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# THE SOILS OF THE MALHAM TARN AREA

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The soils are developed mainly in drift derived from local Silurian shales, Carboniferous Limestone, Yoredale sandstones, shales and limestones and Millstone Grit, and only thin soils on Millstone Grit pavement and on scree slopes on limestone are likely to be residual. On Carboniferous Limestone, there is a close relationship between soil type, thickness of drift and plant cover. Rendzinas, eutrophic and mesotrophic brown earths occur in thin drift where nutrient cycling by roots maintains a reasonable base status in spite of the intense leaching. In thick drift, roots cannot tap the limestone and oligotrophic brown earths and peaty gleyed podzols are developed beneath a calcifuge vegetation.

Peat is extensive above 437 m. on drift derived from Yoredale rocks and Millstone Grit and here the main soil types are peat, peaty gleyed soils and peaty gleyed podzols.

## CONTENTS

## INTRODUCTION

THE soils of the Craven District, in which the Malham Tarn Field Centre lies, have been considered in a broad manner in two general accounts of the soils of Yorkshire. Crompton (1961) produced a sketch map of the soils of Yorkshire in which soils of the Craven District were divided into two groups, mountain limestone soils and moorland soils, but the accompanying report gave few details. More recently, some soils in the two groups were described in an account of the agriculture and soils of the Pennine foothills and uplands by Holliday and Townsend (1967).

Detailed studies of soils in the Malham Tarn area (Figure 1) were made by research workers from the Universities of Leeds, Nottingham and King's College, Newcastle. Barratt (1960) investigated the morphology of grassland humus forms on calcareous and non-calcareous soils; Wood (1963) studied the distribution of soil fauna, particularly Collembola and Acarina, in calcareous and non-calcareous soils; Syers (1964) studied the early stages of soil formation on limestone and especially the part played by lichens; Bullock (1964), during a reconnaissance survey of the soils of the Craven District, investigated the origin of soil-forming materials and the formation of deep soils over limestone in the Malham Tarn area.

This paper describes soil development in the area at a level between the very broad and very specialized studies listed above. Soil development on limestone has been studied intensively; this, together with soil formation on the Millstone Grit, Yoredale Series and associated drift of Fountains Fell, and on the drift on Silurian shales south of the Tarn, is discussed. Although written with specific reference to the Malham Tarn area, the information is relevant to a further 300 sq. km. of the Craven District.

## SOIL-FORMING PROCESSES

Soil development is studied in the soil profile, which consists of a series of more or less distinct soil horizons roughly parallel to the ground surface that differ from each other in colour, texture, structure, organic matter content, faunal activity, etc. These horizons result from the interaction of several complex processes and those in soils around Malham Tarn are discussed below.

### *Weathering*

Weathering breaks down rocks to produce soil. During the early stages of soil formation, physical weathering breaks down parent rock into progressively finer particles by freezing and thawing and wetting and drying. Weathered debris can lie directly over the parent rock or, as in areas of glacial deposition such as that of Malham Tarn, can be transported some distance from its source.

Physical weathering is mainly responsible for the formation of soil on the Millstone Grit pavement at 594 m. on Fountains Fell. It also breaks down massive Carboniferous Limestone into progressively finer blocks, which are then more accessible to chemical weathering.

Elsewhere, the parent rock is covered by more or less thick drift and protected from physical weathering. In all but the most shallow soils, chemical is more important than physical weathering; this is mainly by rainwater containing oxygen and carbon dioxide. The principal processes involved are solution, hydration, hydrolysis and oxidation-reduction, by which carbonate rocks are dissolved and primary silicate minerals broken down to secondary, often more clayey, products.

