K. Taylor

Aspects of the Ecology of The Northern Pennines

Occasional Papers

No. 9

MOOR HOUSE

"Aspects of the Ecology of the Northern Pennines" is a series of informal review and discussion papers for the reader with a general interest in the subject. They are not official publications of the Nature Conservancy Council and do not necessarily reflect the Council's official views.

Aspects of the Ecology of the northern Pennines

9. Soils of Moor House

by

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Introduction

Early references to soils

Although the present review is concerned mainly with work carried out since the establishment of the Reserve it is interesting to note some of the earlier references to the soils of the area. The earliest are usually in books on natural history and are essentially asides to considerations of vegetation. Thus Robinson (1709) in his study of the natural history of Cumberland tells us that limestone soils are "productive of a great variety of fine sweet Herbs, Plants and Flowers which afford rich feeding". A little later Hutchinson (1794) says of the adjacent Cumberland fells: "climate and soil are best suited to grazing".

The earliest works which contained sections devoted specifically to soils were the Board of Agriculture county reports and in the report for Cumberland (Bailey and Culley 1794) the soils of the county are divided into fertile clays, dry loams, wet loams and "black peat earth". The "black peat earth" is said to be "most prevalent in the mountainous districts, particularly those adjoining Northumberland and Durham". The report for Westmorland (Pringle 1794) contains the references to soils in the "Preliminary Observations" by the Bishop of Landaff. The Bishop makes the following observation: "Others constitute extensive mountainous districts, called by the natives fells and moors; the soil of these is, generally speaking, a hazel mould. In its natural state, is produced little else than a coarse benty grass, heath and fern; or in the language of the country, ling and brackens." While discussing the Pennines in general Johnston (1844), in his "Lectures on Agricultural Chemistry and Geology" has the following to say about soils developed over the Carboniferous 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".

The first publication devoted entirely to the soils of an area which includes Moor House was "A preliminary examination of the soils of Cumbria" (Bainbridge 1939). The author recognises three main classes of soils:-

(a) Mountain soils;

(b) Forest soils;

and (c) Marine soils

which are further subdivided on the basis of parent material and texture. Although Mountain Soils are recognised as one of the primary divisions Bainbridge dismisses the Pennine uplands as being peat covered.

The earliest soil work on the Reserve

The provision of initial data in ecological studies gave rise to the earliest soil work after the establishment of the Reserve. For this purpose a relatively detailed examination was made of the soils of several sites on which long-term enclosure tree planting experiments were set up on Hard Hill, Little Dun Fell, Knock Fell and Green Hole. Investigations included the digging of soil pits and the subsequent production of annotated profile descriptions and diagrams (Fig. 1); the intention being to provide a profile of each of the soil variants included (Reserve Record Volumes). The profiles were sub-divided on the basis of colour and texture but although horizons were designated by A, B and C cymbols these latter were not used according to current pedological conventions. The soils were not classified on a pedological basis but were referred to by the dominant vegetation of the soil in question. Notes were also recorded on the variation in soil type within the plots, the parent materials and, sometimes, on the inter-relationships of the various soils. Soil analyses were also carried out on 0 - 5 and 5 - 10 cm samples from the enclosure sites. This soil information forms basic data designed to allow monitoring of changes resulting from the long-term enclosure of the sites. The investigation of any such changes awaits resampling of the enclosures.

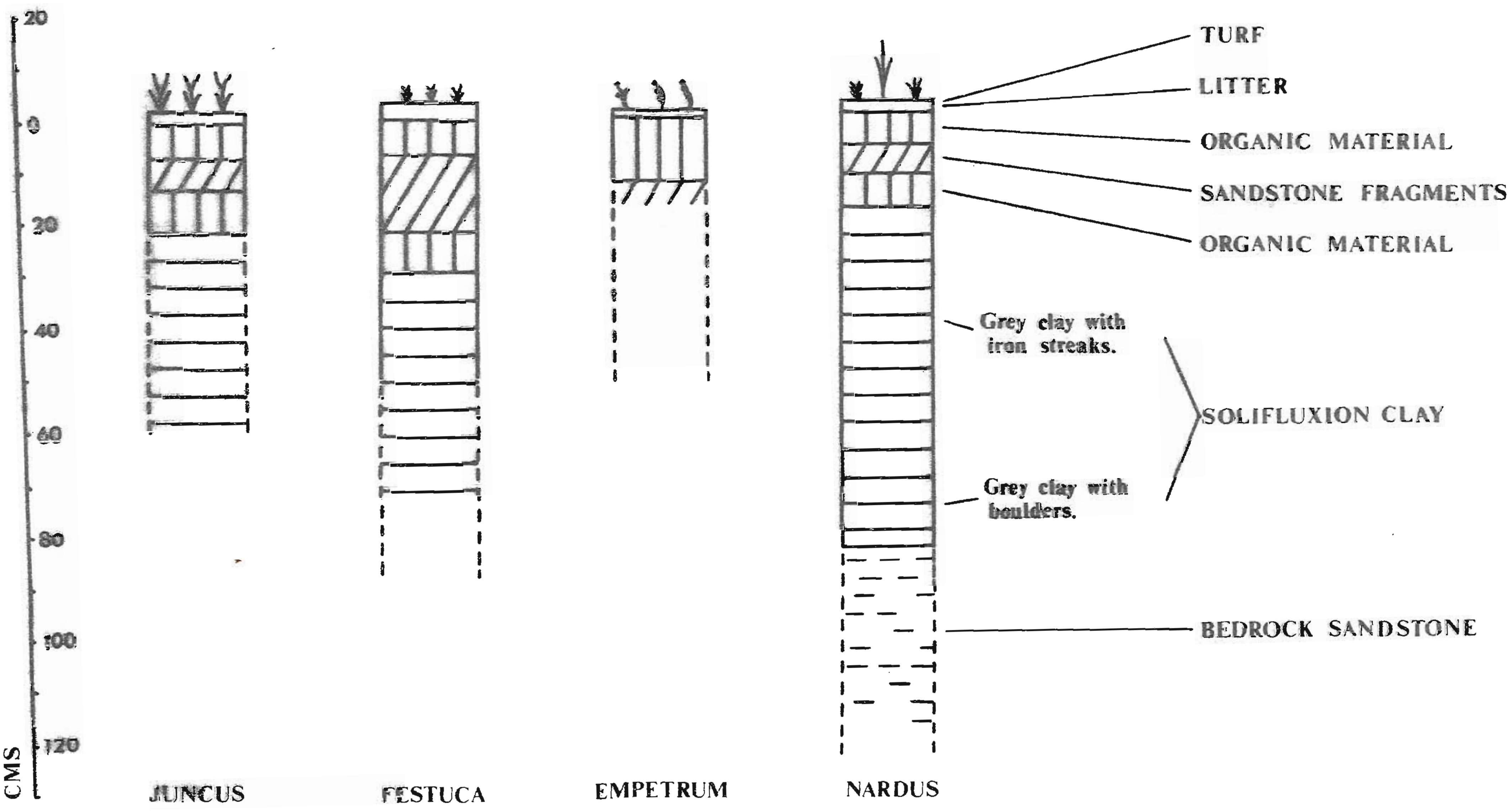
A soil map prepared for one of the experimental sites (Green Hole) constitutes the first attempt to actually map soils anywhere on the Reserve (Fig. 2). The exercise was carried out by three students as a vacation exercise and the resulting map distinguishes thick peat, thin peat, alluvial mineral soils, non-alluvial mineral soils and pot-hole soils. The map was intended as a base against which to monitor subsequent changes.

