) friable loam; moderate medium granular; high organic matter content; dense root mat; earthworms; clear and regular boundary.
(B) 1 - 6	Brown (7.5YR 4/2), slightly stony; firm, silty loam; moderate coarse granular; frequent roots; earthworms; merging boundary.
(B)C 6 - 10	Brown (7.5YR 4/4), very stony, firm silty clay; moderate coarse granular; frequent roots; many, highly weathered, decalcified limestone fragments; merging boundary.
CD 10+	Bedrock limestone with some brown soil material along joint faces.

Profile no. 6 A.B.E.

Sample no	Depth (ins)	pH	$CaCO_3$ %
HH 8	0 - 1	4.5	0
HH 9	3 - 5	4.5	0
HH 10	8 - 10	6.4	Trace

	U.S.Sand	I.Sand	I.Silt.	Clay	U.S.Silt %
HH 8	10.2	22.3	59.2	18.5	71.3
HH 9	15.0	23.3	56.1	20.6	64.4
HH 10	8.1	18.8	40.6	40.6	51.3

		Extractable							
	%B.S.	Ca	Mg	Na	K	L.O.I.%	%C	%N	C/N
HH 8	12	0.30	0.27	0.29	0.09	10.26	3.02	0.50	6.0
HH 9	27	1.21	0.54	0.27	0.13	8.38	2.15	0.37	5.8
HH 10	53	3.67	0.73	0.27	0.11	6.84	1.42	0.12	11.8
		meq./100g.							

				Total							
	Si	Al	Fe	Mg	Ca	Na	K	Ti	Mn	H_2O	P %
HH 8	n.d.	3.7	4.6	0.15	0.19	0.15	0.59	n.d.	0.6	n.d.	0.50
HH 9	n.d.	3.3	4.4	0.14	0.28	0.09	0.54	n.d.	0.59	n.d.	0.37
HH 10	n.d.	5.1	4.9	0.23	0.70	0.16	1.03	n.d.	0.009	n.d.	0.12

12.5. Peaty Gleyed Podzol. (Plates 34 and 35).

The particular aspects of these soils as they occur in association with limestone grassland will be discussed here; soils of this type are also found on sites completely distinct from areas of limestone grassland (Chapter 17).

On limestone sites peaty gleyed podzols are found in two main situations. The first is at the edges of the areas where the grassland gives way, via a zone of moor edge vegetation, to blanket peat. The podzol is associated with this zone of moor edge vegetation. The second situation is associated with the larger rounded mounds of superficial material which are found resting on the limestone surface and in the channels cut in the limestone surface. In both cases the depth of the superficial material is at least 18 inches.

In both situations the soil is associated with a similar vegetation. The community is somewhere between the Nardetum sub-alpinum and the Juncetum sub-alpinum and Nardus stricta and Juncus squarossus are important species. It is noteworthy that the grasses which require a fairly base rich soil, e.g. Agrostis tenuis, are absent, or virtually so.

The striking features of the morphology of these soils are similar to those described from other sites and this is a very typical peaty gley podzol. An acid mat of mor humus is found at the surface and below this is a bleached and gleyed A_2 horizon. Between the humus and the A_2 a very sharp junction is present and little, if any, mixing of humus and mineral material has taken place. The A_2 horizon is generally a grey-brown or a grey colour. The A_2 contains a large number of roots but most of these are limited to this horizon

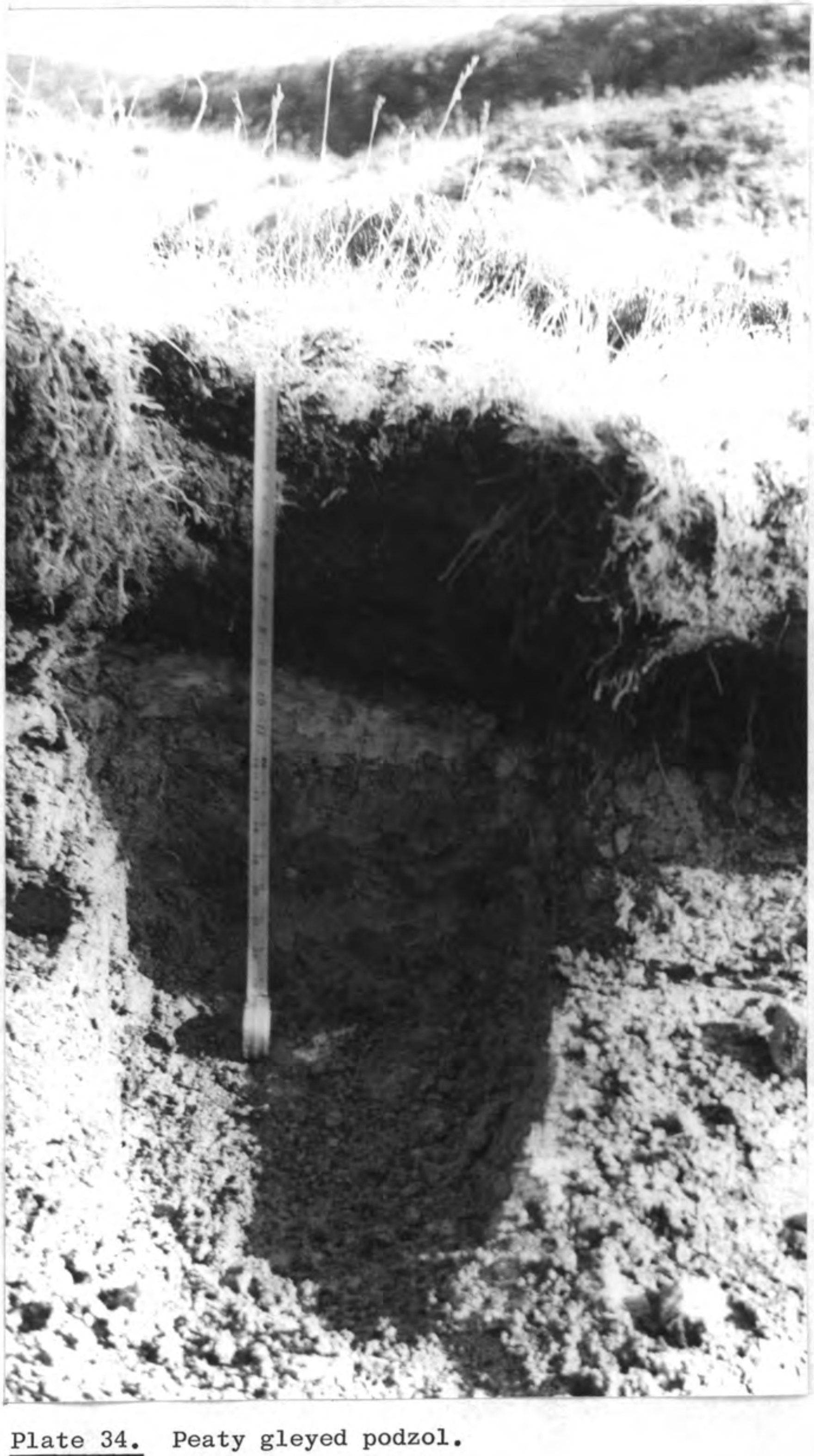


Plate 34. Peaty gleyed podzol.
(Profile 7 P.G.P.)

because of the thin iron pan found at the junction of the A_2 and the B horizon. The iron pan is not always present and when absent the roots penetrate deeply into the B horizon. The boundary between the A_2 and the B is very sharp but is often highly irregular, when present the thin pan follows these irregularities of the junction. A root mat is usually found on the upper surface of the pan and this surface is often stained black. Below this black stained layer a deep rust red layer, which makes up the bulk of the pan, is present and this usually gives way to a yellowish-red lower surface. The pan is rarely more than 5 m.m. thick.

A strong brown layer some two inches thick is found below the pan and shows the enrichment in iron. The lower boundary of this B_2 horizon is a merging one and gradually gives way to yellowish brown horizon. The limestone soil junction is very sharp but at the base of the yellowish-brown layer one commonly finds a band of dark brown, clay rich material. Usually this layer is less than 1" thick but in places it thickens to produce masses up to 6" thick.

These soils are markedly acidic with the p.H increasing from around 4.0 at the surface to 4 - 4.5 at the bottom of the profile. The total calcium content also gives some indication of the extreme acidity and is commonly less than 0.1% through the profile. The base saturation rarely reaches above 5%. Texturally the soils are a loam or a clay loam and a clay content of above 20% is common to them all. As with the other soil types examined the texture is liable to vary from site to site. The structure is very poorly developed and at best is weak to moderate blocky which becomes weaker down the profile. The A_2 horizon is often extremely compacted, as is the lower part of the profile, and in some cases the structure is best developed in the B horizon. There is no regular variation in texture down the profile.

Plate 35. Peaty gleyed podzol, Moss Burn - Sheep Fold Site.

Peaty Gleyed Podzol

Profile no : 7 P.G.P. Sample no's : M.H. 7 to 9.

Location : Green Hole.

Site Reference : Fig 24. C. 60.5

Nat. Grid Reference : 764324.

Altitude : 1850 ft. O.D.

Relief and aspect : Approx. 10° slope to the north west.

Geological data : Superficial material resting on the Tyne Bottom Limestone.

Vegetation : Nardetum sub-alpinum.

Horizon : ins	
4 - 0 H	Blacky, friable peat; moderate medium crumb; abundant roots; clear regular boundary.
0 - 2 A_{2G}	Dark grey brown (10YR 4/2), firm, clay loam; weak, coarse blocky; frequent roots; low organic matter content; few, clear small strong brown (7.5YR 5/6), mottles - chiefly along root channels; clear regular boundary.
2 - 2½ B_1	Reddish brown (5YR 5/4), firm, stony clay loam; weak coarse blocky; frequent roots; low organic matter content; gradual irregular boundary.
2½ - 5½ B_2	Dark brown (7.5 YR 4/4), firm, stony clay loam; weak coarse blocky; roots common; low organic matter content; gradual regular boundary.
5½ - 24 C B	Grey brown (10YR 5/2), slightly indurated, stony, clay loam; structureless - massive; occasional roots to 12"; low organic matter content; sharp, irregular boundary.
D	Bedrock - Tyne Bottom Limestone.

Profile no. 7 P.G.P.

Sample no.	Depth (ins)	pH.	$CaCO_3$ %
MH 7	0 - 2	3.9	0
MH 8	4 - 6	4.2	0
MH 9	8 - 12	4.9	0

	U.S.Sand	I.Sand	I.Silt	Clay	U.S.Silt %
MH 7	36.7	44.5	21.3	34.2	29.1
MH 8	35.7	46.8	13.6	39.6	24.7
MH 9	34.5	39.4	22.7	37.9	27.6

		Extractable							
	% B.S.	Ca	Mg	K	Na	L.O.I.%	%C	%N	C/N
MH 7	5.6	0.48	0.3	0.09	0.13	10.12	2.96	0.35	8.46
MH 8	8.2	0.51	0.22	0.08	0.10	8.47	2.13	0.20	10.65
MH 9	14.0	0.38	0.39	0.02	0.08	7.18	1.55	0.16	9.69
		meq./100g.							

			Total								
	Si	Al	Fe	Mg	Ca	Na	K	Ti	Mn	H_2O	P %
MH 7	n.d.	4.2	1.3	0.10	0.05	0.18	1.13	n.d.	0.02	n.d.	0.03
MH 8	n.d.	6.1	8.8	0.15	0.05	0.33	1.65	n.d.	0.20	n.d.	0.06
MH 9	n.d.	8.0	5.9	0.25	0.05	0.44	2.06	n.d.	0.35	n.d.	0.08

12.6. Peaty Gley. (Plate 36).

Peaty gleys are found at the edge of the blanket peat which surrounds the areas of grassland and in this position they often form a complex with peaty gleyed podzols. They are found under similar vegetation to the peaty gleyed podzol but Juncus squarrosus is generally more important than Nardus stricta and indicates poorer drainage.

An acid surface layer of mor humus is found and the junction with the mineral soil is very sharp reflecting the almost complete lack of intermixing of organic material and mineral soil. The upper 2 - 4" of the mineral soil, A_G, is a dull grey or grey brown gleyed horizon. It is often extremely difficult to sub-divide the soil any further as it often remains constant in texture and morphology until close to the soil-limestone junction. The body colour of the lower soil is usually a grey-brown colour with medium ochreous or brown distinct mottles. Sometimes a zone is found below the A_G, i.e. the B_G, in which the mottles are restricted to the root channels, which are frequent, and this gives way to the zone in which they are spread throughout the soil.

A better drained horizon of varying depth is found at the limestone surface. In a few cases this better drained horizon may be absent and gleying persists to the soil-limestone junction. Beneath deep peat the soil is often a blue-grey colour throughout its depth. When a freely drained layer is present at the base of the profile it is generally a yellow brown colour. The clay rich layer found at the base of the peaty gleyed podzol can also be found at the base of the peaty gley profile. Once again this clay rich layer varies greatly in depth. The overall depth is at least eighteen inches but usually more than two feet.

Plate 36. Peaty gley over limestone, Rough Sike Site.

As with the peaty gleyed podzol the soil texture varies somewhat from site to site but it is usually a clay loam : the soils are usually stony. There is no regular variation in texture with depth. The structure is weak and the soil material can be extremely compacted and somewhat indurated. The structure, if any, is weak, coarse to medium blocky. The soil material often gives the impression that it is, little altered glacial drift.

The soils are very acid with a pH of 4 to 4.5 near the surface and rarely increasing above 5.5 down the profile. A higher pH may be found at the soil-limestone junction. No free carbonate is present and total calcium oxide contents are rarely above 0.5%. The base saturation is commonly between 2 and 5%.