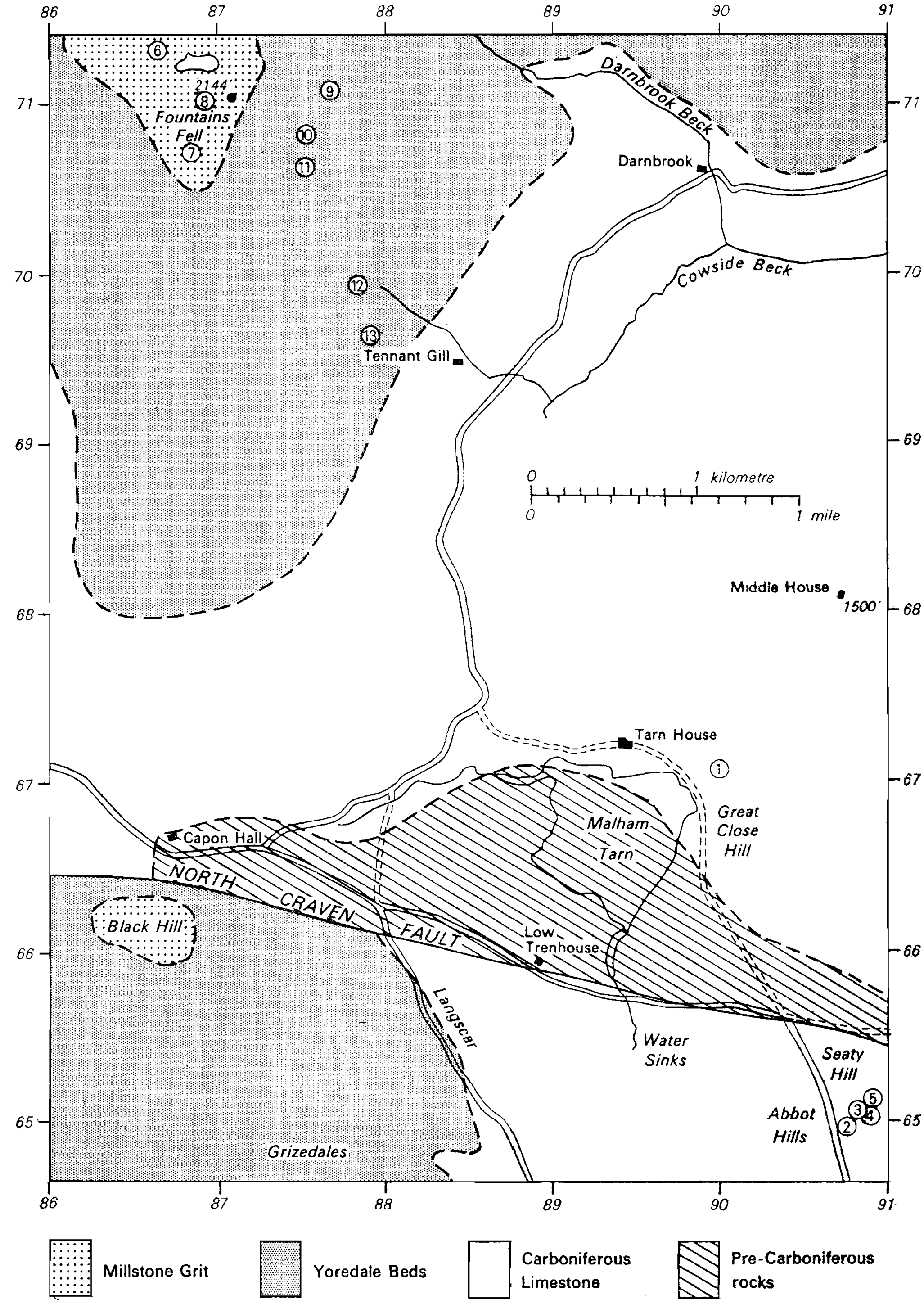



FIG. 1.



The Malham Tarn Area — locality and solid geology (based on O'Connor, 1964)

On the Carboniferous Limestone the main form of chemical weathering is solution. Rain and soil water charged with carbon dioxide readily react with calcium carbonate in the limestone to give the relatively stable bicarbonate ion that is removed in the drainage water. The process is summarized by the general equations:

$$CO_2 + H_2O = H_2CO_3$$

$$CaCO_3 + H_2CO_3 = Ca^{++} + 2HCO_3^-$$

The differential removal of the more soluble constituents of the limestone leaves residual products and these, with any drift present, form the material in which soils develop initially.

The chelating action of organic compounds produced by colonizing vegetation on the limestone is also important in removing some elements. Under lichens, $CaCO_3$ is the constituent most affected but Syers (1964) showed that some $Fe_2O_3$ may also be lost.

In the shallow shale soils and deeper soils in drift, solution is of lesser importance. Hydration, hydrolysis and oxidation-reduction are the main weathering processes that alter primary and some secondary minerals, and the ions released are removed in the drainage water.

### *Accumulation and decomposition of organic matter*

The amount of organic matter in the soil represents a balance between the rates at which plant remains are added, decompose and become mineralized; the last is largely a function of environmental conditions. Three main types of humus occur in the Malham Tarn area. Mull humus is an intimate mixture of mineral and organic matter and occurs in soils of moderate to high base status on the limestone. Mor humus, usually an indicator of acidity and low faunal activity, consists of plant litter in various stages of decomposition, unassociated with mineral matter. Peat develops from mor humus where waterlogging and anaerobic conditions inhibit decomposition of plant residues, and organic matter accumulates at the surface. The humus form affects the pedogenic processes operating on the mineral fraction of the soil.

### *Leaching, podzolization and gleying*

Wherever rainfall exceeds evaporation, as it does in the Malham Tarn area, leaching removes soluble components from the soil. The extent is shown by the acidity of most of the soils, for even many with limestone near the surface are largely decalcified. The exceptions are on scree slopes, limestone ledges, and on Yoredale shales lying immediately downslope of a Yoredale limestone band, all of which receive bases from above compensating for those lost by leaching.

Intense leaching increases acidity, decreases faunal activity and produces an acid humus favouring podzolization. Organic compounds liberated during decomposition of plant residues react with oxides of iron and aluminium to form mobile complexes carried by percolating water to a lower horizon. A bleached surface horizon, depleted of iron and aluminium, then forms over a horizon enriched in humus and/or iron and aluminium. At Malham, the process forms both a thin iron pan in thick drift soils with a peaty surface horizon, and a diffuse, sesquioxide-rich B horizon in coarse-textured soils on Millstone Grit.

Gleying is also an important pedogenic process, especially in thick drift soils with a peaty surface horizon. Periodic or permanent waterlogging develops horizons with grey and ochreous mottles. The variegated appearance is either from reduction and re-oxidation of iron compounds or from partial removal of iron in the more soluble ferrous form.

## The soil-forming environment

The extent and direction of soil development depend on the nature of the parent material, on past and present environmental factors such as climate, vegetation and topography, and on the length of time the processes have been acting on a more or less stable landscape.