A soil related topic which received considerable attention in the early records of the Reserve was the former extent of blanket peat. The general opinion was that it had been much more extensive in the past and that erosion was still continuing in some areas. The small limestone outcrops which occur on the Reserve below [illegible] m (2500 ft) O.D. were also the subject of particular interest. The question was whether they had remained as "peat-free oases" or had been peat covered and subsequently re-exposed. Many were thought to have been covered at one time with peat (Reserve Record Volumes). The distribution of calcicole and calcifuge communities associated with these out-crops may be attributed to variations in the thickness and degree of modification of the drift cover over the limestone. Thus the <u>Juncus squarrosus-Nardus stricta</u> vegetation over limestone may be present due to "areas where, for various reasons, the residual drift is less highly modified" and not due to "the effects of over-grazing and/or leaching". Further reference will be made to these limestone outcrops later.

Studies on nutrient input and loss

A further line of research which involves soil studies or the collection of soil data is the attempt to construct a balance sheet for the annual input and loss of plant nutrients. This research also began soon after the Reserve was established (Park, Rawes and Allen 1962) and a preliminary balance sheep (Table 1) showed that more calcium was added to the soil in rainfall than was removed in an annual crop so that calcium shortage was not a factor on the grassland examined. The addition of

FIG 1 SOIL PROFILES DEVELOPED BENEATH VARIOUS COMMUNITIES ON HARD HILL.