It is difficult to find a suitable term to designate the soil complex of these areas. To include the names of all the sub-groups within the complex would make the term too bulky but any other method must be a compromise. Despite the drawback it is suggested that the complex is referred to as a brown earth - calcareous soil complex as these are the sub-groups which give rise to the very distinct vegetation.

Peaty Gley

Profile no : 8 P.G. Sample no's : M.H. 10 to 12.

Location : Green Hole.

Nat. Grid. Reference : 764324.

Altitude : 1850ft. O.D.

Relief and aspect : Gradual slope to the north.

Geological data : Superficial material resting on the Tyne Bottom Limestone.

Vegetation : Juncetum squarrossi sub-alpinum

Horizon ins	
3 - 2 L + F	Raw plant remains, easily recognisable, mainly Juncus and Nardus debris.
2 - 0 H	Black (7.5 YR 2/0), friable peat; moderate medium crumb; clear regular boundary.
0 - 4 A_G	Grey brown (10YR 5/2), friable to firm, clay loam; moderate medium crumb; frequent roots; low organic matter content; gradual irregular boundary.
4 - 38 C_G B_G	Grey (10YR 6/1), indurated, stony clay loam; structureless - massive; roots common to 13"; low organic matter content; frequent, distinct, medium reddish-yellow (7.5 YR 6/8) mottles; sharp irregular boundary.
38 + D	Bedrock - Tyne Bottom Limestone.

Comment: In the C_G B_G horizon the mottles increase in frequency towards the limestone-soil interface but it is a gradual increase and does not make it possible to sub; divide the horizon.

Profile no. 8 P.G.

Sample no.	Depth (ins)	pH	$CaCO_3$%
MH 10	0 - 3	4.5	0
MH 11	8 - 12	5.1	0
MH 12	14 - 18	5.4	0

	U.S.Sand	I.Sand	I.Silt	Clay	U.S.Silt %
MH 10	29.4	43.0	20.6	36.4	35.2
MH 11	20.2	49.0	23.4	37.6	42.2
MH 12	31.1	46.3	22.8	30.9	38.0

	% B.S.	Extractable Ca	Mg	Na	K	L.O.I.%	C%	N%	C/N
MH 10	19	1.79	0.53	0.10	0.02	4.3	1.8	0.07	25.7
MH 11	23	1.83	0.60	0.08	0.019	4.61	0.80	0.06	13.3
MH 12	41	3.6	0.82	0.12	0.017	n.d.	n.d.	n.d.	-
		meq./100g.							

Not analysed for total constituents.

CHAPTER 13

Parent Material

13.1. Introduction and Analytical Methods Used.

Two primary questions need to be considered with respect to parent materials of the limestone grassland soils which were described in the last chapter. Firstly, whether the material was derived from the underlying limestone bedrock in situ or whether it was transported. Secondly, if the material is shown to be transported, the origin and method of transport. Examination of the parent material, in an attempt to answer these questions, has been carried out.

An immediate consideration is the amount of residual material which would be left after solution of the limestone by weak acid; such action would take place under the climatic conditions at Moor House. The amount of this insoluble residue depends on the purity of the limestone and the length of time the material has been accumulating. The length of time available for accumulation is impossible to determine but some idea can be gained by taking the time since the last glacial episode as a maximum, i.e. approximately 10,000 years. Sweeting (1966) suggests that the rate of lowering of the limestone surface in north-west Yorkshire is roughly 41 m m. in 1000 years. This would give a total lowering "since the last phase of the Quaternary Ice Age" of "40 - 50 cm." (Sweeting 1964). Taking this as a guide an estimate can be made of the amount of insoluble residue which would be produced in the same period; this amount will depend on the purity of the limestone. If the limestone were 95% acid soluble, as are some of the Carboniferous limestones, this would have produced 2.0 - 2.5 cm. of residue in the period considered by Sweeting (1964). Working on this basis any of the pure limestones with a soil cover greater than a few centimetres must have received at least part of their cover as transported material.

If the superficial material is shown to be transported its origin must be considered. Much of the area covered by the Reserve has a cover of "glacial drift" and above the limit of the drift there is an almost complete cover of head, or colluvial material. These two are the most likely sources of transported material and both are likely to have a very similar make up as they are derived from relatively close at hand from the local Carboniferous rocks. In recent years a succession of workers have demonstrated the existence of an aeolian layer near the surface undisturbed soils in Britain (e.g. Avery et al 1959, Perrin 1956, Findlay 1965, Pig'ott 1962, and Bullock 1963). This provides another possible source of transported material.

Examination of parent material and associated unconsolidated deposits followed the pattern used by previous workers and involved mechanical analyses of the soil material, and, where possible the insoluble residue of the limestone. Heavy minerals of the fine sand fraction of the soil material were separated and compared with those from the insoluble residue of the limestone. Quartz of the fine sand fraction of the soils and of the limestone residue were compared because both Piggott (ibid) and Bullock (ibid) found the quartz of the limestone to be bipyramidal and that of the aeolian material rounded and eroded. Determination of the clay minerals present in the materials was completed. All fragments of rock and other materials in the soil in the size range 2 cm. - 2 m.m. were identified. Total major and trace element chemical analysis were carried out on the soil material to determine whether or not this would indicate addition. It was thought that strontium content may be high in sedentary soils over limestone as it is preferentially accumulated with carbonates. Rubidium content was expected to be high in the drift as it is preferentially accumulated.

in clay minerals. By comparing the soil parent material with the insoluble residue of the underlying limestone one can show whether the soil is sedentary or transported but it is rather more difficult to prove whether any transported material present is colluvium, drift or loess.

13.2. Work on Aeolian Materials.

Aeolian transport preferentially carries and accumulates material of the fine sand and silt fractions. The clay fraction is carried on by the wind and the coarse end of the fine sand fraction, and anything coarser, is too large to be moved by the wind. Aeolian material will, therefore, have a low clay and coarse sand content, be almost stone free, and have a high silt content. Udden (1914) says of loessial material, that a cumulative curve will show a steep rise between 80 and 10μ . Russell (1944) says of loess, "..... the single fraction 0.01 - 0.05 m.m. ordinarily constitutes at least 50% (by weight) of a sample ...," but he was doubtful whether this could be due solely to wind sorting. Swineford and Frye (1945) showed that this degree sorting could be achieved by aeolian agency and confirmed the view of Russell (ibid) that at least 50%, by weight, fell between 0.01 and 0.05 m.m. Russell (ibid) also said of loess, it "is unstratified, homogeneous, porous, calcareous silt". Lugn (1962) rejects the necessity for loess to be calcareous; he also shows the concentration in the very fine sand and silt fractions.

Perrin (1956) examined chalk heath soils in England and because of the concentration in the silt and very fine sand fractions, the lack of stones, and the homogeneous nature of the deposit he formed the opinion that it was of loessial origin : first having proved that the deposit was dissimilar to the insoluble residue of the chalk, Perrin (ibid) compared cumulative curves of the material with those for known loess and showed the similarity. He suggested that the higher clay content, compared to north American and European loess, was due to the fact that silt sized clay aggregates had existed. Avery et al (1959) also suggest a loessial origin for material they examined because the distribution in the intermediate size range was, "indicative of sorted material with a well defined maximum at around 60 - 20μ" and said that the similarity to Perrin's cumulative curves (Perrin, ibid) "suggest that the materials are at least partly derived from loess". This and later work, e.g. Piggott (1962), Bullock (1963) and Findlay (1965) followed the pattern of Perrin's work, i.e. first showing by heavy mineral analysis, clay analysis and particle size work that the material was unlikely to be a limestone residue, then, if the mechanical analysis showed a concentration in the fine sand and silt, and the material was homogeneous and almost stone free, suggesting an aeolian origin.

Bullock (ibid) added another method of analysis to those commonly used in that he did a detailed breakdown of the distribution within the fine sand fraction by sieving into eight separate fractions. He then plotted a distribution curve of $^{\delta M}/_{\delta R}$ against mean R, where δM is the percentage mass retained on a given sieve, δR the interval in cms. between two adjacent sieves and $R = \log_{10} d$, d being the width of the sieve appatures in centimetres. The area of any vertical strip beneath the curve is said to represent a mass and the total area below the curve is always a constant value of 100 units, as percentage masses are used. Bullock (ibid) constructed curves for his material using this method and compared them with curves for accepted loess from the Yorkshire Wolds. In both cases a marked peak is produced in the 0.10 - 0.15 m.m. area, and a subsidiary peak in the 0.15 - 0.2 m.m. area; these Bullock ascribes to aeolian material. After the large peak at 0.10 m.m. there is a marked decline at 0.08 m.m. and a marked increase at 0.05 m.m., the latter Bullock says is loessial. The above method has been used on selected soils in the present study. The curves Bullock obtained from the Yorkshire Wolds material and from his Malham material are almost identical and certainly imply a similar origin. The present writer thinks this method must be used in conjunction with other results, e.g. homogeneity, lack of stones, etc. A Moor House sample containing large boulders (Sample B.H.2) throughout gave a curve almost identical to Bullocks "loess", (fig.29).

13.3. Parent Materials of the Soils on the Tyne Bottom Limestone.

A major difficulty encountered in the present study has been that the sites are located on one of three different limestones, i.e. the Tyne Bottom, the Scar and the Four Fathom, and that these three limestones differ in their physical characteristics, e.g. colour, purity and nature of insoluble residue. Also the limestones vary considerably within themselves. This is in marked contrast to the situation in most similar previous work, e.g. Piggott (1962) and Findlay (1965), where one limestone of reasonable constant composition was involved. Each of the three limestones involved will be considered separately. The parent material will then be considered

Plate 37. Decalcified impure Tyne Bottom Limestone.

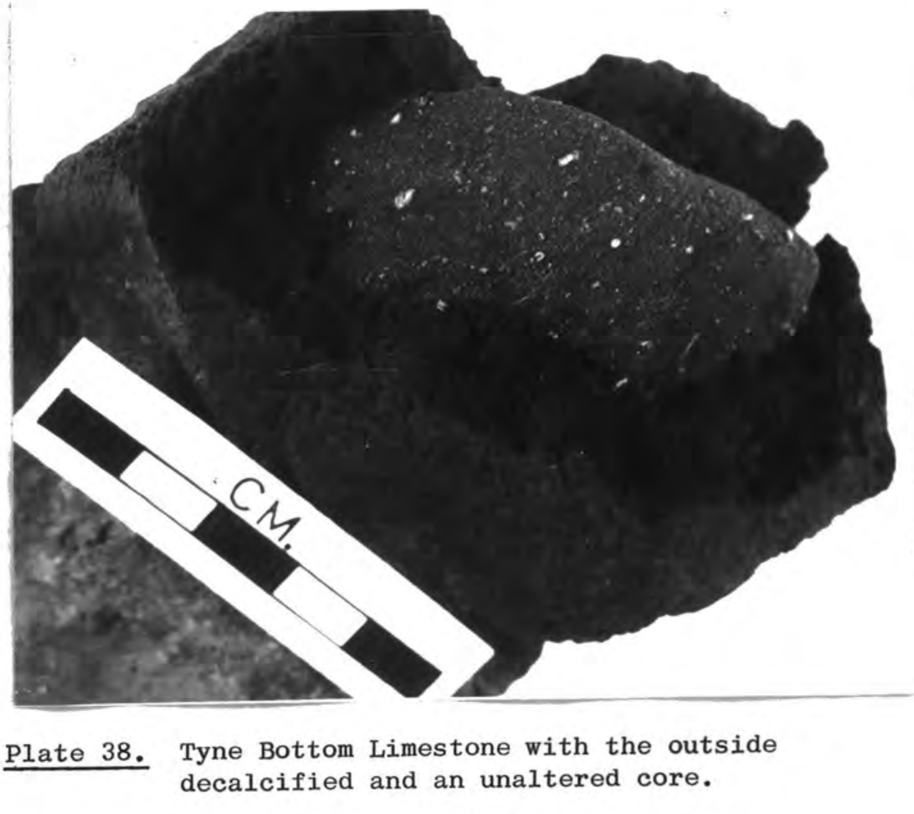


Plate 38. Tyne Bottom Limestone with the outside decalcified and an unaltered core.

by soil types as the uniform layering of parent material found elsewhere was not present.

The Tyne Bottom Limestone was found to vary greatly in its acid solubility. It varied between 40 and 90 per cent soluble, by weight, in $^{N}/_{10}$ hydrochloric acid. Far more important than the percentage insoluble residue by weight is the volume of insoluble residue produced. The impure limestone, when treated with acid, would leave a block of material of the same dimensions as the block before treatment. These blocks of decalcified material are very light and porous and are commonly known as gingerbread or 'famp' (Plates 37 to 38). In theory a given thickness of this impure limestone can be decalcified and leave an identical thickness of 'gingerbread' behind. The volume of the material when disintegrated is difficult to determine but was estimated, after crushing, to be at least 50% of the original volume. Such a limestone would produce at least 25 cm. of material in the period considered by Sweeting (1964) (p.180). This impure material may have been deposited as an impure limestone or it may have been altered during the mineralisation which affected the area. Examination of the insoluble residue by X-ray diffraction, in thin sections and also sieving and examining the fractions shows it to be essentially composed of quartz and chlorite with subsidiary kaolinite and goethite. It contains very few heavy minerals but a few grains of zircon, fluorite and pyrite were found. The quartz of the fine sand fraction is angular but rarely bipyramidal. The clay fraction has a high content of chlorite with subsidiary quartz and kaolin. Mechanical analysis of the material is very difficult as the decalcified material has to be crushed to simulate disintegration in the soil but it is difficult to be certain when one has crushed down to the primary particles. Results that were obtained indicate a

Plate 39. Decalcified (Gingerbread) impure Tyne Bottom Limestone.

concentration of material in the silt fraction with a low clay content, e.g.