### *Parent material*

The geology of the Malham Tarn area was described in detail by O'Connor (1964) who also gives an extensive bibliography of geological research in the area. Except for the inlier of Silurian rocks around Malham Tarn and on which it lies, all solid formations are of Carboniferous age (Figure 1). Carboniferous Limestone, represented by the very pure Great Scar Limestone, is the most important formation giving excellent examples of karstic topography (Moisley, 1955). Above is the Yoredale Series, comprising interbedded sandstones, shales and limestones, and Millstone Grit caps Fountains Fell (668 m.) and Black Hill (468 m.).

Only small areas of soil, however, have formed directly from these geological formations and even here it is difficult to ascertain their absolute residual nature. Severe erosion of parts of the plateau of Fountains Fell has removed any former drift cover, and here shallow soils on the Millstone Grit pavement may well be residual. Similarly the present soil on steep limestone-scree slopes is almost solely limestone-derived, partly from *in situ* weathering of the limestone below and partly from colluviation of limestone material from upslope.

The main contribution of the solid geological formations to parent material is through drift, in which most soils are formed.

Although the Craven District was covered by thick ice for much of the Pleistocene period, lack of erratics from outside the immediate area indicates that glacial and periglacial deposits over the solid formations are of local origin. Raistrick (1926) postulated that this part of the Pennines was by-passed by the large ice streams flowing southwards and eastwards into the Vale of York and attributes the drift deposits of the area to a local ice sheet. The glacial and periglacial deposits vary in composition but the influence of a particular geological formation extends only a short distance from its outcrop.

As the limestones such as the Great Scar Limestone are very pure, only a few centimetres of residual soil could have formed by weathering since the end of the last glaciation (Perrin, 1955), for which the date of 13000 B.C. has been given by O'Connor (1964). Perrin's hypothesis is supported by Sweeting's (1965) estimates of the rate of solution of limestone in this part of the Pennines, which indicate a lowering of the limestone surface by only 2 cm. each 500 years. Therefore, except on receiving sites, drift must be present wherever there is more than a few centimetres of soil.

The main parent material of soils over limestone is a loamy deposit, usually less than $1\frac{1}{2}$ m. thick and stoneless except for rare large boulders. Field morphology and laboratory investigations suggest this material is aeolian (Bullock, 1964). Particlesize distribution curves show a large peak at 20–70 $\mu$m. and also a smaller one at 100-150 $\mu$m. from material moved by saltation. The loam deposit is locally separated from the limestone by a thin band of plastic clay and in some places (Seaty Hill) by shaly drift, showing that it is not directly derived from the limestone below. Mineralogical analyses indicate that approximately one-third of the sand and silt fractions of the deposit is an insoluble residue of the limestone and the remainder is probably from the Millstone Grit.

Except on the limestone, the drift cover is closely related to the geological formation below. Immediately south of the Tarn, the transition from Carboniferous Limestone to Silurian shale is marked by an increase in thickness and stone content of the drift and some patches are much finer in texture. Similarly, on the middle and lower slopes of Fountains Fell, extensive boulder clay deposits are closely related to the outcrop of Yoredale shales and do not appear to extend on to neighbouring islands of Yoredale limestone which carry a loamy, well-structured drift. The use of the term drift for these clayey deposits is based mainly on the content of rock fragments, which often increase with depth and are foreign to the solid formation on which they lie. However, the origin of these fragments can usually be traced to within a kilometre of where they now lie.

### *Climate*

Climate is a very important soil-forming factor in the Malham Tarn area. A large excess of precipitation over evapotranspiration ensures intense leaching of bases, not replenished by weathering. Even soils on limestone, therefore, if not already acid, become so progressively.

Manley (1957) described the uplands around Malham Tarn as windy, humid and cloudy, with many days with measurable rainfall. The altitude ranges from 320 m. to 640 m. however, giving considerable climatic variation. On the main limestone plateau at 388 m., the mean annual temperature range is 11·6 °C. (13·3 °C., July; 1·7 °C., January) and the average annual rainfall 1,524 mm. falling in measurable amounts on 220 days. Potential evapotranspiration is about 500 mm. On Fountains Fell at an altitude of 640 m., the rainfall increases to 2,000 mm. and there is correspondingly less potential evapotranspiration. Thus, even allowing for surface run-off and absorption by plants, the climate has a large leaching potential.

A further climatic factor is atmospheric pollution as the area is in lee of the West Riding and Lancashire conurbations. Raistrick and Gilbert (1963) estimated that one-third of all winds recorded at Malham Tarn Field Centre (1952–1961) are from that direction. Measurement of atmospheric pollution by $SO_2$ showed the area to have twice as much pollution as Brixham, Devon. Such pollution lowers the pH of rain and increases its weathering potential. This, however, will only have been effective over the past 200 years and thus should be considered more as a factor likely to influence future evolution of these soils.

### *Vegetation*

Vegetation is the third of the main soil-forming factors in the Craven Uplands. Plant communities partly determine the nature of surface organic horizons, which in turn influence soil-forming processes, especially leaching and podzolization. At Malham, soil development on limestone is closely related to the plant community (see later section and Table 14), and the relationship is similar on other geological formations of the area, although less evident.

The vegetation of the mid-Pennine area was described by Smith and Rankin (1903) and Raistrick and Illingworth (1959), and of the Malham Tarn area by Sinker (1960).

During early post-glacial periods most of the area carried woodland (Pigott and Pigott, 1959). From the Atlantic period onwards the woodland degenerated and was destroyed, being replaced on the limestone by various grassland associations and at higher altitudes by cotton-grass moor.