GREEN HOLE ENCLOSURE - SOILS

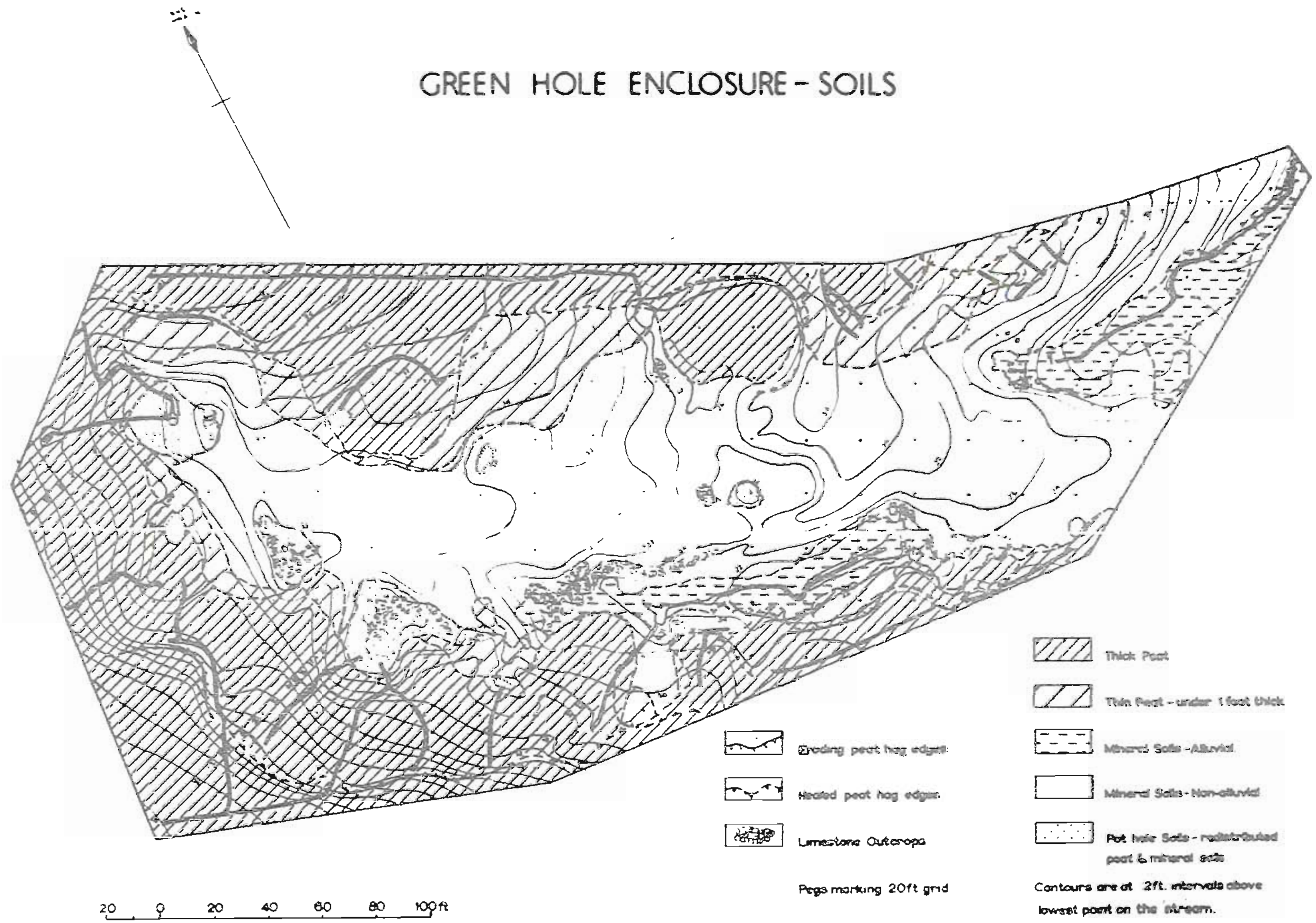


FIG. 2

potassium from dung and rainfall was sufficient to offset the loss by leaching but much less than that removed in an annual crop. It has been suggested that plant roots are able to tap resources of potassium within the soil which are not so loosely bound that they are removed by leaching. Little phosphate was removed by leaching, but little was added by rainfall, and the amount returned in dung was "of the same order of magnitude" as that removed by cropping. As a result the phosphorus balance was precarious and a phosphate deficiency may be expected to develop and increase. This type of research was continued with a detailed study of the input and output of minerals in a small area of moorland, the 88 ha Rough Sike catchment (Crisp 1966). This study determined the input of nutrients in precipitation, and the losses in stream water, as animal material in suspension in stream water, and due to sheep grazing (Table 2). An attempt was also made to determine the amount of material, in suspension and solution, added to the stream waters from the banks and beds of the streams. The results showed that sheep "have a negligible effect as a direct drain on the mineral resources of the system". For all five elements studied, sodium, potassium, calcium, phosphorus and nitrogen, the output was much greater than the input, but there may be additional input of the three metal ions by solution of mineral material, e.g. limestone bedrock, within the catchment. Also the losses of nitrogen and phosphorus in the stream water are large when compared to losses due to heather burning.

The effect of heather burning on the mineral nutrients and nutrient cycling has been studied in the laboratory (Allan 1964). Over half the carbon, nitrogen and sulphur in the heather is driven off in the smoke. The mineral nutrients, particularly potassium, are readily dissolved from the residual ash but the potential loss is reduced because the soil retains nutrient ions from the percolating solutions. However, it seems that if there is any loss of nutrients from the plant-soil complex as a result of burning, precipitation can "restore the mineral nutrient balance within a short period except on porous soils".

Several other investigations include small amounts of background soil work as annotated descriptions or a limited range of analyses, most commonly pH and loss-on-ignition. Thus, for example, Latter, Cragg and Heal (1967) carried out some soil analyses (Table 3) as part of their study of the microbiology of four moorland soils. The actual sites investigated were a "*Festuca-Agrostis* grassland" on a rendzina, "*Juncus squarrosus* moor" on a peaty gley, "mixed *Calluna-Eriophorum* moor" on blanket peat and "bare eroded peat". The study established an activity gradient with its highest values on the mineral-rich, freely drained rendzina and its lowest on the mineral-poor, acid waterlogged conditions of the bare peat.