There is a continuous variation in purity from the impure, 40% acid soluble, to the pure, 90% acid soluble. Comparison of results obtained from the acid insoluble residue of the pure and impure limestone show them to be compositionally very similar. As the limestone becomes more impure the content of quartz and chlorite increases. Heavy minerals are still rare in the purer limestone and seem to be restricted to zircon, fluorite and pyrite. Bipyramidal quartz crystals are rather commoner than in the impure limestone but are still few when considering the whole of the quartz present. The purer limestone does not produce gingerbread when decalcified and the residue occupies an extremely small volume when compared to the original limestone. If we take the 10% insoluble residue as roughly proportional to volume then the purest Tyne Bottom Limestone would only produce 4-5 cm. of residue in the same period as the most impure produced 25 cm. One feature of the insoluble residue of this limestone which has not been mentioned so far is its black greasy nature. It would seem that this material is carbonaceous. It has not been analysed, but it is known to be completely removed after treatment with hydrogen peroxide. This black material might be expected to influence the colour of any soil of which it formed a part.

Turning to the soils found on the Tyne Bottom Limestone, most of them are developed in a layer of clay loam of varying thickness, which is quite stony. In places this clay loam in underlain by a layer of much stonier clay loam in which all the stones are gingerbread material. Small patches of a thin loam layer are found over the normal clay loam and a discontinous layer of clay is found at the soil-limestone interface below the deeper soils. The normal, moderately stony clay loam is the most important parent material and the various soil types are developed in varying thicknesses of the material. The cobble sized stones, which are always present, are predominantly sandstone but large pieces of ore vein material are often found. The 2 cm. - 2 m.m. fraction contains sandstone fragments, quartz fragments, shale fragments, fragments of vein material and sometimes gingerbread fragments (Table 4). The clay fraction contains illite, chlorite and quartz. The illite is dominant in the deep soil types but in the rendzinas the chlorite may be dominant and in brown calcareous soils they are often in roughly equal amounts (Table 5). The chlorite can be taken as indicating a contribution from the limestone and illite from transported material. The coarse sand fraction is dominated by quartz fragments but it may contain a considerable number of iron and manganese concretions. The quartz fragments are much larger than any found in the insoluble residue and must be transported. The quartz of the fine sand fraction is a mixture of rounded and angular grains but little can be learnt from this fraction. Heavy minerals present in the fine sand fractions include fluorite, rutile, zircon, garnet and tourmaline, plus a large opaque assemblage, and both by the quantity and increased variety indicate a transported origin (Table 5).

The results mentioned so far indicate a transported origin for the material, or at least part of it. The way that chlorite dominates the clay fraction of the rendzina type soils indicates the large contribution of the limestone to the soil. This contribution is more important if the limestone is more impure, but the most impure limestone have a layer of stony clay loam below this clay loam layer. In the somewhat deeper soils, i.e. the brown calcareous soils, the chlorite is codominant with the illite in the clay fraction and again illustrates a significant contribution from the limestone. In the acid brown earths, and peaty podzols formed entirely in a layer of clay loam the chlorite becomes more important near the base of the profile, although in some cases it is virtually absent altogether. This does indicate that even the deepest cover of superficial material the limestone may have contributed. The picture produced is one of a declining contribution of the limestone as one proceeds from a rendzina to a peaty gleyed podzol, although this decline may be relative. The absolute contribution may well be very similar but in the deeper soils it is swamped by a much greater volume of transported material. Another important factor is that in the shallower soils the limestone residue will be integrated into the upper soil more rapidly because of greater soil fauna activity.

Turning to the question of the source of the transported material the mechanical analyses gives the best indication. The clay content of the clay loam seems to be too high (25 - 35%) to make an aeolian origin feasible. It is also important that this clay content is much higher than that of the insoluble residue. The silt content would also seem to be rather low (40 - 50% U.S.D.A. silt) for aeolian material. Large stones are also too common to allow an aeolian origin. The graph of $^{\delta M}/_{\delta R}$ plotted against mean R shows a tremendous concentration in the fine end but not the marked drop at 0.08 m.m. (fig.30). As mentioned earlier the results of this method must not be used alone and although Bullock (1963) says a rise in the 0.05 m.m. size grade indicates a loessial fraction other evidence mentioned above seems to overrule this. The most likely origin for the transported material is either glacial - periglacial drift or colluvium.

All the rendzinas and brown calcareous soils examined on the Tyne Bottom Limestone have been developed in this clay loam and in the case of these soils the material can fairly be considered an admixture of drift or colluvium and limestone residue with the limestone residue dominant in the rendzina. Some acid brown earths, peaty gleyed podzols and peaty gleys are developed entirely within a deeper layer of this clay loam but only where it overlies the purer type of limestone. In these soils the transported material is completely dominant with a minor contribution from limestone residue.

Where the clay loam discussed above is found overlying the most impure type of Tyne Bottom Limestone, i.e. that which produces gingerbread on decalcification, it is underlain by a very stony clay loam layer. The stones were almost entirely gingerbread material and the 2 m.m. - 2 cm. fraction was also completely dominated by this type of material. With increasing depth the blocks of gingerbread material are closer to their in situ position and near the base of the layer one has blocks of gingerbread showing the original bedding with only a small amount of clay loam between the blocks (Fig.31). One problem concerning the gingerbread blocks is that they are yellowish, reddish or brownish whereas insoluble residues obtained in this work have always been black and greasy. If the black colouration is due to carbon then it must be broken down in the soil. The interface between unaltered limestone and decalcified at the base of the profile is always black and greasy so the breakdown must take place some time after decalcification. The clay loam associated with the gingerbread has a clay fraction which is completely dominated by chlorite with subsidiary quartz and kaolin and virtually no illite. This clay loam contains very few heavy minerals and those which are present are also found in the insoluble residue of the limestone, i.e. zircon, fluorite and pyrite. This layer of material is essentially the insoluble residue of the very impure type of Tyne Bottom Limestone. The clay loam material between the blocks of gingerbread cannot definitely be said to be the insoluble residue. The heavy mineral analysis would seem to support this origin but the clay content is very much higher than the results obtained for the insoluble residue of the impure limestone (Table 7). As mentioned earlier the results from the insoluble residue may be dubious as the material may not have been reduced to its primary particles and in particular clay aggragates may not have been broken down resulting in an artificially high silt and an artificially low clay. When the fine sand fraction of this clay loam is broken down into smaller fractions and the graph of $^{\delta M}/_{\delta R}$ v. $\log_{10} d$ plotted it indicates a strong concentration at the fine end of the fraction. Microscopic examination of the insoluble residue of the impure limestone shows that it has a concentration in the fine sand fraction at the end. Some of the clay loam may have been carried down from the overlying clay loam layer and it may be significant that when the normal clay loam layer overlies the stony clay loam there is a highly merging interface with considerable intermixing between the layers. The stony clay loam is predominantly residual and in situ but may have some slight addition of material.

A discontinuous layer of clay is found at the soil-limestone interface of the acid brown earths and peaty gleyed podzols. It is usually yellow in colour and highly variable in thickness (Table 8). The clay fraction is almost entirely chlorite and quartz with the chlorite dominant. It contains few heavy minerals and only those also found in the insoluble residue of the limestone. It would seem to be an insoluble residue of the limestone but some process must operate to concentrate the clay if results obtained for the clay content of the insoluble residue are correct. Another problem is the colour of the material as all samples of insoluble residue obtained during this work were black and greasy. The mineralogy would indicate it is an insoluble residue but the process of concentration of the clay and the change in colour from black to yellow is problematical. (Some suggestions regarding the colour change have been made earlier, p 191).

On the Rough Sike Grassland Site a thin layer of sandy loam is found associated with the acid brown earths and the peaty podzols. This layer is found at the surface and is usually 2-3 inches thick and it seems to be associated with the tops of the low mounds over patches of the very impure limestone. The 2 m.m. - 2 cm. fraction of the material contains numerous fragments of shale and sandstone but fragments of weathered vein material are also common. The heavy mineral suite of the fine sand fraction is enriched compared with that of the insoluble residue of the limestone. The dominant clay mineral of the clay fraction is illite. These factors together indicate a transported origin for the material. The low silt content, 30-35%, would rule out an aeolian origin. Material nearby, on Burnt Hill, which contains many large boulders and would appear to be a head deposit contains a high sand content also but its silt and clay content are higher than in this sandy loam. The clay content, around 15%, is lower than most drift which has been examined but one cannot rule out the possibility of illuviation of clay into the underlying clay loam. The close similarity of the various fractions of the sandy loam and clay loam when examined in detail give some support to this suggestion. If they are of similar origin, or indeed the same material, a drift origin would be most likely. Finally, at this particular site one cannot rule out a considerable likelihood of human influence as a great deal of mining activity has taken place hereabouts.

The high counts of vein material in the 2 m.m. - 2 cm. fraction of soils from the Rough Sike Site (Table 4) may indicate that this site has been disturbed. Alternatively it could indicate a strong contribution from the limestone below. Chemical analysis on the Rough

Sike material show very high lead, zinc and iron contents and could well indicate a contribution from the limestone bedrock as this is a heavily mineralised site. No distinct trend was shown by the strontium and rubidium contents but zirconium contents are very low in the rendzinas (Table 10) and the acid brown earths formed in the impure limestone. This low zirconium may be in contrast to the values in nearby drift as the drift contains zircons from the sandstones. If this were the case the low zirconium would be evidence of a sedentary origin or, at least, a lower transported element.

13.4. Parent Materials of the Soils on the Scar Limestone.

The Scar Limestone insoluble residue is much less than that of the Tyne Bottom Limestone. The most impure sample of the Scar Limestone was more than 95% soluble in N/10 hydrochloric acid and so the Scar Limestone would have provided only a few centimetres of material since the ice age even if exposed to weathering for the full period of time. The insoluble residue has a black colouration which is removed after treatment with hydrogen peroxide and so may be taken to be due to carbon. Mechanical analysis of the residue is very difficult due to the small amounts obtained but has roughly equal proportions of clay, silt and sand. Microscope examinations show the sand fraction to be almost entirely fine sand and concentrated at the fine end of the fine sand fraction. (This result was obtained by measuring the long axes of grains and hence can only be taken as a rough guide). The fine sand fraction contains quite numerous bipyramidal quartz crystals. The heavy mineral suite of the fine sand fraction is very poor and only zircon and fluorite were found.

Almost all the rendzinas and some of the brown calcareous soils developed over the Scar Limestone are associated with a stony loam (Table 12). This material is restricted to the isolated, upstanding limestone surfaces found on some of the sites, e.g. Moss Burn - Sheep Fold Site and The Currick Site. The stones in the soil are almost all limestone but a few sandstone cobbles are usually found. In the 2 cm. - 2 m.m. fraction small limestone fragments are again dominant but occassional sandstone and shale fragments are found. The coarse sand is dominated by quartz plus frequent iron concretions. In the fine sand quartz dominates the light fraction and bipyramidal quartz crystals are present. Heavy minerals are rare but occassional grains of minerals not found in the limestone residue were found, e.g. tourmaline. The clay fraction contains quartz and illite but little can be learnt from this as the limestone residue and the nearby transported material contain these minerals. This stony loam appears to be derived partly in place and partly as transported material. An aeolian source for the transported contribution is ruled out by the low silt content, around 35%, and colluvial or drift addition is most likely. The rendzinas show a low zirconium content and this may be evidence of a low transported element (Table 14).

The acid brown earths, peaty gleyed podzols, peaty gleys and some of the brown calcareous soils and rendzinas are developed in a clay loam which is generally stony (Table 13). The commonest stones in this material are sandstone cobbles and these are dominant. The 2 m.m. - 2 cm. fraction contains a very large number of fragments and four groups make up the vast majority : sandstone, fragments, shale and mudstone, quartz fragments, and iron and manganese concretions (The latter are not as common in the peaty podzols as in the acid brown earths and brown calcareous soils). The coarse sand fraction is almost entirely quartz fragments. Quartz also dominates the light fraction of the fine sand. In the heavy fraction zircon, garnet, tourmaline, magnetite, leucoxene and fluorspar have been identified. The clay fraction contains strong quartz peaks and weak illite peaks. The material is certainly of a transported origin. The high clay content, 30 - 40% and the low silt content 25 - 35% rule out an aeolian origin although the fine sand fraction gives a $\sigma M/\sigma R$ against mean R (fig 32) graph similar to the one which Bullock takes to indicate aeolian addition. A drift or colluvial origin is again the most likely. Chemical analyses give no indication of the origin of the material (Table 14).