True limestone associations are restricted to shallow soils. Elsewhere, the thickness of the drift governs the ability of roots to tap bases from the limestone below and hence determine the calcicole or calcifuge nature of the plant community. The cover on much of the limestone outcrop is transitional between true limestone associations and those of acid moorland. Thus *Sesleria caerulea*, *Festuca ovina*, *Viola lutea*, *Thymus serpyllum*, *Vaccinium myrtillus*, *Calluna*, *Erica*, *Nardus stricta* and *Polytrichum* were observed in a single quadrat on a shoulder overlooking Cowside Beck (Smith and Rankin, 1903).

South of the Tarn, on thick acid drift over Silurian shale, an acid grassland vegetation with tussocky *Nardus stricta* and *Deschampsia flexuosa* predominates with *Juncus* and *Carex* spp. in many wet areas where the drift is more impervious or where there is a thin peaty cover.

The Fountains Fell area has extensive peat associated with *Eriophorum vaginatum* on both the Millstone Grit plateau and lower drift-covered slopes. Strong erosion has left waste areas free of vegetation but peat is actively forming under *Sphagnum*, especially on lower slopes.

On steep slopes of the Fell, soils on limestone and shale carry an acid grassland vegetation similar to that on deep drift over limestone. On the Millstone Grit plateau the barren nature of the parent rock is indicated by shrub-heath vegetation, e.g. *Calluna vulgaris* and *Vaccinium myrtillus* on thin shallow soils.

## Classification of the soils

Soils are classified by characteristics of profile horizons which are conveniently designated by letters. The notation adopted for the present soils is:

*Organic and organo-mineral surface horizons*

L  Undecomposed litter
F  Partially decomposed litter
H  Well decomposed humus with little mineral matter
A  Mixed, mineral-organic layer
Ag  A horizon with rusty mottling, subject to periodic waterlogging

*Sub-surface horizons*

Ea  Pale coloured horizon depleted of iron and aluminium
Eag  Pale coloured horizon, depleted of iron and aluminium, subject to periodic waterlogging
B  Altered horizon distinguished by colour and/or structure, or by an illuvial accumulation from overlying A, Ea or underlying C horizons

Bh B horizon containing illuviated humus, characteristic of podzols
Bfe B horizon containing illuviated iron, characteristic of podzols
Bg Mottled (gleyed) B horizon, subject to waterlogging
C A little-altered horizon except in some cases by gleying
Cg A grey or mottled C horizon subject to waterlogging

The soils of the Malham Tarn area fall into five major groups in the classification of Avery (1965), viz. calcareous soils, brown earths, podzolized soils, gley soils and organic soils. Brown earths are the most widespread, both in the country and locally at Malham, and studies of their classification continue. To deal with the local examples, Avery's system has been modified (Table 1).

Table 1. *Classification of the soils in the Malham Tarn area*

| Major group | Sub-group |
|---|---|
| Calcareous soils; soils with $CaCO_3$ in all horizons, or the A horizon is only slightly acid | Scree rendzina: shallow A, C soils with black mull and high content of limestone fragments in the A horizon.<br>Clint rendzina: shallow A, C soils with black mull, free of limestone fragments.<br>Brown rendzina: soils with black mull overlying an incipient brown horizon between limestone fragments. |
| Brown earths: slightly acid to acid soils with brownish B horizons | Eutrophic brown earth: slightly acid soil with mull humus; base saturation $>60$ per cent and pH $>6.5$ in the B horizon.<br>Mesotrophic brown earth: moderately acid soil with mull humus; base saturation 30–60 per cent and pH 5–6.5 in the B horizon.<br>Oligotrophic brown earth: strongly acid soil with acid mull or laminated mor humus; base saturation $<30$ per cent and pH $<5$ in the upper B horizon.<br>Oligotrophic brown earths with surface gleying occur with prominent mottling in the top few centimetres beneath acid mor. |
| Podzolized soils: strongly acid soils normally with mor humus or peat; bleached horizon (Ea) overlying horizon of organic matter and/or sesquioxide accumulation | Podzol: Ea, Bh and/or Bfe, C soils. Bleached Ea horizons over black or orange brown B horizons of accumulation, includes humus-iron and iron podzols.<br>Podzolized brown earth: A, B, C soil with laminated mor humus. B horizon is sesquioxide-rich and commonly ochreous in colour.<br>Peaty gleyed podzol: strongly acid peaty horizons $<36$ cm. thick overlie grey Ea horizons with Bfe horizon occurring as a thin hard pan. |
| Gley soils: soils with gleyed (Eag, Bg, Cg) sub-surface horizons attributable to waterlogging | Surface water gley soil: slightly to strongly acid soil with acid mull overlying brown, mottled Eag horizon followed by Bg and C horizons.<br>Peaty gley soil: less than 36 cm. of acid peat overlying grey Eag, Bg and Cg horizons. |
| Organic soils | Peat ranker: strongly acid thin peat on rock pavement or peat mixed with Millstone Grit fragments.<br>Peat: slightly to strongly acid soils with $>50$ per cent organic matter in a surface horizon more than 36 cm. thick. |

## SOILS ON LIMESTONE

### *Early stages of formation and colonization*

The sequence of colonization from a bare limestone surface to a well developed rendzina on limestone pavement was studied by Barratt (1960), Wood (1963) and Syers (1964), and this section owes much to their original work. Figure 2 shows the most common stages of colonization and soil formation but it should be noted that each step in the succession may not necessarily occur, and there is often slight variation with exposure and habitat.