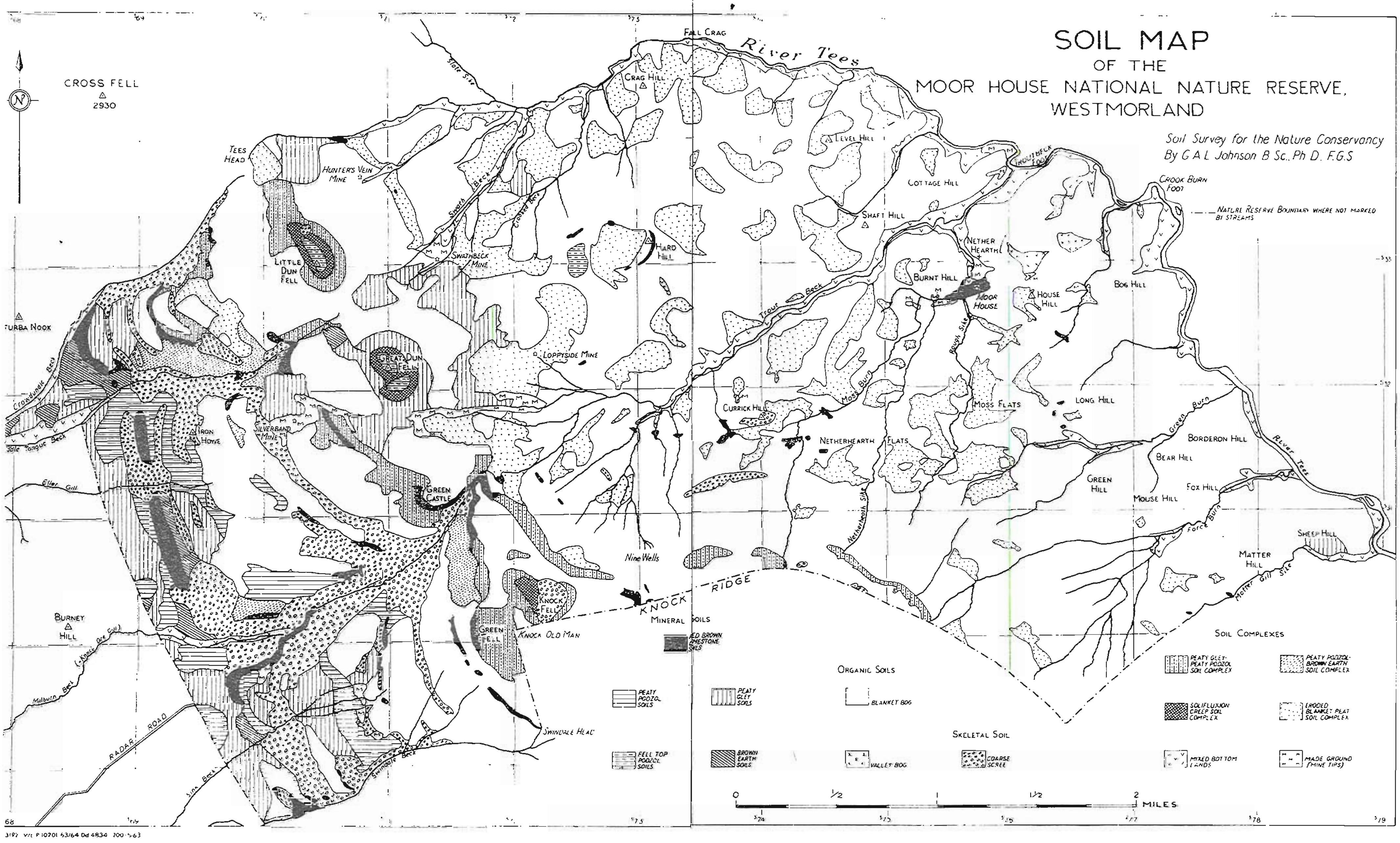
Detailed pedological studies

The first detailed pedological work on the Reserve was carried out by Dr. G.A.L. Johnson and developed from his geological research project. The initial work was stratigraphic and palaeontological but this was later expanded to include an examination of the clay minerals of some of the Carboniferous sediments, and eventually, of various soils. The soil aspects of the work developed and a soil survey of the Reserve was carried out from which a soil map was produced. The map (Fig 3) and a brief account of the soils were included in the book "The Geology of Moor House" (Johnson and Dunham). In 1963 the present author began work at Moor House to continue the research of Johnson and to provide more detailed information, e.g. profile descriptions and chemical analyses, on the more important mineral soils on the Reserve. This work did not involve a re-survey of the entire Reserve although large-scale mapping of soils and slopes was carried out in some of the soil complexes adjacent to limestone outcrops, and some of the soils described by Johnson were reclassified.

The original mapping was carried out on the basis of major soil groups and sub-groups with complexes of two sub-groups also being recognised. The soil classification used was based upon that of "Robinson (1951) with emendations suggested by the Soil Survey (Muir, 1956)". No indication of parent material was included on the map or incorporated into the mapping units. Fourteen mapping units were recognised and used on the final map: these fourteen units were grouped under the following headings - Mineral Soils, Organic Soils, Skeletal Soils and Soil Complexes, (Fig 3). The Mineral Soils include five mapping units which are either Great Soil Groups or sub-groups. Some of the units were based upon well established soil sub-groups, e.g. peaty podzols and peaty gleys, but others, the brown earths and red-brown limestone soils, are rather more vague and ill-defined. The name "fell top podzols" was originated by Johnson to describe podzols occurring on the higher fell tops. Six of the mapping units are grouped as "Soil Complexes" and these include complexes composed of two soil sub-groups, e.g. peaty gley-peaty podzol. Others such as "mixed bottom lands" indicate the location and other indicate a controlling influence in the evolution of the soils, e.g. "solifluxion creep soil complex" and "eroded blanket peat soil complex". Two mapping units, "blanket bog" and "valley bog" make up the "Organic complex". The "Skeletal Soil" only includes one mapping unit, "Coarse Scree". The published map was on a scale of 2½ inches to the mile although the field mapping was carried out at six inches to the mile.

The mapping illustrated the dominance of organic soils, in particular blanket peat, within the area of the Reserve but more especially on the gentle slopes east of the summit ridge. In this latter area the only gaps in the peat-cover below about 670m (2200 ft) are small areas around limestone outcrops, along the valleys of the larger streams and on sandstone outcrops. Above c. 670 m (2200 ft) scattered larger areas of non-organic soils occur as the slopes steepen; these are generally complexes of peaty gleys and peaty podzols or peaty podzols and brown earths. The fells of the summit ridge, ie. Great Dun Fell, Little Dun Fell and Knock Fell, have "fell top podzols" on the actual summits and non-organic soil complexes on the peripheral steep slopes. The western escarpment has a much lower proportion of peat-covered ground, this being restricted to the larger gently sloping benches. On the other, more typical, steeper slopes the whole range of "mineral soils" found on the Reserve are represented.

One chapter of "The Geology of Moor House" was devoted to "Soils" and dealt with the "mineral soils". This contains short sections on mapping and classification before considering the parent material and the distribution pattern of the soils. Each soil group and the soil complexes are then considered in turn. The work carried out by the present author formed the subject of an unpublished Ph.D. thesis and


SOIL MAP
OF THE
MOOR HOUSE NATIONAL NATURE RESERVE,
WESTMORLAND
Soil Survey for the Nature Conservancy
By G A L Johnson B Sc., Ph D. F.G.S
NATURE RESERVE BOUNDARY WHERE NOT MARKED BY STREAMS
CROSS FELL
2930
River Tees
FALL CRAG
CRAG HILL
TEES HEAD
HUNTERS VEIN MINE
SWATHBECK MINE
LITTLE DUN FELL
GREAT DUN FELL
HARD HILL
LOPPYSIDE MINE
LEVEL HILL
COTTAGE HILL
SHAFT HILL
CROOK BURN FOOT
NETHER HEARTH
BURNT HILL
MOOR HOUSE
HOUSE HILL
BOG HILL
TURBA NOOK
IRON HOWE
SILVERBAND MINE
GREEN CASTLE
CURRICK HILL
NETHERHEARTH
FLATS
MOSS FLATS
LONG HILL
BORDERON HILL
BEAR HILL
GREEN HILL
MOUSE HILL
FOX HILL
SHEEP HILL
MATTER HILL
Nine Wells
KNOCK RIDGE
KNOCK FELL
KNOCK OLD MAN
GREEN FELL
SWINDALE HEAD
BURNEY HILL
RADAR ROAD
Trout Beck
Moss Burn
Rough Sike
Green Burn
Force Burn
Netherhearth Sike
Eller Gill
Milburn Beck
Swindale Beck
Crowdundle Beck
MINERAL SOILS
RED BROWN LIMESTONE SOILS
PEATY PODZOL SOILS
PEATY GLEY SOILS
FELL TOP PODZOL SOILS
BROWN EARTH SOILS
ORGANIC SOILS
BLANKET BOG
VALLEY BOG
SKELETAL SOIL
COARSE SCREE
SOIL COMPLEXES
PEATY GLEY-PEATY PODZOL SOIL COMPLEX
PEATY PODZOL-BROWN EARTH SOIL COMPLEX
SOLIFLUXION CREEP SOIL COMPLEX
ERODED BLANKET PEAT SOIL COMPLEX
MIXED BOTTOM LANDS
MADE GROUND (MINE TIPS)
0
1/2
1
1 1/2
2
MILES
3197 Wt P 10701 63/64 Dd 4834 200 5-63

was divided into three sections; the first considered the factors of soil formation, the second the soil complexes associated with limestone outcrops and the third the more important soil sub-groups found on the Reserve before considering the soil distribution pattern on the western escarpment.