The clay loam which has just been discussed is the most common material found overlying the Scar Limestone but isolated pockets of material are found which differ markedly and whose origin is difficult to explain. On the Moss Burn - Flush Site the parent material is a clay with clay contents of between 48 and 60% (Table 15). The material is not as stony as the clay loam. Most of the stones which are present are sandstone but some are limestone, pieces of *Lithostrotum junceum* colony with the calcareous mud from between the corallites dissolved away are quite common. It is significant that large colonies of *Lithostrotum junceum* are common in the limestone outcrops associated with this particular grassland. The 2 m m. - 2 cm. fraction contains fewer fragments than the clay loam and sandstone and shale fragments are dominant but fragments of corallites are reasonably common. The coarse sand, fine sand and clay fractions give results similar to those just noted for the clay loam. The material is transported and is of colluvial or drift origin. It has the appearance of raw drift, with the rock fragments being rotten, and apparently structureless. The lower parts of the deeper profiles have a speckled appearance with yellow-brown patches alternating with blue-grey. The *Lithostrotuim junceum* fragments suggest an origin very close to the present site or an intense admixing at the present site, perhaps by solifluxion. It is extremely difficult to imagine a process which would concentrate clay at this particular site and it is probably easier to have the material originating rich in clay. The obvious source for such a material is a shale outcrop but if this were the source the material could not be transported for or the clay would be diluted by the effect of material from sandstones.

On the Moss Burn - Sheep Fold Site a fairly stony loam layer is found which is quite distinct from the other loam layer previously mentioned. The stones in this layer are almost all sandstone and the 2 cm. - 2 m m. layer contains sandstone fragments, shale, quartz fragments and iron and manganese concretions. Detailed examination of the coarse sand, fine sand and clay fractions gives similar results to those obtained from the clay loam. The materials have a similar source but this really only tells one that they were both derived on the immediately surrounding slopes. This loam post dates the clay loam which it overlies and would appear to post date peat development as the clay loam continues under the peat whereas the loam does not. If this is correct it would make this material very recent and a colluvial origin is the most probable.

A discontinuous clay rich band is found at the limestone /superficial material interface (Table 16). The layer is usually found as small pockets and is the horizon which Johnson refers to as a'chocolate-brown layer'. The material is very plastic and has a smooth feel. It contains no large fragments and very little sand. The suprising thing about it is the high organic carbon content but this would explain the very dark brown colour. The horizon has no structure and no roots are apparent, or root holes. The clay fraction is dominated by illite and quartz, the fine sand and silt seems to be dominated by quartz and bipyramidal crystals are quite common. The material is most likely a solution residue of the limestone and the thin ¼" or so of this material commonly found could well have formed since the glaciation but the thicker pockets are more difficult to explain. The high organic matter content could come from the limestone but it does tempt one to see the deep pockets as a fossil soil formed during a previous cycle of soil formation. The material is very similar to the yellow clay layer found associated with the Tyne Bottom Limestone, except for the high organic content.

13.5. Parent Materials of the Soils on the Four Fathom Limestone.

The Four Fathom Limestone varies in acid solubility in much the same way as the Tyne Bottom Limestone. The most impure sample examined of the Four Fathom was not as impure as those of the Tyne Bottom but it was impure enough to produce a gingerbread material (Plates 39-40). On the summit of Hard Hill near to the trig point are several shake holes and in the margins of these blanket peat is underlain by a few inches of superficial material which in turn rests on up to 18" of decalcified limestone which is still in situ. In larger swallow holes to the south west of the trig. point the limestone walls around the swallow hole are also decalcified for several inches in a horizontal direction and along joints in the surrounding limestone decalcification has taken place along the sides of the joints. In these places various stages in the decalcification of the limestone can be seen and they show the way that it takes place with no reduction in volume of the rock. This impure limestone leaves a large amount of insoluble residue available for soil formation even though the gingerbread material, initially the same volume as the unweathered limestone, will disintegrate under soil formation.

Plate 40. Impure Four Fathom Limestone decalcified around the rim.

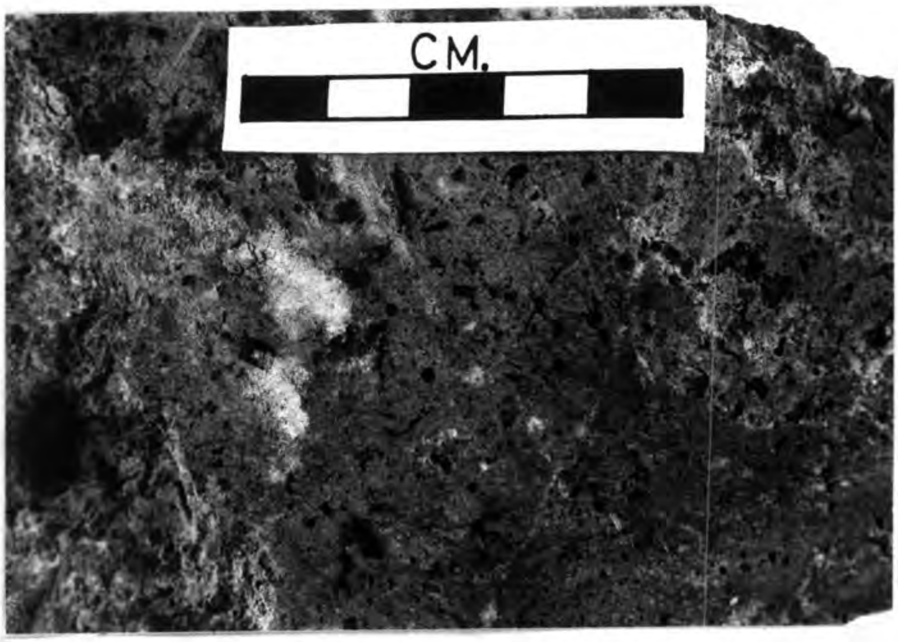


Plate 41. Close up of the decalcified surface.

Attempts to carry out mechanical analyses on the insoluble residue encountered the same problems as with the Tyne Bottom Limestone residue, i.e. it is difficult to know when one has crushed to the primary particles. Results that were obtained indicate that the residue has a concentration in the silt fraction, silt content about 70%, and a low clay content, less than 20%. A coarse sand fraction is essentially absent and the fine sand fraction is almost entirely quartz, but bipyramidal quartz crystals are rare. Very few heavy minerals are present but zircon and fluorite were identified. The clay fraction is mainly quartz with subsidiary illite. The change in purity of the limestone seems to be essentially an increase in quartz content with little increase in illite.

Only the soils on the northern slopes of Hard Hill were examined in detail and in these two layers of material could be detected, a silty loam (Table 17) and a silty clay (Table 18). The silty loam is the surface layer and was present on all of the limestone hummocks. The silty clay is discontinuous beneath the silty loam and appears to be connected with patches of the very impure limestone. The most striking character of both layers of material is the high silt content. This varies between 64 and 74% (U.S.D.A. silt) for the silty loam and is about 50% (U.S.D.A. silt) for the silty clay. The stones present in the silty loam are mostly limestone, especially when this material directly overlies an area of the rather purer limestone, but sandstone cobbles are also always present. Very few fragments are found in the 2 m m. - 2 cm. size range but those present are usually equally divided between sandstone, shale and limestone. The coarse sand fraction is dominated by coarse quartz fragments, but iron and manganese concretions are also fairly common, and no similar coarse quartz fragments are obtained from the limestone residue. The fine sand light fraction is almost entirely quartz but muscovite is fairly common. The heavy fraction is enriched compared to the insoluble residue of the limestone

Plate 42. Impure Four Fathom Limestone decalcified around the rim.

Plate 43. Close up of the decalcified surface showing the impressions of fossils.

Plate 44. Gingerbread limestone produced by treating unaltered Four Fathom Limestone with $N/_{10}$ hydrochloric acid.

and contains zircon, fluorspar, tourmaline, garnet, rutile, magnetite and leucoxene. The clay fraction contains quartz and illite. At least part of the material has been transported to its present position, e.g. sandstone cobbles, sandstone and shale in the 2 m.m. - 2 cm. fraction, large quartz fragments in the coarse sand, mica and heavy minerals in the fine sand, but it is extremely difficult to asses the relative importance of transported and residual material. The high silt content could be derived from the limestone residue and need not necessarily indicate an aeolian origin. The fine sand fraction shows a concentration towards the fine end (Fig.33) but not the marked drop in concentration at 0.08 m.m., when the $\delta M/\delta R$ v. $\log_{10} d$ is plotted, which Bullock (1963) found. As mentioned earlier it is doubtful whether this method can be used alone. The relatively abundant muscovite in the fine sand light fraction could have been derived from the Quarry Hazle which outcrops some twenty yards upslope as muscovite is an important constituent of this rock. The sandstone cobbles in the soil material are also similar to this particular sandstone and the quartz fragments in the coarse sand and the added heavy minerals could also come from this source.

Two factors need further consideration, the clay content is higher than in the limestone residue and the sandstone cannot be considered a source and the bias of the fine sand fraction towards the fine end runs against the pattern of the sandstone fine sand which shows a median concentration (p.329). The increased clay could be derived from the shale overlying the limestone by colluvial action or slope wash. The addition at the fine end of the fine sand may be due to a similar bias in the limestone residue or due to , at least some, aeolian influence; the former seems to be the case. In this connection it is significant that no aeolian layer is present on the flat top of Hard Hill formed by the Quarry Hazle outcrop. The essential characters of this silty loam could almost certainly be obtained by mixing residual material from the limestone plus colluvial material.

The silty clay is a stony material and all the stones are limestone in various stages of decalcification. At the base of the horizon the decalcified limestone is virtually in situ with silty clay between the blocks. The 2 m.m. - 2 cm. fraction is composed entirely of decalcified limestone. The coarse sand fraction is very small but contains a few coarse sand fragments. In the fine sand some muscovite is present but not much and the heavy mineral suite shows some addition but it is not as marked as in the silty loam. The clay fraction once again consists of quartz and illite. The evidence suggests that the horizon is a mainly limestone residue plus a little transported material. The high clay content is a difficult problem. As suggested for the silty loam it could have been derived from a shale horizon but if this were the case then it is difficult to see why this clay content should be higher than that of the silty loam. It may be due to clay illuviation from the overlying silty loam or the mechanical analyses of the limestone residue may be false with clay aggregates which were not broken down, being recorded as silt. It is very likely that both factors may be involved.

The resultant picture is of a layer of limestone residue with addition of material, most probably from a close proximity, this addition being most important at the surface and declining with depth and superimposed on this an illuviation of clay. The fact that the silty clay is a discontinuous layer tends to make illuviation more difficult to apply but as it is always associated with a great deal of gingerbread material this could improve drainage enough to produce illuviation. The brown calcareous soils are usually developed in a thin layer of silty loam, but the acid brown earths may be in a thicker silty loam layer or in a thin silty loam layer over a silty clay layer. A few acid brown earths were also found in loam or clay loam that the peaty podzols were developed (see below) in, but these are less common.

The peaty podzols and peaty gleys are developed in a loam or clay loam in which the influence of the limestone residue is much reduced, in fact the residue is sometimes present as an in situ layer of gingerbread below the loam or clay loam. This loam or clay loam is transported and most probably of colluvial origin, e.g. it contains sandstone cobbles, shale and sandstone fragments, large quartz grains, and enriched heavy mineral suite, but the clay content is too high and the silt content too low for it to be aeolian.

13.6. The Possibility of an Aeolian Contribution.

As has been mentioned several times in this present chapter, a great number of the fine sand fractions, when examined by plotting ${}^{\delta M}/_{\delta R}$ against mean R, give a curve which Bullock says indicates loessial and/or aeolian addition. Earlier (p.124) the drawbacks of this method were suggested when it was stated that material containing large boulders throughout gave a similar result. The bulk of the evidence also points against a mainly aeolian origin for most of the material considered. The curves can be explained in one of two ways : either, other than aeolian material can show a similar fine sand distribution, or the materials have received an aeolian addition which has subsequently been mixed into and dominated by drift or colluvium. The local sandstones seem to give a different curve with a concentration around 0.18 m m. which decreases with increasing and decreasing size. Bullock suggests an interglacial age for the aeolian material and if this were the case then at Moor House the material would definitely have been removed or completely mixed with drift and head deposits of the last glacial epoch. Until we can find further evidence to prove or disprove Bullock's (1963) conclusion that his ${}^{\delta M}/_{\delta R}$ curves are characteristic of aeolian material, the possibility of some addition, to soil parent materials by this method cannot be ruled out. Despite this the dominant parent material is glacial and periglacial drift, or colluvium, plus a greater or smaller contribution from insoluble limestone residue.

CHAPTER 14

The Inter-relationships of the Soil Sub-groups found on the Limestone Grassland Sites.

14.1. Variation in Soils with Increasing Depth of Superficial Material.

The inter-relationship of the various sub-groups associated with the limestone grassland areas on the Moor House Reserve was given considerable attention throughout the period of study. Some idea of the relationship can be gained from routine examination of sites but more is learnt from the detailed mapping and augering associated with the mapping. Two short trenches were also dug to investigate the transition from one sub-group to another and a brief account of these is given at the end of this chapter. Investigations along these lines disclosed the close association of soil sub-group with depth, and character, of unconsolidated material and also with microtopography. The sequence of soils from rendzina, to a brown calcareous soil, to an acid brown earth (and possibly a brown podzolic soil, p.114) and finally to a peaty gleyed podzol or even a peaty gley, parallels an increase in depth of superficial material on limestone bedrock (Fig.34). The depths of unconsolidated material with which each soil is associated overlap to some extent but this does not invalidate the general relationship. Typical depths of the various soils overlying limestone are shown in the following table :

TABLE 18

R.	B.C.S.	A.B.E.	P.G.P.	P.G.
4"	3"-9"	6"-12"	12"	15"

R - rendzina. B.C.S. - brown calcareous soil.

A.B.E. - acid brown earth. P.G.P. - peaty gleyed podzol.

P.G. - peaty gley.

Apart from any overlap there are soils which do not fit in with this general scheme and these will be examined later (p.216).