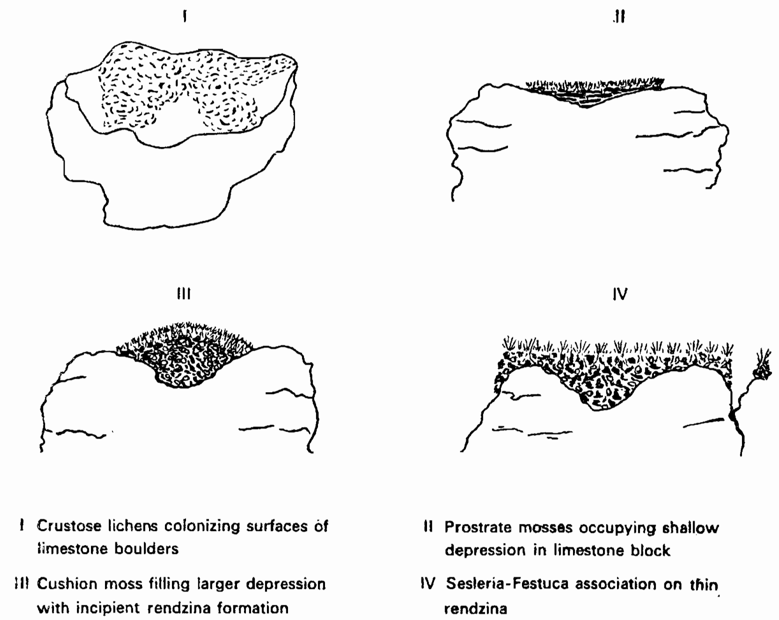



FIG. 2.
Initial colonization and soil formation on limestone. (Modified after Barrett 1960.)

*Lichens* (Stage I, Figure 2): The first plants to colonize the limestone rock are crustose lichens (e.g. *Aspicilia calcarea*, *Verrucaria nigrescens*). Their ability to attach themselves to a smooth rock surface and penetrate a short way into it partly explains their success as initial colonizers. Crustose lichens are succeeded by more squamulose species (e.g. *Caloplaca heppiana*) which become firmly encrusted on the limestone, their rhizomes penetrating fine vertical cracks. These in turn can be succeeded by foliose lichens (e.g. *Physcia caesia*, *P. adscendens*).

Small amounts of organic matter accumulate beneath the colonizing lichens, particularly foliose species, which Syers (*loc. cit.*) has attributed to decomposition of crustose thalli below and to the activity of small invertebrates, visible when thalli of squamulose and foliose species are detached from the rock.

The role of lichens as precursors to soil formation is threefold: (1) penetration of thalli causes micro-disintegration of the limestone rock; (2) chelating compounds produced by lichens increase the rate of solution of the limestone and removal of some elements; (3) the accumulation of organic matter provides a habitat for other plants.

*Mosses* (Stages II and III, Figure 2): Prostrate mosses (e.g. *Camptothecium sericeum*, *Hypnum cupressiforme*) often succeed lichens in the sequence, and the distribution of species is mainly controlled by exposure and the moisture regime of the habitat. Irregular accumulations of organic matter, mainly droppings of small fauna, form beneath prostrate mosses and some also line microfissures in the limestone. In dry sites, small cushion mosses (e.g. *Grimmia apocarpa*) grow in crevices and hollows on the limestone. Fine reddish-brown rhizoids penetrate the rock and further micro-fracture the limestone surface.

A further stage of development is represented by larger cushion mosses such as *Tortella tortuosa.* Beneath them, aggegates of droppings and moss residues are mixed with limestone fragments to form an incipient rendzina up to 2 cm. thick, and provide a site for the first flowering plants. The activity of microflora and microfauna increases during this stage and earthworms appear for the first time in the succession.

*Grasses and other higher plants* (Stage IV, Figure 2): Cushion mosses are often colonized by *Festuca ovina* and *Sesleria caerulea* in dry sites and in some cases by *Thymus drucei Galium sterneri* (*pumilum*) and *Sedum acre.* The colonized cushions become rich in roots, which form a mat over the limestone. Fauna are active in moist sites and aid the formation of a granular structure. Organic matter is intimately mixed with quartz and calcite grains and the soil is a shallow rendzina.