Johnson stresses the dominating role of climate as a soil-forming factor. High rainfall, coupled with low temperatures has the result that peat formation can proceed at the present time and the non-organic soils are acid and leached and commonly have an organic-rich surface horizon. In a more detailed consideration of the soil-forming factors Hornung (1968) devotes a chapter to each of the factors. An outline is given of the effect of each factor on soil formation; the factor as found at Moor House is then detailed and finally its effect on soil formation in the area of study is assessed. In this way the manner in which topography is known to affect soil formation is outlined, the topography of the Reserve is then discussed and finally the influence of the topography of the Reserve on soil formation in the area is discussed. Past as well as present climate must be considered as any drastic change in the climate would cause a change in the pattern of soil formation and begin a new cycle.

Climate is once again emphasised but the modifications to the overall pattern due to variations in the other factors are also pointed out. Thus variations in topography give a poorly developed slope sequence. This sequence is best developed on the stepped escarpment where blanket peat occupies the flat, or very gently sloping areas, and this gives way to peaty gleys, peaty podzols, brown earths and brown podzolic soils as the slope increases and drainage improves. The blanket peat deposits were certainly more extensive in the past than they are today and Johnson is of the opinion that "Only steeply sloping ground, the near vicinity of streams and perhaps some of the larger limestone outcrops were left bare of peat at this period". The present author considers the spread of blanket peat and its subsequent erosion an important factor in mineral soil formation. Any soil covered by blanket peat is, in effect, sealed off from the soil-forming agencies and soil "development" will only begin again when the peat is removed by erosion.

The parent material of the mineral soils is briefly considered by Johnson (ibid) and is said, for almost all the soils, to be derived from the underlying local Carboniferous rocks with only a small area of soils in the north-west of the Reserve being derived from the underlying lower Palaeozoic strata. The most recent work has confirmed these conclusions. The eastern slopes below the summit ridge are almost entirely mantled by a locally derived mixed Carboniferous drift with a clay loam texture. The western escarpment is also largely drift-covered but while most material is dominated by the rocks occurring immediately upslope a contribution of erratic material is present below about 549 m (1800 ft). Even the shallow soils associated with limestone outcrops can be shown to be developed in a drift remnant and it is probable that the only truly sedentary soils over limestone are those found on ledges on the limestone cliffs. The rankers developed on Ordovician tuffs, and originally mapped as brown earths, and small areas on the Whin Sill are dominated by material derived from the underlying rock although they also contain some drift material. The "fell top podzols" are other soils which contain only a minor drift influence, as will be discussed later.

Clay mineral studies by Johnson (ibid) showed that the Carboniferous shale contributed illite to the drift deposits and the soils formed in them, whereas kaolin was present in the sandstones and seat earths. Little breakdown of the clay minerals is apparent although there is some indication of a development of mixed layering in the illites and chlorites. Later work has confirmed the dominance of illitic clays in the most widespread drift but significant and useful variations do occur. Thus the Namurian rocks of the higher summits have a clay fraction dominated by kaolin and this is reflected in the soils of the summit ridge especially the fell top podzols. The Tyne Bottom Limestone in places contains appreciable amounts of clay grade material which is dominated by chlorite and this can have a local influence on the derived drifts. The kaolin from some seat-earths may also become locally important and this is particularly true in the drift downslope of the seat earth which overlies the Melmerby Scar Limestone. These detailed and local variations have proved extremely useful in pedogenetic studies on specific soils and in drift studies.

In the sections of the "Soils" chapter of the "Geology of Moor House", which are devoted to each mapping unit, the soil being discussed is defined. The distribution is outlined and the pedogenic factors controlling their formation are noted. A generalised profile is also included for each sub-group and in some cases a specific profile/colour photographs of six soils are presented. Section 3 of the present author's work (Hornung 1968) is somewhat similar but differs in the classification and grouping of the soils and in the level of detail. A chapter is devoted to each sub-group and profile descriptions and routine physico-chemical data are presented; the parent material, factors controlling distribution and the evolution of the soils are discussed.

In the case of the peaty gleys the work enlarges that of Johnson and provides analytical data. The peaty gleys developed are very similar to those described by many other authors using the current classification of the Soil Survey of England and Wales (Avery, 1973) and would almost all belong to the stagnohumic gley soils although small areas of humic gley soils are also present. The type peaty gleyed podzols are similar to those of Muir (1934) and Crompton (1956) and subsequently reported from many localities. There is, however, great variability within the sub-group as developed on the Reserve, especially where it merges into the peaty gleys. Thus examples with and without thin iron pans are found and also with gleying in the B and a freely drained B horizon. Most of the variants would be designated as stagnopodzols in the classification by Avery (ibid) and almost all belong to the iron pan stagnopodzol sub-group. Some of the hypotheses for the formation of these soils are discussed in relation to the examples from Moor House. Although they have limitations the theories put forward by Crompton (1956) and Muir (1934), and developed by Damann (1965) still seem to be the most convincing. These stress the presence of the water-holding peaty surface mat, the anaerobic conditions in the A2 horizons and relatively free drainage in the B horizon.

In the case of the "Fell Top Podzols" there is a considerable difference in treatment. Although the term "fell top podzol" describes the location of these soils and places them in the correct great soil group it does not show the affinity of these soils with similar ones elsewhere. As a result the soils were reclassified as humus iron podzols; in the more recent classification (Avery, ibid) they would belong to the sub-group of typical humo-ferric podzols. They are restricted to areas of sandstone which form cappings on some of the higher fells, ie. Knock Fell, Great and Little Dun Fell, Cross Fell, and Hard Hill. Two phases, a deep one and a shallow one, are recognised. The deep phase is found on the more extensive, flatter sites, ie. Cross Fell and Hard Hill. The unstable, and restricted summit of Great Dun Fell carries the shallow phase and Little Dun Fell a mixture of the two phases. Clay mineral studies, heavy mineral studies and pebble counts have shown that the soils were formed in situ from the sandstone debris produced by in situ physical weathering. It has also been shown that translocation of clay size material has taken place and also that a platey structure has been developed in the B horizon.