14.2. Variations in Soil Properties.

The increase in depth of superficial material over limestone is paralleled by a number of other changes. The most significant of these is the increase in acidity particularly of the surface horizons; the p.H. of the surface horizon of the mineral soil usually decreases from around 6 to near 4 as one moves from the rendzina to the peaty gleyed podzol or peaty gley (Fig.34). With this increasing acidity the calcium content of the surface soil decreases. Free carbonates are present in the rendzinas and brown calcareous soils but not in the other soil types and the total calcium oxide content decreases from around 1.25% in the rendzina to 0.05 in the peaty gleyed podzol. (Fig.34). There is a similar decline in the percentage base saturation from between 70 and 80% in the rendzina to less than 5% in the peaty gleyed podzol.

The changes in vegetation reflect the changes in the soils. The Species-rich Agrosto-Festucetum found associated with the rendzinas persists on the brown calcareous soils. The vegetation over the acid brown earths has a marked increase in Nardus stricta when compared to the calcareous soils and an increase in mosses is often present. This increase in Nardus is paralleled by a decrease in Agrostis tenuis and basiphilous species such as Thymus drucei. The vegetation associated with the peaty gleyed podzol is usually dominated by Nardus stricta. The change from rendzina to peaty gleyed podzol is, therefore, paralleled by an increase in acidophilous species and a decrease in calcicoles and basiphilous species.

The humus form and its distribution shows very definite changes (Fig.34) with the vegetation. In the very shallow rendzinas the humus is a calcic-mull and is very evenly distributed throughout the soil. In the brown calcareous soil the humus is still a calcic mull as it is concentrated in the upper soil to give a humus rich surface horizon. The humus of acid brown earths is much more acid and is probably related to a mull type mor. A very marked change in the transition from brown calcareous soil to acid brown earth is the concentration of the humus of the acid brown earth at the soil surface in a narrow 1-1½" zone. In some types, possibly those more closely related to a brown podzolic soil, a surface humus mat begins to accumulate. In the peaty gleyed podzol and the peaty gley the trend towards separation of humus and mineral soil is continued and a thick surface mat of mor humus is produced.

Soil structure changes in type and 'strength'. The rendzina has a fine to medium, strong crumb, or polyhedral. The humus rich A horizon of the brown calcareous soil has a medium, strong polyhedral but the (B) has a medium, moderate to strong blocky. The acid brown earth A horizon may have a moderate, medium polyhedral but the (B) and C horizons have variable structures but they are generally fairly weak. Some of the (B) horizons show a weak prismatic structure which breaks down to moderate medium blocky; in others a weak platy structure is developed. The peaty gleyed podzols and peaty gleys have a weak structure throughout.

The changes in colour between the various soil types are also very marked. The rendzina like soil is a very dark brown or black whereas in the brown calcareous soils the surface horizon is very dark brown but the subsoil is rather lighter being a mid-brown. In the acid brown earth the striking feature is the very even coloured (B) horizon which is light brown to reddish-brown. The peaty gleys have much duller colours with grey-browns and ochreous mottles. The same dull grey-browns are associated with the A_2 horizon of the peaty gleyed podzol but mid-browns are characteristic of the B and C horizons. Iron contents will be discussed later in connection with the variation in colour.

14.2. Relationship of Soil Properties to Depth of Superficial Material.

It would seem that the variations which take place in the properties of the limestone grassland soils can almost all be related to the increase in the depth of material resting on the limestone bedrock. In the rendzina like soils the limestone is sufficiently close to the surface for the vegetation to be able to use it as a supply of nutrients. The actual soil material is leached so that most of the nutrients are removed despite the close proximity of the limestone. These soils are so shallow that the plants are able to counteract the leaching by tapping the limestone. The fact that the plants can maintain the nutrient content at a reasonable level will give a favourable environment for a large soil fauna population which causes a rapid breakdown of plant debris and a rapid incorporation of this material into the mineral soil. This in turn allows a stable clay-humus complex to develop and as a result a strong crumb structure forms. The incorporated humic material gives the dark brown colour of these soils.

In the brown calcareous soils the increased depth of soil material is still not sufficient to cut the surface vegetation off from the source of nutrients in the form of the limestone bedrock. The vegetation is still predominantly basiphilous.

The plant debris is still rapidly incorporated into the soil (It is worth noting that earthworms are present in the calcareous soils) but the humic material is concentrated in the upper soil. As a result the upper soil is darker coloured than the lower, despite this the organic matter content of the 'subsoil' is still much higher than in the more acid and deeper soils. The clay-humus complex in the lower soil is probably not as well developed as in the upper soil and this plus the fairly high clay content results in a blocky structure : the soil fauna population will also be lower. The organic matter content is still sufficient throughout to make the dominant soil colour a brown.

In the acid brown earth acid plant species start to appear and calcicoles are reduced. The limestone bedrock with its reserves of nutrients would seem to be beyond the reach of the plant roots of the calcicoles which are, therefore, unable to offset the removal of nutrients by leaching. In this more acid, nutrient poor, environment the soil fauna will decrease and this is evidenced by the accumulation of plant debris at the surface and very slow incorporation into the mineral soil. As a result of this the clay-humus complex will be extremely poorly developed and some evidence of this is gained by the medium to weak blocky structure - this also reflects the lower root density. The colour of the (B) horizon is often a reddish-brown the reddish tones reflecting the moderate iron content but also the fact that there is little organic matter to mask the colour. The iron must also be in an oxidised state and reflects the freely drained nature of the soil. With very clay rich C horizons the reddish colours are subdued, as they are if the surface organic debris thickens. This reflects the fact that these soils are rather less freely drained. The actual iron content plus the drainage conditions controls the importance of the reddish tones in the soil colour.

In the peaty gleyed podzols and the peaty gleys the surface vegetation is completely acidophilous being dominated by calcifuges. The limestone is now beyond the reach of the roots of the calcicoles and little if any nutrient is added from this source to replace that lost by leaching. The plant debris accumulates at the surface and little if any is incorporated into the mineral soil. The soil fauna will be much diminished and the slow break down of organic matter reflects this. The peaty gleyed podzol can be seen as a logical end product of the series of soils discussed so far. The increased depth giving the completely acid vegetation and this producing a mat of mor humus or peat which produces the surface conditions necessary for this type of podzolisation : the freely drained subsoil, which is also necessary would be produced because of the underlying limestone bedrock.

The peaty gley does not fit into the succession of soil types as easily. It is found in similar depths of superficial material to the peaty gleyed podzols. The vegetation is similar and the peaty surface mat is similar. The iron content of the parent material and the mechanical composition are also similar. The essential difference is that one has a freely drained subsoil and one has not but the reason for this difference is hard to find. The only reason which can be put forward is that the drainage in the underlying limestone varies as rapidly as do the soil types which are therefore reflecting the relative freedom of drainage in the bedrock. It may be that in some cases the joints in the underlying limestone are still firmly plugged by drift. An indication that this is the answer is given by the way a circular zone of peaty gleyed podzol is found around shake holes and this zone gives way to a peaty gley as one moves away from the shake hole but with no accompanying change in depth of superficial material. The shake hole is evidence of a zone of free drainage in the limestone bedrock which in turn produces a zone with free drainage in the soil.

In the foregoing section the limestone bedrock and the soil in close proximity to the limestone has been considered an important source of nutrients to surface vegetation. The availability of the nutrients to the surface vegetation has been considered an important factor in determining soil type and vegetation as, if available, they would replace those lost from the soil by leaching. In work carried out on a brown calcareous soil in the Rough Sike Site, Rawes and Allen (1962) show the large amount of nutrients removed by leaching but they show that calcium is not in short supply. This result may not be suprising but the reasons are : the calcium added annually by rainfall is more than that removed in an annual grass crop. This would seemto infer that the vegetation is not dependent on a supply of calcium from the limestone bedrock. Loss of calcium by leaching is much greater than annual addition from precipitation so that the soil is being depleted of calcium. If the plants were unable to obtain calcium from the limestone leaching would soon reduce the content in the soil to such a level that unless the calcium in the precipitation were almost all extracted there would be a deficiency. We can put the position another way - leaching can only take place at such a rate because the supply in the soil is being constantly replenished from the limestone. As Crompton (1960) has pointed out chemical weathering will be reduced to a minimum in the upland climate and so very little calcium, and other nutrients, will be released by break down of minerals within the soil. Thus it is valid to consider rainfall and bedrock as the major sources. Excessive leaching with little true chemical weathering is thought by Crompton (ibid) to be the key to acid soils occuring on calcareous parent material.

The other nutrients are also added from rainfall and the bedrock but here the amount extracted in the annual grass crop is greater than that added in precipitation and this added to the loss due to leaching gives a resultant depletion.

14.3. Role of the Limestone Bedrock in the Different Soils.

The contribution of the underlying limestone bedrock to the various soil types is an interesting problem. The limestone underlying all the soil types is being attacked by the acid soil solutions and the insoluble residue from the limestone is therefore being added to the soil. The solution of the limestone in this way is extremely slow and addition from this source must be slight (This is not the case with the impure limestones which are considered later). In some of the soils this lower boundary of the soil will be essentially beyond the agents causing integration into the upper soil. In the rendzina type soil and the brown calcareous soil the limestone is a source of nutrients tapped by the plant roots, the insoluble residue of the limestone being attacked at the soil-rock interface will also be integrated fairly rapidly and be a source of soil material; also the limestone gives the soil its free to excessive drainage. In the acid brown earths and the peaty gleyed podzols the limestone virtually ceases to be a source of nutrients, more so in the podzol than in the brown earth, and the insoluble residue of the limestone will only be incorporated very slowly (Once again this will not be true of the very impure limestones). In this case probably the major function of the limestone bedrock is in ensuring a freely drained subsoil. In the peaty gleys the limestone must make little if any, impact on the overlying soil. It is interesting to note that limestone will tend to accelerate acid conditions because of its effect on the drainage of the soil as the excessive to free drainage will increase the leaching effect of a given rainfall amount.

The transitions between the various soil types are interesting. The transition from the rendzina type to the brown calcareous soil is rather gradual but that from the brown calcareous soil to the acid brown earth remarkably sharp. Some of the 'sharpness' may be apparent due to the changes in colour and humus form being more visually striking than those from rendzina to brown calcareous soil. If the change is as sharp as it appears it must indicate a very sharp line dividing the calcicoles dominated vegetation from that in which acid species become important. This in turn suggests that the depth at which the calcicolous plant roots are unable to reach the calcium in limestone is critical and sharply defined.

In the succession of soil types discussed there are very few occassions on which one is able to demonstrate the complete sequence in a gradually thickening cover of superficial material. This is almost certainly because there are relatively few places where one finds a superficial cover which increases gradually in depth and sudden increases are much more common. It is far commoner to find sharply defined hummocks of deeper drift within a shallower cover, with consequent sharp soil boundaries. Where the continuous drift cover comes in at the outer limits of the grassland areas the edge of the drift sheet is usually abrupt giving a step like increase in thickness and hence a sharp change in soil type.

14.4. Origin of the Red Colouration of some of the Calcareous Soils and Brown Earths.

The reddish colour of some of the acid brown earths has been considered by Johnson (Johnson and Dunham 1963) who postulates that the iron necessary to give this colouration has been derived from the limestones by capillary action in dry weather. The brighter reds being taken to infer a greater age of the soil and a greater period available for concentration of the iron. As has been mentioned above the iron contents of the various soil types at any one site are very similar which would necessitate equal concentration from the limestone if this were the source. A simpler explanation would be that the parent material was similar and has a similar content of iron. Results outlined in the previous chapter infer a similar parent material. It is also significant that the drift beneath blanket peat surrounding any site has a similar iron content to the soils developed on that site (Table 19) and capillary accumulation beneath blanket peat is extremely doubtful. Finally the amount of iron in solution in water in contact with limestone would be extremely small as the solubility of iron in water increases rapidly as p.H. decreases and the amount soluble in alkaline solutions, as those solutions in contact with the limestone would be, would be extremely small. The iron content would seem to be a reflection of the content of the parent material. Only in certain places will the underlying limestone be an important source and this will be over the impure limestones.

The brighter red soils are not thought by the writer to indicate greater age but to reflect initial iron content of the parent material plus the extremely free draining character of the soil. Added to this the acid brown earths have little organic matter incorporated into the soil to dull the colour due to the iron content.

14.5. Variations on the General Depth - Soil Sub-Group Succession.

The most important factor determining soil type is the depth of superficial material in which the soil has formed. The broad limits of the depth of material which gives the various soil types have been given earlier but, there are soils which do not fall in with this general scheme. The brown calcareous soils which are developed in the grykes are developed in up to 3 ft. of superficial material but the usual range of depths for this soil type is 3"-9" (Table 18). The depths of material found in the grykes is usually associated with acid brown earths or peaty gleyed podzols. The reason for the apparent discrepancy is the lateral proximity of limestone to the plant roots. It has been suggested earlier that in the deeper soils the calcicoles are unable to tap the calcium in the lower soil and limestone and as the calcium is leached out of the upper soil they cannot obtain these nutrients and are driven out by acidophilous species. In the grykes although the limestone at the base of the gryke is beyond the reach of the calcicoles the limestone surrounding the soil, i.e. the walls of the gryke, is within reach and maintains a reasonably high calcium content. The soil in the gryke is encased in limestone.

Another apparently anomalous case is the acid brown earths over the impure limestones. In this case the acid brown earth can be found developed beneath a much shallower cover of superficial material than is normal, e.g. 3" - 6" instead of 6" - 12". Below the cover of superficial material the soil merges into a layer of decalcified limestone which represents the former limestone bedrock now devoid of acid soluble material. The upper surface of the unaltered limestone is some 9" to 1 ft. below the base of the superficial material. As this is the nearest source of calcium, the effective soil depth to any vegetation is the superficial material plus the decalcified material, i.e. 1' to 1'6".