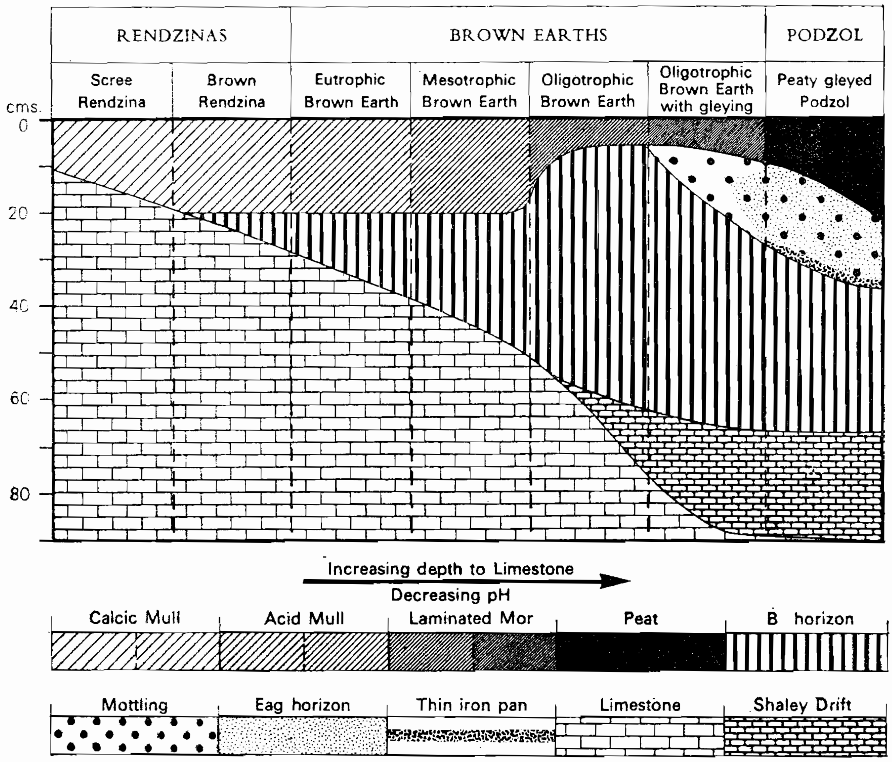
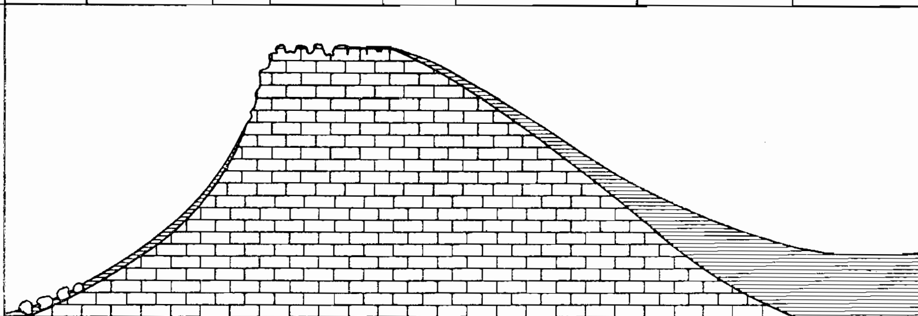



FIG. 3.
Soil development on limestone

## *Deep soils*

A distinct morphological group of soils occurs over the limestone (Figures 3 and 4). The main members are rendzina—mesotrophic brown earth—oligotrophic brown earth—peaty gleyed podzol. Other soils of transitional character also occur: brown rendzinas and eutrophic brown earths are intermediate between rendzinas and mesotrophic brown earths, and oligotrophic brown earths with gleying are transitional between oligotrophic brown earths and peaty gleyed podzols.

| LOCATION | Boulders | Scree | Scar | Pavement | Drift covered dip-slope | | | |
|---|---|---|---|---|---|---|---|---|
| SOIL FAUNA Sites L,G,P, I - VI | L,G,I,II | | III | P | | IV | V VI | |
| SOIL PROFILES 1 - 5 | | 1 | | 2 | | 3 | 4 | 5 |



| VEGETATION | Lichens Mosses | Sesleria caerulea | | Sesleria caerulea Festuca ovina (Agrostis tenuis) | Festuca ovina / Agrostis tenuis Trifolium repens Sesleria caerulea | | Nardus stricta | Nardus stricta |
|---|---|---|---|---|---|---|---|---|
| SOILS | Incipient Rendzina | Scree Rendzina | | Clint Rendzina | Eutrophic Brown Earth | Mesotrophic Brown Earth | Oligotrophic Brown Earth | Peaty Gleyed Podzol |

FIG. 4.
Sites of soil formation on limestone (modified after Wood 1963).

The soil types do not change over the altitudinal range of the limestone (230 m.), but the difference in climate between the highest and lowest parts is expressed in two ways. Rendzinas at lower altitudes are more base rich, usually deeper and occupy more of the limestone area than those higher up. Secondly, the acid members of the group—oligotrophic brown earths and peaty gleyed podzols—are more common at higher altitudes. This may, however, also reflect thicker drift deposits.

Although the morphological grouping of soils is clear, the distribution of the various soil types is very complex. The account of initial soil formation on limestone assumed drift material was lacking, except for small amounts of windblown material trapped in the colonizing vegetation. In deeper soils ($>10$ cm. thick), however, the thickness of drift significantly affects the types of soil developed and their distribution. The present thickness of the loam deposit is determined by the irregular surface of the limestone below, in which extensive joints have widened by solution, giving deep, wide fissures separating limestone blocks (Clayton, 1966). The soil distribution pattern is so complex that the occurrence of individual soil types can be represented on a map only by sampling in a very close grid pattern.

*Rendzinas* are the shallowest soils on limestone. Two types have been recognized in this area, a clint rendzina on limestone pavement and a scree rendzina on stable slopes.

*Profile 1. Scree rendzina*

Locality: North west of Great Close Hill (899673), slope overlooking Malham Tarn.