The brown earth mapping unit of Johnson has been shown to include a variety of soils. The generalised profile presented by him is that of a high level acid brown earth or a brown podzolic soil, but without accurate colours for the B horizon and free iron values it is difficult to decide to which of these two sub-groups it belongs. Included within his mapping unit are brown rankers, developed over Ordovician tuffs near the Middle Tongue Beck - Crowdundle Beck confluence, normal acid brown earths with a deep A horizon, high level acid brown earth with a thin humic A of H/A, and brown podzolic soils with free iron values in the B horizon. The normal acid brown earths are commonest in association with the feature due to the Melmerby Scar Limestone. The high level acid brown earths (this naming is recognised as temporary and unsatisfactory) are mainly at higher altitudes. They are on steep slopes or associated with limestone outcrops. The brown rankers would now be reclassified (Avery, ibid) as humic rankers while the normal acid brown earths and the high level acid brown earths would both be typical brown earths although they could be separated at the phase level into a mull and moder phase.

Podzolic soils with gleying, which are recognised by the present author, have no direct parallel in Johnson's grouping. They are almost certainly transitional from a high level brown earth to a peaty podzol. The discontinuous greyish gleyed/leached horizon developed below the H/A horizon is the first stage in the formation of a continuous A2 horizon. The brown podzolic soils are commonest on the steep valley sides of the escarpment and are often in complexes with the brown earths. The "solifluxion soils" are essentially a complex of brown earths and podzolic soils and it is doubtful whether they should be separated at this level.

The lighter texture of these "solifluxion soils" reflects the character of the Namurian rocks which form the parent material while the bulk density is due to their instability and to frost action.

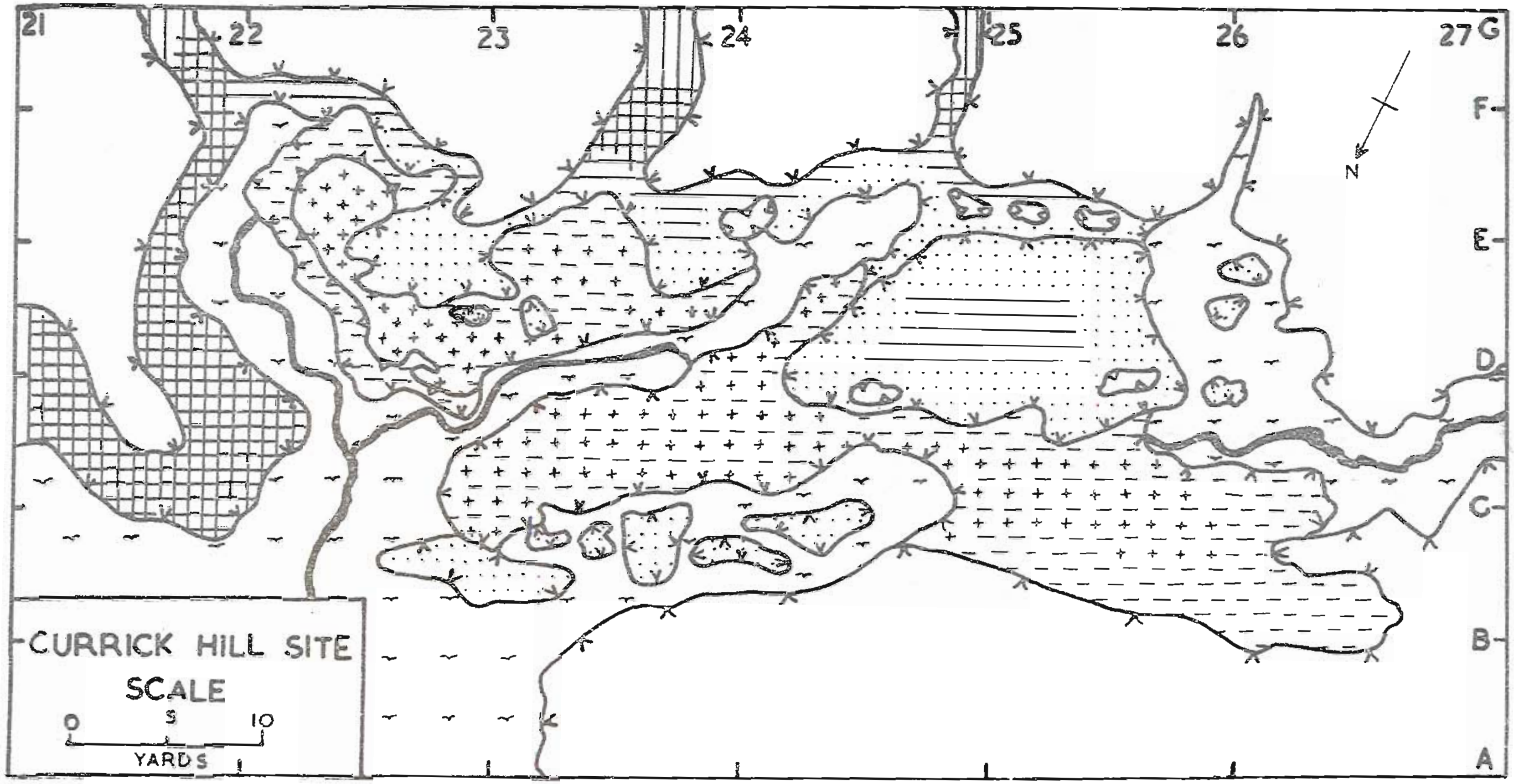
The skeletal soils of Johnson include a variety of rankers developed over sandstones and the whin sill plus rendzina-like soils developed over limestone. It is interesting that the brown rankers developed on the Ordovician tuffs are included in this section by Johnson although shown as brown earths on the map. Profiles of these skeletal soils are not included. The brown rankers and rendzinas were investigated further by the present author but the other rankers await more detailed research.