The permanence of the relationship between soil depth, soil type and vegetation is open to debate. The more acid conditions of the deeper soils favour an acid vegetation. This acid vegetation will tend to intensify the acidity due to accumulation of plant material at the surface and the slow incorporation of this into the soil. Once acid species become established there is reason to believe that the transition to a peaty gleyed podzol from an acid brown earth will take place fairly rapidly. In all cases the end product of the evolution of soils on these sites would seem to be the peaty gleyed podzol since conditions will become increasingly acid as the depth of soil material increase. Increase in soil depth will take place as the underlying limestone bedrock is dissolved and the insoluble residue is added to the soil. Over the pure limestones the increase in depth will be extremely slow and the progression from rendzina to acid brown earth very slow. The writer, never-the-less, thinks the change will be inevitable as the layer of acid insoluble residue builds up. The suggestion of Scheffer et al (1962) that the rendzina is a stable phase over pure limestones does not seem applicable under the climatic conditions prevailing at Moor House. Similar changes over the impure limestones will take place much quicker as the amount of insoluble residue is much greater and hence the increase in effective superficial material much more rapid.

14.6. The Effect of Grazing on Soil Evolution.

The effect of grazing on vegetation and through this on soil type must also be considered. If grazing is prevented the amount of plant litter on the surface increases rapidly and the incorporation into the mineral soil becomes slower (Welch and Rawes 1964). The latter effect is probably due to the fact that the soil population decreases as the organic matter increases (Cragg 1961), hence breakdown is slower. The increase in litter and the slower breakdown would be expected to increase the acidity of the soil and the slower breakdown of the litter will lead, eventually, to an impoverishment of nutrients in the surface horizons. If this were correct one would expect the soils to evolve rapidly to the acid types. The initial results of Welch and Rawes (ibid) do not support this as the acid species present in the sward during grazing (e.g. Nardus stricta and Juncus squarrosus) are supressed after grazing is prevented. This may be a short term effect which will be reversed in time or it may be that it is because the brown calcareous soil of the site examined is shallow enough for the limestone to be able to counteract increasing acidity. No work is available on prevention of grazing on deeper soils but brief examination of an area enclosed for a tree planting experiment at Green Hole showed the following. The acid species had once again been initially supressed but again litter had increased and soils mapped by Orrell, Charlton and Minter (1957) as brown earths showed signs of incipient podzolisation. It may be that the mapping was at fault or alternatively the deeper soil involved has become markedly more acid and podzolisation has begun.

Welch and Rawes' work (ibid) does show that grazing favours the spread of acidophilous species and this could have an important influence on soil evolution. In soils intermediate in depth between a brown calcareous soil and an acid brown earth grazing could well allow acid vegetation to invade the site and may cause an acid brown earth to develop as a result.

14.7. The Relationship between Rendzinas and Brown Calcareous Soils.

When examining previous work and comparing it with the Moor House calcareous soils care is needed because much of this previous work was carried out on soils formed entirely in the insoluble residue remaining after solution of the limestone, whereas the present work is concerned with soils in a transported parent material. Studies on brown calcareous soils have mainly been directed towards examining their relationship with rendzina soils and in particular whether they are derived from rendzinas or whether the two soil types are from different types of limestones (p. 83).

It is envisaged from the present work that a brown calcareous soil would derive from a rendzina as the depth of the soil cover is increased by addition of insoluble residue from the limestone. Decalcification does seem to take place in the transition from rendzina to brown calcareous soil but there is no evidence for desilicification as suggested by various authors, e.g. Kubiena (1948), Robinson (1948). No difference in iron or silica content has been detected between the two soil types in a given locality which tends to rule out Khan's suggestion that the brown calcareous soils are developed from more ferruginous and less siliceous residues (Khan 1957).

The fact that the two soil types can be found on the same limestone would seem to overrule the theory that the brown calcareous soils are from a hard limestone and rendzinas from a soft one. e.g. Glinka (1914), Reifenberg (1938). The nearest approximation within the area are the very impure parts of some of the limestones and on these the rendzinas phase seems to be rarer than on the harder limestones due to the quicker build up of residue.

Robinson (1949) envisaged the brown calcareous soils as a mature phase of soil development on limestone and other calcareous materials. While it is difficult to determine what Robinson was infering by 'mature', the climax soil on limestone under the climatic conditions prevailing the northern Pennines would seem to be a peaty gleyed podzol and the brown calcareous merely a transitional phase.

As has been stated earlier a rider must be added to all conclusions from work on the present soils that they are developed in transported parent material and not only from the insoluble residue of the limestone. Bearing this in mind it would seem that the climax soil on limestone in the northern Pennines is a peaty gleyed podzol and that the other soil types found are transitional phases between the colonisation of the limestone and this climax. The way that the various soil types are found on the same limestone rules out the type of limestone having a controling effect on soil type, although the rendzina phase would appear to be shorter on an impure limestone. Transition from rendzina to the other stages involves a decalcification of the soil and eventually a mobilisation of iron : there is no evidence of desilicification.

14.8. Rough Sike Trench. (Fig.35. Table 20. Plates 45-48. Also plates 23 and 24.)

The trench was sited across one of the low elongate mounds of material found on the Rough Sike Grassland. It was on the upper bench formed by the limestone (p.126). The bench in general has a large number of bare limestone blocks and a generally thin soil cover with a hummock-hollow surface. A number of elongonate mounds of deeper soil run across the area and it is across one of these that the trench was sited (Fig.23).

The original intention was to investigate the transition from rendzina like soil, through a brown calcareous soil to an acid brown earth. This was done but any results must be qualified by certain reservations. The deepest part of the mound was underlain by a very impure patch of the Tyne Bottom Limestone and so the acid brown earth was of the type characteristic of this parent material and could not strictly be compared with all the acid brown earths. The trench was also cut by several small veins which stood up like small barriers running across the trench. This mineralisation would introduce a considerable amount of silica, iron, lead, zinc and sulphur into the soil and analyses for these elements must be examined with this background.

Some additional comments to the diagrams and profiles are useful. The limestone below the shallow soil at the south end of the trench was eroded into clints and grykes but the outlines of the blocks were very smooth. The general appearance of this limestone surface on excavation was like a pot-holed limestone river bed. This smooth nature of the limestone on exposure agrees with the results of Clayton (1966) in the Malham area and it is worth mentioning that after being exposed for a year the limestone surfaces were freted. This highly irregular limestone surface gives rapid variations in soil depth within a lateral distance of a few inches. The initial very gradual increase in soil depth showed very well the lightening of the colour of the base of the profile as the humic material was accumulated in a surface horizon. This change was very gradual and not immediately striking.

The change from brown calcareous soil to acid brown earth was rather more rapid, the black surface accumulation of humus appears within no more than eighteen inches horizontal distance. At the north side of the mound the horizon merges with the more mull like humus of the brown calcareous soil just as quickly. This rapid change is suprising as the increase in soil depth within the transition zone is not very much.

Beneath the deepest part of the mound there is considerable layer of decalcified limestone which is virtually in situ. This material is very soft and when the trench was dug the material could be dug out as easily as the overlying soil.

<u>Plate 45.</u> The Rough,Sike Trench from the south end showing the rapid variation in soil depth and the eroded limestone surface.

Plate 46. Rough Sike Trench from the north end showing the deeper section.

<u>Plate 47.</u> The south end of the Rough Sike Trench showing the rapid variation from rendzina to brown calcareous soil.

<u>Plate 48.</u> A close-up of part of the Rough Sike Trench showing the dissected limestone surface.

Brown Calcareous Soil

Profile no : 9 B.C.S. Sample no's : R.S. 10, 11, 12.

Location : 8 ft. from the south end of the Rough Sike Trench.

Nat. Grid Reference : 756327.

Altitude : 1850 ft. O.D.

Relief and aspect : Level, north facing limestone terrace.

Geological data : Bedrock is the Tyne Bottom Limestone.

Vegetation : Agrosto-Festucetum.

Horizon ins	
0 - 3 A_1	Very dark brown (10YR 2/2), friable loam; strong, medium crumb; dense root mat ; moderate organic matter content; earthworms; merging regular boundary.
3 - 7 (B)	Very dark grey brown (10YR 3/2), firm, clay loam; moderate medium polyhedral; frequent roots; moderate organic matter content; earthworms; gradual, regular boundary.
7 - 9 C	Very dark brown (7.5 YR 3/2), firm, stony clay loam; weak medium polyhedral; roots common; low organic matter content; earthworms; sharp, irregular boundary.

Profile 9 B.C.S.

Sample no.	Depth (ins)	p.H.	$CaCO_3$%
RS 10	0 - 2	5.9	Trace
RS 11	4 - 7	6.3	Trace
RS 12	9 - 12	6.6	1.1

	U.S.Sand	I.Sand	I. Silt	Clay	U.S.Silt %
RS 10	47.5	58.1	22.3	19.6	32.9
RS 11	25.4	33.2	29.4	37.4	37.2
RS 12	28.4	28.9	31.8	29.3	41.3

	% B.S.	Extractable Ca	Mg	Na	K	L.O.I.%	%C	%N	C/N
RS 10	31	0.92	0.75	0.23	0.09	10.31	4.3	1.1	3.9
RS 11	48	2.86	0.81	0.30	0.14	8.26	3.34	0.42	7.9
RS 12	77	6.52	0.80	0.28	0.13	9.41	3.91	0.17	23.0

meq./100g.

These samples were not analysed for total constituents.

Acid Brown Earth

Profile no : 10 A.B.E. Sample no's : R.S. 14 - 20.

Location : 16' 6" from the south end of Rough Sike Trench.

Nat. Grid. Reference : 756327

Altitude : 1850 ft. O.D.

Relief and aspect : Level, north facing limestone terrace.

Geological data : The parent material is mainly decalcified impure Tyne Bottom Limestone which rests on unaltered limestone.

Vegetation : Agrosto-Festucetum but with an important contribution of *Nardus stricta*.

Horizon :

ins	
0 - ¾ A_1	Dark reddish brown (5YR 2/2), friable, sandy loam; moderate medium crumb; dense root mat; moderate organic matter content; sharp regular boundary.
¾ - 3 A_3	Dark reddish brown (5YR 3/3), friable, stony sandy loam; strong fine crumb; dense root mat; moderate organic matter content; earthworms; gradual regular boundary.
3 - 9 B	Reddish brown (5YR 4/4), friable, stony clay loam; moderate medium crumb; roots common; low organic matter content; earthworms; gradual irregular boundary.
9 - 20 C	Dark reddish brown 5YR 3/3), friable, very stony clay loam; weak medium crumb; a few roots to 12", low organic matter content; fairly sharp regular boundary. The stones are all blocks of decalcified limestone and become closer packed with depth.
20 + D	First bed of unaltered limestone.

Profile no. 10 A.B.E.

Sample no.	Depth (ins)	p.H.	$CaCO_3$%
RS 14	1 - 3	5.1	0
RS 15	4 - 8	5.4	0
RS 16	10 - 14	5.5	0
RS 18	16 - 20	6.1	0

	U.S.Sand	Int.Sand.	I.Silt.	Clay.	U.S.Silt %
RS 14	52.9	73.1	11.2	15.7	31.4
RS 15	19.4	37.6	23.7	38.7	41.9
RS 16	23.3	46.1	22.8	31.1	45.6
RS 18	n.d.	n.d.	n.d.	n.d.	n.d.

		Extractable							
	% B.S.	Ca	Mg	K	Na	L.O.I. %	%C	%N	C/N
RS 14	11	0.75	0.60	0.46	0.38	5.5	1.3	0.46	2.7
RS 15	10	0.52	0.13	0.16	0.33	2.75	0	0.23	-
RS 16	6	0.42	0	0.11	0.35	1.85	0	0.21	-
RS 18	13	0.60	0	0.11	0.31	1.28	0	n.d.	-
		meq./100g.							

	Si	Al	Fe	Mg	Ca	Na	K	Ti	Mn	H_2O %
RS 14	61.46	9.77	10.29	0.5	0.55	0.65	0.89	0.41	0.71	9.85
RS 15	59.74	12.63	11.92	0.44	0.54	0.66	0.96	0.43	0.85	8.69
RS 16	68.99	8.49	10.10	0.39	0.57	0.73	1.52	0.28	1.14	6.86
RS 18	84.57	2.64	4.69	0.22	0.65	0.68	1.37	0.28	0.63	4.29

Brown Calcareous Soil

Profile no : 11 B.C.S. Sample no's : R.S. 26, 27 and 28.

Location : 3 ft. from the north end of the Rough Sike Trench.

Nat. Grid. Reference : 756327.

Altitude : 1850 ft. O.D.

Relief and aspect : Level, north facing limestone terrace.

Geological data : Bedrock is the Tyne Bottom Limestone.

Vegetation : Agrosto-Festucetum.

Horizon : ins	
0 - 2 A_1	Very dark brown (10YR 2/2), friable sandy loam; strong, fine to medium crumb; dense root mat; moderate organic matter content; earthworms; merging regular boundary.
2 - 7 (B)	Dark brown (10YR 4/3), firm clay loam; strong medium polyhedral; abundant roots; moderate organic matter content; earthworms; gradual regular boundary.
7 - 10 C	Very dark brown (LOYR 2/2), firm stony clay loam; moderate medium polyhedral; frequent roots; moderate organic matter content; earthworms; stones all limestone; the soil-limestone interface is stained black; sharp, irregular boundary.