Altitude: 400 m.

| | |
|---|---|
| Slope and aspect: | 12° SSW. |
| 0–20 cm.: A | Very pale grey (10 YR 3/1), dry (black 10 YR 2/1, moist) loam. Strongly developed granular structure. Abundant angular and subangular limestone fragments. Friable consistency. Abundant fine fibrous roots. Few bleached quartz grains. |
| 20 cm.+: C | Shattered limestone scree with interstices filled with black (10 YR 2/1), moist loam. |

*Profile 2. Clint rendzina*

| | |
|---|---|
| Locality: | Seaty Hill (906647) |
| Altitude: | 380 m. |
| Slope and aspect: | Nil. |
| 0–11 cm.: A | Very dark grey (10 YR 3/1) dry loam. Strongly developed granular structure. Stoneless. Friable consistency. Abundant fine fibrous roots. Few bleached quartz grains. |
| 11 cm.+: C | Solid Carboniferous Limestone with pitted surface but otherwise no sign of weathering. |

Table 2. *Summary of characteristics of scree and clint rendzinas*

| Soil | Horizon | Depth (cm.) | Silt* (%) | Clay (%) | Org. matter (%) | pH | Base sat. (%) |
|---|---|---|---|---|---|---|---|
| Scree rendzina | A | 5–9 | 37 | 31 | 18 | 6.3 | 96 |
| Clint rendzina | A | 5–9 | 38 | 31 | 19 | 4.8 | 47 |

Most clint rendzinas are at the edge of limestone pavements wherever less than 20 cm. of soil overlie limestone. Most profiles have a dark granular A horizon resting on solid limestone, but deep varieties may also have a grass mat about 1 cm. thick at the surface, and a dense root mat mixed with granular soil material just above the limestone.

Scree rendzinas differ from clint rendzinas in several respects. They are constantly rejuvenated by colluviation of material and contain many fragments of limestone, whereas clint rendzinas are usually stone-free. Scree rendzinas also contain more bases than their clint counterparts presumably because the bases are renewed by downslope wash. Of the two rendzinas, the scree rendzina is likely to have the least drift contamination.

Both types of rendzina are widespread in the area, which in contrast to the Southern Pennines (Pigott, 1962), has well developed limestone pavement and scree slopes. Clint rendzinas are well developed in Seaty Hill pasture (9065), north of Malham Tarn House (8967) and north of Turf Hill (8869). Scree rendzinas occur on most steep valley sides. Good examples are on the south-west facing slope above the Tarn (8966) and on steep slopes above Cowside Beck (8969).

*Brown rendzinas* and *eutrophic brown earths* occur in occasional deeper pockets on scree slopes. The B horizon of the brown rendzina is incipient and occurs as small

* For all analytical results quoted: silt fraction is 2–50 $\mu$m, clay fraction $<2\mu$m and pH determined on a soil/water ratio of 1 : 2.5.

browned pockets between limestone blocks whereas that of the eutrophic brown earth is more developed and more leached although its fine earth fraction (<2 mm.) can still contain small amounts of carbonate. The two soils also differ in their humus form; the brown rendzina has a strongly granular, black calcic mull humus, whereas that of the eutrophic brown earth is lighter coloured with a crumb rather than granular structure. Both soils occupy only a small part of the Malham Tarn area.

*Mesotrophic brown earths*, the most widespread soils on the limestone outcrop, are more deeply decalcified than eutrophic brown earths and under natural conditions have an acid mull humus.

*Profile 3. Mesotrophic brown earths*

| | |
|---|---|
| Locality: | Seaty Hill (908651). |
| Altitude: | 380 m. |
| Slope and aspect: | Nil. |
| $2\frac{1}{2}$–0 cm.: | Open fibrous mat. |
| 0–15 cm.: A | Very dark greyish brown (10 YR 3/2) loam. Moderately well developed medium crumb structure. Few rounded limestone cobbles. Friable consistency. Common fine to medium pores and fine fissures. Abundant fine fibrous roots. Common earthworm casts. Merging boundary to: |
| 15–36 cm.: B1 | Complex mixture of yellowish brown (10 YR 4/4) loam with moderately developed medium subangular blocky structure and very dark greyish brown (10 YR 3/2) crumb-structured earthworm casts. Few rounded limestone cobbles. Friable consistency. Common fine to medium pores. Few fine fibrous roots. Merging boundary to: |
| 36–48 cm.: B2 | Limestone gravel set in a yellowish brown (10 YR 4/4) fine gravelly matrix. |
| 48 cm.+: C | Solid limestone. |

Table 3. *Summary of characteristics of mesotrophic brown earths*

| Horizon | Depth (cm.) | Silt (%) | Clay (%) | pH | Base sat. (%) |
|---|---|---|---|---|---|
| A | 5–13 | 38 | 30 | 6.4 | 67 |
| B1 | 20–34 | 37 | 29 | 6.4 | 57 |

Mesotrophic brown earths have developed on both morainic limestone gravel and solid limestone. Most of the profile is in the superficial loam deposit but there is sometimes a thin band of plastic yellow clay at the junction with the limestone. Profiles are usually 20–50 cm. deep.

At the upper end of the pH range of these soils, organic matter and mineral soil are intimately mixed in a mull humus with moderately developed crumb structure. At lower pH, the crumb structure in the A horizon is weaker, mixing is less intimate and there is an incipient fibrous grass mat. At a high pH value there is much earthworm activity and the B horizon is a complex mixture of crumb-structured earthworm casts and yellowish brown loam. Under more acid conditions, earthworm activity is absent from most of the B horizon but occurs in a thin zone at the junction with the limestone where it may be sufficient to give a second mull horizon.

Most well-structured soils with brown B horizon developed in grykes between clint rendzinas are also classified as mesotrophic brown earths. These gryke soils carry a specialized flora, including many species adapted to shady conditions. The soils have a uniform loam texture and may be deeper than the 50 cm. usually given as the limit for mesotrophic brown earths on limestone. They probably continue to receive material washed in from surrounding clint rendzinas and, also, calcium-rich water, which helps to maintain their mesotrophic state.