The complex of soils associated with limestone outcrops have formed one of the major parts of research, particularly those outcrops, east of the summit ridge, where they are surrounded by blanket peat. Several such areas were mapped in detail to show slope changes and soil distribution (Fig. 4).

The study indicated common features of their micro-topography with a series of dissected surfaces being developed on peat, head or drift and limestone. The dissection of the limestone was shown to pre-date the deposition of the head. This dates it as inter-glacial or pre-glacial. Each of the areas carries a very rapidly varying complex of soils although they were mapped as uniform areas of red-brown limestone soils by Johnson. The complex always includes the same sub-groups, ie. rendzina, brown calcareous soil, acid brown earth, peaty podzol and peaty gley. (Some of the soils referred to as rendzinas would be grouped with the humic rankers in Avery's classification and while some of the brown calcareous soils would remain as typical brown calcareous earths others would be included in the typical brown earths.) The distribution of the various soils within the complex depends on the depth of superficial material resting on the limestone (Fig. 5). The rendzinas are the shallowest and rarely more than 7.5 cm. deep, the brown calcareous soils vary between 7.5 cm and 22.5 cm, the acid brown earths 15 cm to 30 cm, and the peaty gleyed podzols and peaty gleys more than 30 cm. The rendzinas and brown calcareous soils are usually found on the upstanding remnants of the original limestone surface which now have only a thin drift cover. Acid brown earths and peaty gleyed podzols are usually found in the thicker drift blanket which passes under the blanket peat surrounding the area. Remnant mounds of deeper drift may also be present within the area and acid brown earths or peaty gleyed podzols are associated with these.

The parent materials of the soils are discussed in detail with the separate limestones being considered in separate groups. The intention was to attempt to show the origin of the parent material of each soil sub-group, the contribution of the underlying limestone and also to see if a loessial contribution could be detected. The dominant parent material was shown to be drift or head although some aeolian material may have been incorporated. The shallow soils, ie. the rendzinas and the brown calcareous soils contain a significant contribution from the underlying limestone and in some rendzinas the limestone contribution is dominant. The parent materials of the deeper soils have little, or no contribution from the limestone. Exceptions to this general scheme can be found and some acid brown earths are developed over very impure parts of the Tyne Bottom and Four Fathom Limestones; the parent material of these soils is derived mainly from the underlying limestone although transported material is also incorporated.

The inter-relationship of the soils which make up the complex is of interest along with the significance of the limestone bedrock in the evolution of each member of the complex. Two short trenches were dug to investigate the transition from one member of the complex. In the calcareous members of the complex the limestone bedrock acts as a source of calcium to the vegetation and hence helps to maintain the high base status and near neutral pH of these soils. In the deeper members of the complex the limestone would seem to be beyond the reach of plant roots and hence much less important as a source of nutrients and also as a corrective to the acidity caused by the intense leaching due to the high rainfall. In these soils the limestone helps to maintain the sub-soil as freely drained.



21
22
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CURRICK HILL SITE
SCALE
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10
YARDS

FIG. 4

KEY TO FIG. 4.

Rendzina

Brown calcareous soil

Acid brown earth

Peaty gley podzol

Peaty gley

Blanket peat

Concave change of slope

Convex change of slope

Shake hole or swallow hole

(Soil complexes are indicated by mixing symbols)