Profile no. 11 B.C.S.

Sample no.	Depth (ins)	p.H	$CaCO_3$ %
RS 26	1 - 3	6.0	Trace
RS 27	5 - 8	6.2	Trace
RS 28	9 - 12	6.5	0.8

	U.S.Sand	I.Sand	I.Silt	Clay	U.S.Silt %
RS 26	51.0	68.1	17.0	14.9	34.1
RS 27	21.9	36.6	23.1	40.3	37.8
RS 28	26.3	55.0	24.5	20.5	53.2

	% B.S.	Extractable Ca	Mg	Na	K	L.O.I.%	%C	%N	C/N
		meq./100g							
RS 26	47	1.17	0.77	0.29	0.09	11.67	3.69	0.39	9.5
RS 27	62	4.3	0.69	0.28	0.13	9.86	2.82	0.22	12.8
RS 28	85	7.91	0.73	0.28	0.17	9.56	2.68	0.19	14.1

	Si	Al	Fe	Mg	Ca	Na	K	Ti	Mn	H_2O %
RS 26	57.21	12.28	13.19	1.46	0.53	0.63	0.88	0.38	0.97	8.58
RS 27	53.98	19.49	9.92	0.88	0.57	0.63	1.27	0.53	0.64	9.43
RS 28	55.22	18.62	8.94	1.35	0.66	0.60	0.88	0.43	0.62	10.11

14.9. Moss Burn - Sheep Fold Trench. (Fig.36. Table 21. Plate 49. See also plates 35 and 31).

This trench was dug on the Sheep Fold Site and was dug from the limestone bench (Fig.13) into the large 'island' of peat found on this site. The line of the trench is marked on fig.13. It was hoped to expose a succession from a brown calcareous soil through an acid brown earth to a peaty gleyed podzol. The actual soils exposed were a brown calcareous soil which changed directly into a peaty gleyed podzol. The succession of soils was also unsatisfactory, from the point of view of the present study, as it contained a buried soil on which the calcareous soil rested for at least part of the trench (It is hoped to carry out work on this buried soil at some future date).

The limestone exposed on the floor of the trench was weathered into smooth surfaced clints and grykes with the grykes very wide and deep. What appears to be a buried A_2 and B, profile is found at depth between the clints. The soil overlying this buried A_2 contains frequent sandstone cobbles and it is rather difficult to explain its origin (p. 188). Despite these unsatisfactory features the details of the trench are included as the details on exchangeable cations show the increasing acidity extremely well.

Plate 49. Moss Burn Trench from the west end showing the deeply dissected limestone.

Brown Calcareous Soil.

Profile no : 12 B.C.S. Sample no's : M.B. 1 and 2.

Location : The east end of the Moss Burn Trench.

Nat.Grid Reference : 745318

Altitude : 2050 ft. O.D.

Relief and aspect : Gentle slope to the north east.

Geological data : Superficial material resting on the Scar Limestone.

Vegetation : Agrosto-Festucetum.

Horizon : ins.	
0 - 2 A	Very dark grey (5YR 3/1), friable loam; strong, fine to medium crumb; dense root mat; moderate organic matter content; earthworms; gradual, regular boundary.
2 - 9 (B)C	Dark reddish brown (5YR 3/2), friable, stony loam; strong medium crumb; abundant roots; low organic matter content; earthworms; sharp irregular boundary.
D	Bedrock, the Scar Limestone.

Profile no. 12 B.C.S.

Sample no.	Depth (ins)	p.H.	$CaCO_3$%
MB 1	0 - 3	6.2	0.6
MB 2	6 - 9	6.9	0.8

	U.S.Sand	I.Sand	I.Silt	Clay	U.S.Silt %
MB 1	44.5	58.0	20.0	22.0	33.5
MB 2	37.8	53.6	20.0	26.4	35.8

	%B.S.	Extractable Ca	Mg	Na	K	L.O.I.%	C%	N%	C/N
MB 1	68	10.4	0.78	0.14	0.29	9.36	3.89	0.27	14.41
MB 2	89	14.75	0.56	0.03	0.16	7.58	3.07	0.25	12.28

meq./100g

	Si	Al	Fe	Mg	Ca	Na	K	Ti	Mn	H_2O	P %
MB 1	n.d.	7.8	5.0	0.31	0.63	1.11	0.9	n.d.	0.24	n.d.	0.112
MB 2	n.d.	7.8	5.7	0.36	1.00	1.43	1.0	n.d.	0.33	n.d.	0.100

Peaty Gleyed Podzol

Profile no : 13 P.G.P.   Sample no's : M.B. 9 to 11.

Location : Five feet from the west end of the Moss Burn Trench.

Nat. Grid Reference : 745318

Altitude : 2050 ft. O.D.

Relief and aspect : Gentle slope to the north east.

Geological data : Superficial material resting on the Scar Limestone.

Vegetation : Callunetum

Horizon : ins	
9 - $8\frac{1}{2}$ L	Mainly Calluna litter.
$8\frac{1}{2}$ - 7 F	Dark brown; plant remains clearly recognisable, mainly Sphaghum and Calluna.
7 - 0 H	Black, wet, greasy peaty humus; sharp regular boundary.
0 - 2 A_{2G}	Dark grey (5YR 4/1), firm, clay loam; weak coarse prismatic; abundant roots; low organic matter content; organic staining along vertical fracture faces; clay skins along root channels; sharp regular boundary.
2 - $4\frac{1}{2}$ B_2	Yellowish red (5YR 5/8), firm clay loam; weak coarse blocky; frequent roots; low organic matter content; gradual regular boundary.

4½ - 13 CB	Very dark brown (10YR 3/4) very firm clay loam; weak coarse blocky; occassional roots; very low organic matter content; sharp irregular boundary.
13+ D	Bedrock - Scar Limestone.

Profile 13 P.G.P.

Sample no.	Depth (ins)	p.H.	$CaCO_3$%
MB 9	6 - 10	4.7	0
MB 10	10 - 14	4.9	0
MB 11	21 - 25	5.5	0

	U.S.Sand	I.Sand	I.Silt	Clay	U.S.Silt %
MB 9	36.1	45.93	20.53	33.5	30.4
MB 10	31.33	42.06	15.02	42.9	25.75
MB 11	34.43	38.52	22.55	38.9	26.64

	% B.S.	Extractable Ca	Mg	Na	K	L.O.I.%	%C	%N	C/N
		meq./100g							
MB 9	20.8	6.35	0.28	0.06	0.11	4.09	1.47	-	-
MB 10	18.3	5.45	0.18	0.15	0.05	7.15	2.87	0.12	23.92
MB 11	39.1	9.4	0.43	0.03	0.07	8.08	3.3	0.17	19.41

	Si	Al	Fe	Mg	Ca	Na	K	Ti	Mn	H_2O	P %
MB 9	n.d.	7.3	0.4	0.29	0.31	0.94	1.0	n.d.	0.01	n.d.	0.04
MB 10	n.d.	6.7	11.7	0.36	0.73	1.47	8.0	n.d.	0.10	n.d.	0.11
MB 11	n.d.	9.2	5.7	0.60	0.90	2.08	1.1	n.d.	0.39	n.d.	0.11

Peaty Gleyed Podzol.

Profile no : 14 P.G.P. Sample no's : M.B. 12 to 14.

Location : The west end of the Moss Burn Trench.

Nat.Grid Reference : 745318

Altitude : 2050 ft. O.D.

Relief and aspect : Gentle, north east facing, slope.

Geological data : Superficial material resting on the Scar Limestone.

Vegetation : Nardetum sub-alpinum.

Horizon : ins.	
L	Trace
$\frac{3}{4}$ - 16 F	Recent plant debris
16- 0 H	Black, greasy, peaty humus; sharp regular boundary.
0 - 4 A_{2G}	Dark grey (10YR 4/1), plastic, clay loam; structureless-massive; abundant roots; clay skins along vertical cracks; low organic matter content; sharp irregular boundary.
B_{PAN}	$\frac{1}{4}$" iron pan; dense root mat on the upper surface of the pan, most impregnated with sesquioxides; some accumulation of humic material on the upper surface of the pan, especially in small depressions; sharp irregular boundary.

B_2 4 - 5½ (7)	Reddish yellow (7.5YR 6/6 - 6/8), very firm, stony clay loam; massive to weak coarse blocky; roots very rare; very low organic matter content; freely drained; clear irregular boundary.
CB 6 - 9	Brown (10YR 5/3), very firm, clay loam; massive; roots very rare - clay skins on those root channels present; very low organic matter content; frequent, fine, distinct reddish mottles (5YR 3/4) mottles; merging, regular boundary.
C 9 - 14	Brown (10YR 5/3), very firm clay loam; massive; very low organic matter content; sharp irregular boundary.
D 14+	Bedrock - Scar Limestone

Profile no. 14 P.G.P.

Sample no.	Depth (ins)	p H.	$CaCO_3$ %
MB 12	0 - 2	4.1	0
MB 13	3 --4	4.5	0
MB 14	6 - 8	4.6	0
MB 15	10 - 14	5.6	0

	U.S.Sand	I.Sand	I.Silt	Clay	U.S.Silt %
MB 12	37.2	47.7	16.7	35.6	27.2
MB 13	34.2	44.9	19.1	36.1	29.7
MB 14	34.1	49.5	19.1	40.4	25.5
MB 15	38.3	57.0	19.2	29.8	31.9

Extractable

	% B.S.	Ca	Mg	Na	K	L.O.I.%	%C	%N	C/N
MB 12	6	0.35	0.18	0.03	0.06	5.85	2.28	0.13	17.5
MB 13	8	0.32	0.11	0.04	0.04	5.74	2.23	0.10	22.3
MB 14	13	0.48	0.13	0.03	0.05	3.88	1.38	0.09	14.4
MB 15	48	10.95	0.33	0.16	0.07	7.86	3.2	0.17	18.8

meq./100g.

	Si	Al	Fe	Mg	Ca	Na	K	Ti	Mn	H_2O	P %
MB 12	n.d.	7.3	0.5	0.16	0.05	0.10	0.8	n.d.	0.01	n.d.	0.016
MB 13	n.d.	6.6	11.8	0.15	0.05	0.12	0.9	n.d.	0.12	n.d.	0.074
MB 14	n.d.	7.6	4.6	0.15	0.05	0.10	1.1	n.d.	0.11	n.d.	0.058
MB 15	n.d.	9.2	5.6	0.23	0.15	0.17	1.2	n.d.	0.11	n.d.	0.058

CHAPTER 15

Evolution and History of the Limestone Grassland Sites.

Twelve grassland sites have been considered in the previous chapters and the features which are common to them or vary will now be considered in an attempt to understand the past history of the sites. Some of the basic parameters of the sites are collected in table 22.

15.1. Effect of Macro and Microtopography on the Evolution of the Sites.

The sites fall into groups at three different altitudes which reflect the association with three different limestones. The three limestones are the thicker found below the Great on the eastern slopes of the Reserve and are the Tyne Bottom, 21ft., the Scar, 36ft., and the Four Fathom, 26ft. Thinner limestones, e.g. the Single Post Cockle Shell, Five Yard and Three Yard, do not give rise to limestone grasslands. The thicker limestones have a greater outcrop and are likely to produce much more distinct topographic features. In the stepped topography produced by the Yoredale type of succession (p. 32), the thicker limestones produce a distinct scar which is a rare feature in the thinner limestones. The significance of whether or not a distinct topographic feature, and in particular a scarp, is present is linked with the presence or absence of superficial material. If a superficial cover, be it drift, head or peat, is spread over a region with stepped topography there is a tendency for the cover to thicken backwards from the crest of each scarp thus smoothing the topography. If the superficial material is subsequently removed by erosion, the underlying bedrock will be exposed first at the crest of the scarp; erosion is most likely to begin at this point. The question of superficial material is important as all the sites are surrounded by blanket peat and most are within drift covered areas.

Almost all the limestone grassland sites contain mounds of superficial material which is drift or head (p.106). These mounds are found on all levels of the exposed limestone surfaces and the channels cut into them and prove the erosion which formed these surfaces and channels pre-dates the superficial deposits. The drift or head was deposited during the last glacial episode at this location and thus the erosion of the limestone surfaces is dated as pre - the last glacial episode. It seems unlikely that the drift or head would be originally deposited as mounds with bare areas between. Far more likely is that the mounds are erosional remnants of a former more continuous cover which has subsequently been eroded.

Blanket peat cover surrounds all the grassland sites and in some cases islands of blanket peat are found within the site, e.g. Moss Burn - Sheep Fold Site (p.100). The sites between Little Dodgen Pot Sike and Green Burn (p.138) are so small that it is difficult to conceive that they existed during the period of maximum peat expansion. The large 'islands' of blanket peat on the Sheep Fold Site (p.100) are unlikely to have formed as they now exist and the peat would originally have been continuous with the surrounding blanket. It is significant that the surface of this 'island' is at a similar level to the surface of the surrounding blanket to the west. To the east a line joining the surface of the peat island to the surrounding blanket would not cover the limestone outcrop, to do this would necessitate a rise in the level of the peat surface, which is a possibility. Other sites would easily be covered by projecting the level of the surrounding blanket. The Moss Burn - Flush Site is below the level of the surrounding blanket to the north, west and south: in an easterly direction blanket peat is replaced by a flushed area, flushed by springs from the base of the site. If a blanket peat cover had formerly existed in this position it would have been readily removed as the site is unstable for peat owing to a moderate slope and strong flushing.

The Currick Site (fig. 17), and the small area to the south of it, appear to show that an extension of the surrounding peat blanket at its present level would cover most of the area. An exception is provided by the steep limestone face to the north east of the Currick Site (fig. 17). Even during the period of maximum peat expansion it seems unlikely that this large steep face would be covered. The same problem is encountered with the Currick Hill Site (fig. 18), and others on the tributaries of Troutbeck, in that the edge of the limestone outcrop presents a steep face on which it is difficult to imagine deep peat forming. As with the Currick Site the larger part of these other sites would easily be covered by extending the existing peat blanket at its present level. At the maximum peat expansion peat cover must have been almost complete excepting on nearly vertical faces and even on these a thin blanket may well have existed. After the maximum peat expansion, when erosion began, these steep slopes with a thin peat blanket would be amongst the first sites affected and cleared of peat. As the steep slope cleared erosion would cause a retreat of the blanket peat back from the slope until a time when the eroding peat face was stabilised by a vegetation cover. This erosion would, in one direction, cause a retreat of the peat blanket across the bench formed by the limestone bedrock. In the opposite direction it would cause a retreat downslope, away from the limestone.

The dissection of the limestone bedrock surface is pre-last glaciation, or solifluxion episode, and therefore predates the development of the blanket peat. The problems of continuous peat cover over the structural slope found at the edge of the limestone outcrops will also be encountered when considering the steep slopes within the outcrop caused by dissection. Both sets of features would tend to be smoothed off by the drift or head cover which existed immediately after the last glacial episode and this would help peat development. This is assuming that a continuous drift (or head) cover existed until peat formation, and there is no way of proving this except that a drift cover is always found beneath the blanket peat surrounding the sites. As with the structural slopes, the slopes due to dissection would be amongst the first places to be affected by peat erosion.

Following peat removal, erosion of the underlying drift would begin and would continue until the surface was stabilised, by a vegetation cover. As with the peat removal, erosion would begin and take place quickest on the steep slopes, or breaks of slope, on the limestone outcrops caused by structure or dissection.

The resulting picture is one of an old (Pre-last glacial episode) dissected limestone surface which was covered with a layer of glacial drift during the last ice advance or by head during the subsequent periglacial conditions. As the climate ameliorated erosion of the superficial cover would begin and continue until the surface was stabilised by a vegetation cover. Soil formation would begin in this superficial material. Peat formation would be the next important phase and this would probably cover large areas of the existing sites although on the larger steep slopes only a thin cover would form. During initial peat formation the soil types would adjust to changing climatic conditions, as the peat thickened the soils would be sealed off and become fossil soils. When peat erosion began, due to instability or a change of climate, it would take place first on the steep slopes and at breaks of slope. Erosion would then cut back the peat across the bench formed by the limestone. Peat erosion would expose the underlying superficial material to subsequent erosion which would continue until vegetation stabilised the surface once again, or until bedrock was exposed. Soil development would take place in the superficial material and the type of soil developed would depend on the depth of the superficial cover remaining at a particular spot when stabilisation took place. This, in turn, would depend on the original depth of the superficial cover which would tend to thin over upstanding blocks and thicken in the channels.

15.2. Effect of Springs on the Evolution of the Sites.

The reasons must be considered, why one area of a given limestone has mineral soils on it while the great bulk of that limestone is covered in blanket peat, i.e. why some patches of peat and drift, or head, have been removed and not others. Alternatively the sites may have been maintained free of peat. The problem is what instigated erosion, or kept the site clear.

A line of springs is commonly found along the base of limestone outcrops owing to the impervious strata directly below the limestone aquifer. The limestones on the eastern side of the Reserve have an easterly dip and hence strong springs are present at outcrop. Even when covered with superficial material seepage takes place from the base of the limestone causing increased instability at this point. It maintains the superficial deposits in a saturated condition and also lubricates any sliding. Springs along the base of the limestone, when exposed, cut back the scarp feature and accentuate it due to spring sapping.

15.3. Effect of Shake Holes and Swallow Holes on the Evolution of the Sites.

Another important set of features are the shake holes and swallow, or pot, holes. Shake holes in local usage refer to drainage hollows wholly within superficial, unconsolidated material (Plate 17); swallow, or pot, holes refer to solution cavities in limestone which may affect overlying bedrock and drift deposits. The shake holes are developed through the peat allowing drainage to the underlying limestone; limestone may be exposed at the base of the shake hole but often only drift or head is exposed. From the site maps (Figs 11-26) it may be seen that many of the areas of limestone grassland have shake holes associated with them and Bower (1960) has said that removal of superficial material down shake holes and swallow holes is an important process (p. 78). It is clear that these features may well play an important part in the stripping of peat and drift, or head, from the sites under study. Some of the smallest sites, e.g. Little Dodgen Pot Sike Sites, consist of a number of shake holes with an area of mineral soil between them, the whole being surrounded by blanket peat.

The shake holes are generally small scale features and would develop after peat formation. One cannot be so certain about the larger scale swallow holes and their associated shake holes. The large swallow holes, e.g. at the head of Little Dodgen Pot Sike (p.138) reaching up to 25 ft. in diameter and 10ft. deep, must be pre-glacial and hence formed before the peat cover. If they remained open it is difficult to imagine peat forming over the largest examples. If the swallow holes were infilled with drift, and they are normally surrounded by deep drift, the peat would probably form on the drift, providing the drift wasn't removed before peat formation. Subsequently the drift, and any covering peat, would be removed as the underground drainage system was re-opened. The existence of these swallow holes would be an important factor in causing erosion initially.

15.4. Sites with Topography, Springs, Shake Holes and Swallow Holes Dominant.

Although the features considered above, i.e. breaks of slope, springs, shake holes and swallow holes, are important in removal of peat and drift only in a few cases have they completely controlled this removal. The crecentic area of grassland on Hard Hill, i.e. Hard Hill - Eastern Unit (p. 119), the Moss Burn - Flush Site (p.107), and the Little Dodgen Pot Sike Sites (p.138), would appear to have developed under the influence of the factors considered so far. The Hard Hill area (p.119) has a sharp break of slope at its upper margin and a less distinct break at its lower limit. These factors were probably dominant in instigating erosion which caused removal of any former peat cover and subsequent thinning of any head deposits. It is difficult to envisage such a narrow strip remaining free of blanket peat when a thick cover still exists above and below the site. At the Moss Burn - Flush Site any peat cover extending over the area would involve a thinning of the peat (Fig 16) or a topographic rise in the peat surface. In either case there would be instability around the edges of the limestone dome. Added to this instability there is strong seepage from springs at the base of the limestone (p.107). These two factors together would seem to be sufficient to account for removal of any pre-existing peat cover and thinning of the drift or head. It is perhaps also significant that the superficial material on this site has a high clay content (p.196) and hence would be relatively impermiable to any water seeping through overlying peat; this would increase instability and lubrication. The springs found on the site are also responsible for the removal of the blanket peat from the flush area which now exists below the site (p.107).

The Little Dodgen Pot Sike Sites have already been mentioned (p.248). The smaller sites have developed around two or more swallow holes which are the controlling factors in the development of these sites. The larger sites have developed around swallow holes plus shake holes.

15.5. Effect of Surface water drainage.

In the case of the other limestone grassland sites surface water drainage is almost certainly the dominant agent of erosion and has controlled the evolution of the sites. These sites, although varying in size and being developed on different limestones, have certain features in common. They are all on fairly marked topographic features, and, more significantly, they lie at the point where streams cross the edge of this feature; in most cases the feature is the edge of the limestone outcrop. Several sites are also at the confluence of two streams and, often, one of the streams now flows underground within the limestone bedrock. A strong permanent stream is the dominant agent of erosion in the removal of any superficial material in the immediate vicinity. The topographic feature due to the limestone outcrop would still be important as the steeper slopes would facilitate erosion by the stream.

We have seen that most of these areas had a former cover of drift or head. Remnants of this cover are found on all levels of the dissected limestone surfaces hence dating the dissection as pre-glacial, or, at least, inter-glacial. This may not apply to the small scale dissection, i.e. the clints and grykes, which may have developed below the drift cover as elsewhere in Britain (e.g. Clayton 1966). This superficial cover would probably infill the dissections on the limestone surface and peat would almost certainly develop on the cover. If the cover had been removed before peat development then peat growth is much less likely. It is, therefore, important to determine when intensive removal of superficial material by streams began and in particular whether it was before or after the major period of peat expansion. Widespread ombrogenous bog formation began at about 5500 B.C. and the development of surface drainage before this, perhaps back to the beginning of Zone II. This leaves some 3300 years for stream development and erosion before peat growth began. The major period of peat erosion is thought to date from about 500 B.C. but Tallis (1963), working in the southern Pennines, has shown that in that area erosion by slow headward extension of streams into the peat blanket along pre-glacial stream began c. 3000 B.C. If a similar date applied in the northern Pennines a period of some 5000 years is left for removal of the peat blanket and the underlying drift from the stream valleys.

In the larger valleys, e.g. Troutbeck and the Tees, streams would rapidly re-establish themselves after the last glaciation but the smaller stream valleys tend to be infilled with drift or head and hence re-establishment of a stream system will be a slower process.

Between 8800 B.C. and 5500 B.C. the present day drainage was established though it is uncertain whether the present stream courses are exactly in the same position as the pre-glacial drainage. Clearance of drift from the limestone grassland sites must have been initiated during this period. The presence of islands of blanket peat on some sites suggests that drift or head still existed here when peat formation began. The exact situation varied from site to site but the cover of drift and, or, head and peat found on these grassland sites was certainly more extensive in the past than it is today and in some cases covered the whole of a grassland site. Further, in the set of sites under consideration, by far the major part of this former, more extensive, drift and peat cover was removed by stream action. As the superficial material was removed so the pre-existing dissected limestone surface was re-exposed. The streams would re-establish themselves mainly by cutting back up the slope so that the first part of the limestone re-exposed would be the edge of the outcrop.

Another problem arises as to why patches of peat and drift are found at random on the sites while adjacent areas have only the thinnest soil cover. The writer would suggest the following explanation. At present on all these sites streams flow underground for part of their course and this is thought to be an extremely important factor. In post-glacial times surface drainage would continue until an underground drainage system was re-opened; drainage certainly existed in the limestones in pre-glaciation times. The amount of superficial material, drift and peat, left on the areas adjacent to the stream depends on how soon this underground drainage became re-established, i.e. how much of the superficial material had been removed before the drainage went underground. The fact that surface drainage existed in places where it is now absent is shown by the heavy alluvial addition to soils in the channels which are now dry (p. 101 and fig. 13).

We return to the picture of a re-excavation of a pre or inter glacial surface with the removal of peat and drift. The superficial material is removed chiefly by the action of surface water and in particular streams re-excavating old valleys : shake holes would also be important. As well as re-excavating old valleys the streams would be re-opening the sub-surface drainage system in the limestone. Once this sub-surface system was re-established and the bulk of the drainage was underground the re-excavation of the limestone surface would be greatly slowed down and the process virtually frozen.

Two factors are seen to emerge, firstly as the streams re-excavate their valleys they will cut down gradually leaving the limestone scar above stream level and outside the influence of rapid stream erosion. This process will allow some areas to retain thicker superficial deposits than others depending on how much material was removed prior to the establishment of a stream course below the level of the limestone scars. Secondly, drainage goes underground once the subterranean drainage system is re-established. Again varying amounts of superficial material will remain on the limestone outcrops depending on how much erosion has taken place prior to this stage being reached (Fig.37). In some cases it seems that one of these two factors has been dominant, e.g. only stream downcutting on the Rough Sike Site (p.126), and elsewhere downcutting and underground drainage are equally important, e.g. Moss Burn - Sheep Fold Site and the Currick Site.

The soils developed on the sites will depend on the varying thicknesses of superficial material remaining and will vary with thickness as outlined in chapter 14 (Fig.37). The cover of superficial material on sites not associated with surface streams, e.g. Moss Burn - Flush Site and Hard Hill - Eastern Unit, has not been thinned as much as on those associated with streams, due to the slower removal. As a consequence the shallowest soil type is not found on this type of site.

The Hard Hill - Northern Unit is mid way between the sites with no associated stream and those intimately associated with streams. A stream seems to have been present for a period but this stage must have been very short lived. As a consequence the superficial material was only thinned a little and only upstanding domes of limestone have been re-excavated. The shallowest soils are absent from this site.

It is thought that the above outline explains most of the features of the limestone grassland sites and the distribution of the soils which make up the complex associated with them. The ultimate controlling factor in the location of the grassland sites is probably the form of the pre-glacial or inter-glacial limestone surface. The sites not associated with streams are often located at some pre-existing feature, e.g. The Flush Site (p.107) is on a structural dome within the limestone, the Hard Hill - Eastern Unit is on the marked break of slope, and some of the Little Dodgen Pot Sike Sites are, essentially, pre-glacial swallow holes. The sites associated with streams are, largely, re-excavated stream systems cut into and through the limestone bedrock. Given some locational factor the soils present on the site have been determined by the thickness of superficial material left on the site and this is determined by 1) micro-topography of the site, e.g. any drift cover would thicken in channels and thin over upstanding blocks; 2) the type of erosion dominant on the site, e.g. the sites not associated with streams have only the thicker soils of the sequence as erosion of the superficial cover is much slower; 3) the duration of rapid erosion, i.e. when the drainage went underground or when it cut down below the level of a given surface so terminating rapid thinning of the superficial material.

Added to these factors are the influences of mining and of grazing. In some cases mining has destroyed the soils of an area and such areas are indicated as made ground. Grazing has altered the vegetation of the sites and hence must have caused changes of the soils, these changes were discussed in chapter 14.