VARIATION IN SOIL SUB-GROUP AND VARIOUS SOIL PROPERTIES WITH INCREASING DEPTH OF SUPERFICIAL COVER OVER LIMESTONE

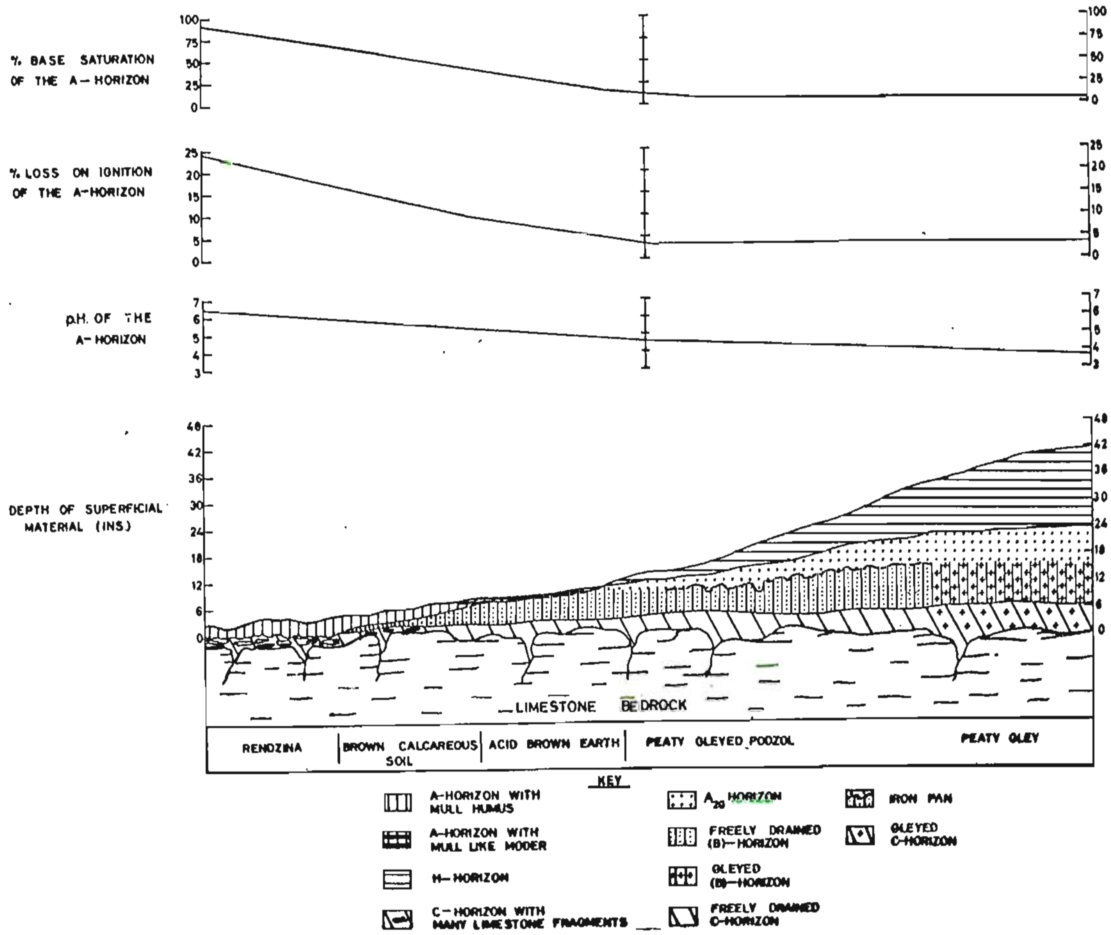

FIG. 5

The climax soil on these limestone areas would probably be a peaty podzol. Solution of limestone bedrock below the shallower soils would add insoluble residue to the soils and hence gradually deepen the soils. As they deepen the limestone will become less important as a source of bases to the surface vegetation, leaching would become dominant and hence the soils become increasingly acid. Over the pure limestone this sequence would be extremely slow and the present complex has probably been stable for a long period. The sequence would proceed quicker over the impure limestones, e.g. some beds of the Tyne Bottom Limestone. The significance of sheep grazing in determining the speed and direction of soil evolution was also considered. If grazing causes an increase in the acidophilous species then this will emphasise the trend towards more acid soils, but if it helps to maintain the basiphilous vegetation it will counteract soil evolution.

Johnson was of the opinion that the reddish colour of some of the calcareous soils was due to iron concentrated in the soil from the underlying limestone. The redder colours were taken to indicate greater maturity. The present writer has shown that the different soil subgroups over the same limestone, or developed in close proximity, contain similar contents of iron. It is unlikely, therefore, that iron is concentrated from the limestone.

The history of these limestone grasslands has been discussed in an attempt to see if it was possible to solve the problem of whether or not they were formerly peat-covered. Most of the areas would be blanketed by head or drift at the end of the Ice Age. If this blanket were still in existence at the time of the maximum peat expansion then peat would undoubtedly develop on them. Some sites, e.g. the crescentic area at the east end of Hard Hill and the area at the top of Moss Burn Flush were almost certainly covered. The large sites, e.g. Rough Sike, Moss Burn, Sheep Fold and Currick sites, were certainly smaller in the past, the peat blanket having been cut back, but parts of these areas may have remained uncovered. The sites are all located at erosion points, e.g. they are domed areas of limestone above which any drift, or former peat cover would thin, or they are located where a stream crosses the edge of the limestone outcrop.

A chapter of "The Geology of Moor House" was devoted to the "Peat Deposits" of the Reserve, but I concentrated on the palynological studies. These indicate that peat formation began in basin sites in Zone V, the Boreal, while the onset of more widespread blanket bog accumulation began during Zone VII, the Atlantic period. The basin peats show a sequence from an open water habitat, through fen stages to a *Sphagnum-Ericaceae-Eriophorum* bog. The blanket peat begins with a thin layer of stiff amorphous peat; this is generally overlain by a forest layer, dominated by birch, which gives way to a sticky peat composed mainly of *Eriophorum*, *Carex*, *Calluna* and *Sphagnum*. There is no evidence of a Boreal forest from the shallow peat on the summit ridge.

Other work on the peat deposits has included investigations on redox characteristics, cation chemistry, factors limiting growth and erosion processes. The variations of redox potential with season and depth were investigated by Urquhart and Gore (1973); the seasonal variations became less marked with increasing depth and showed correlations with temperatures. Vertical profiles of redox showed distinct minima but at varying depths. The growth studies showed that although calcium and phosphate contents are very low in the peats there was no response to additions of these elements, probably because of climatic factors; in contrast there was a marked response to nitrogen.

Peat erosion in the northern Pennines has been studied by Bower (1960, 1961 and 1962) and much of this work was centred on the Moor House Reserve. Two main groups of erosive processes were identified, water erosion and mass movement. Water erosion takes place by dissection of the peat by running water, sheep erosion of the peat surface, and by backcutting at marginal faces developed at the edge of the blanket peat. Mass movement of peat takes place on slopes and involves movement of the whole peat layer. Mass movement can also take place in peat overlying drift-covered limestone outcrops; this occurs when sink holes develop through the opening up of an underground drainage system.

Dissection is the most important kind of peat erosion in the Pennines and Bower distinguishes two types. The first is found in deep peat (at least 1.5 - 2.1 m) and on slopes of less than 5°, is very intense and caused by 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 of slope limits and is much more open with individual gullies rarely branching; it is commonest on slopes exceeding 5° and at higher levels. Three main stages in gulley development are envisaged by Bower. 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.

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 occurred which caused the removal downslope of some 835 tons of peat (dry weight) from an area of some 8,600 sq. m (Crisp, Rawes and Welch, 1964). 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° near the top, to 14 - 17° near the bottom of the scars. The authors suggest that the primary cause of the instability has been the lack of water-courses to drain the slope, for nearby areas with more water-courses have not suffered spectacular erosion.

<u>Summary</u>

The preceding account indicates the scale and range of the soil work which has been carried out to date on the area which has formed the Moor House National Nature Reserve since 1952. These studies have ranged from soil mapping, pedological and mineralogical investigations to microbial, nutrient balance and productivity work. The soil mapping has confirmed the dominance of organic soils but also indicated the range of the subordinate mineral soils from rankers, rendzinas and brown earths to gleys, peaty gleyed podzols and humus iron podzols and the variation within the sub-groups. This spread of soils is typical of a considerable area of the Alston block and some parts of the Askrigg block and the work at Moor House has therefore a wider significance. The more detailed research has investigated the role of the soil within the ecosystems present on the Reserve and has helped in understanding the development of the vegetation patterns found in this part of the Pennines. Further projects have examined the nutrient budget under the present management system and the factors limiting growth on some of the soils.

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