Mesotrophic brown earths occur widely on plateau tops, where a thin loam covers the limestone, and on gently sloping valley sides. A quarry near the entrance to Mastiles Lane (Malham end) (904657) gives good examples of the range of mesotrophic brown earths on morainic limestone gravel.

*Oligotrophic brown earths* are readily separated from the mesotrophic form because the humus is mor rather than mull and they are poor in bases.

*Profile 4. Oligotrophic brown earths*

| | |
|---|---|
| Locality: | Seaty Hill (908651). |
| Altitude: | 380 m. |
| Slope and aspect: | Nil. |
| 7·5–0 cm.: | Grass mat L—1 cm.<br>F—2·5 cm.<br>H—4 cm. Greasy black humus (7·5 YR 2/1) with abundant fine fibrous roots and massive structure. |
| 0–17 cm.:<br>B1 | Dark yellowish brown (10 YR 4/4) loam. Moderately developed medium subangular blocky structure. Friable consistency. Abundant fine fibrous roots. Merging boundary to: |
| 17–67 cm.:<br>B2 | Brown to dark brown (7·5 YR 4/4) loam. Moderately developed medium subangular blocky structure. Friable consistency. Few earthworm channels. Few coarse fibrous roots. Few shale fragments. Merging boundary to: |
| 67–75 cm.:<br>B3 | Yellowish brown (10 YR 5/4) loam. Moderately developed medium to coarse subangular blocky structure. Firm consistency. Common green shale fragments. Narrow boundary to: |
| 75–78 cm.:<br>B4 | Very dark greyish brown (10 YR 3/2) clay. No apparent structure. Plastic consistency. Gritty. Strong effervescence. Sharp boundary to: |
| 78 cm.:<br>C | Blocks of Carboniferous Limestone. |

Table 4. *Characteristics of oligotrophic brown earths*

| Horizon | Depth (cm.) | Silt (%) | Clay (%) | pH | Base sat. (%) |
|---|---|---|---|---|---|
| 5–15 | B1 | 41 | 25 | 4.4 | 5 |
| 20–50 | B2 | 43 | 19 | 4.5 | 6 |
| 68–73 | B3 | 53 | 15 | 6.0 | 63 |
| 75–78 | B4 | 29 | 63 | 7.2 | 97 |

Oligotrophic brown earths are often formed in at least three and sometimes four distinct superincumbent soil-forming materials, together at least 80 cm. thick. The upper 50 cm. is a stoneless loam deposit similar to that over most of the limestone plateau. Beneath is a shaly drift of variable thickness with abundant green shale fragments set in a loamy matrix. A thin band of plastic clay often separates the shaly drift from the limestone below.

The humus form is mor and most examples conform to Barratt's (1964) concept of *laminated mor*. Roots are mainly concentrated in the mor and only a few fibrous roots penetrate the B horizon. Compared to mesotrophic brown earths faunal activity is low and in deeper profiles no earthworm activity is discernible in upper horizons.

Oligotrophic brown earths are the most strongly leached of the brown earths on limestone. This is mainly because of the thickness of drift, which prevents roots reaching the limestone, and so there is little or no recycling of bases to retard leaching. Good examples of oligotrophic brown earths occur in Seaty Hill pasture (9065), on the north western slope of Great Close Hill (9066, 9067), and near Tennant Gill (8869).

*Oligotrophic brown earths with surface gleying* develop where laminated mor is thick and the H layer peaty. A mottled horizon a few centimetres thick occurs beneath the peaty H layer. Fine distinct ochreous mottles in the yellowish brown matrix indicate the early stage of gleying but as the process intensifies, grey patches appear giving a variegated horizon with rust-coloured mottles, grey patches and yellowish brown matrix.

*Peaty gleyed podzols* on limestone occur in areas of thick drift where an acid peat surface layer is thick enough to hold surface water and is waterlogged for much of the year.

*Profile 5. Peaty gleyed podzol*

| | |
|---|---|
| Locality: | Seaty Hill (909652) |
| Altitude: | 380 m. |
| Slope and Aspect: | Nil. |
| 8–6 cm.: | Loose grass mat composed predominantly of *Nardus* roots and sheaths. |
| 6–0 cm.: Peat | Black (7·5 YR 2/1) humified organic matter. No apparent structure. Abundant fibrous roots. Merging boundary to: |
| 0–20 cm.: Eag | Grey (10 YR 4/1) loam with pockets of yellowish brown (10 YR 5/4) loam. Weakly developed, medium subangular blocky structure with faces of structural units lined with black (7·5 YR 2/1) organic matter. Clear boundary to: |
| 20–21½ cm.: Bfe | Incipient, weak red (2·5 YR 4/2) thin iron pan. Clear boundary to: |
| 21½–53 cm.: B | Dark brown (10 YR 3/3) loam containing a thin discontinuous iron pan. Weakly developed subangular blocky structure. Friable consistency. Few fine fibrous roots. Few green shale fragments. Merging boundary to: |

53 cm.+: C — Yellowish brown (10 YR 5/4) loam. No apparent structure. Abundant green shale fragments. Friable consistency. Rare fibrous roots.
Augered to 150 cm. without change.

Table 5. *Characteristics of peaty gleyed podzol*

| Horizon | Depth (cm.) | Silt (%) | Clay (%) | pH | Base sat. (%) |
|---|---|---|---|---|---|
| Eag | 6–18 | 43 | 26 | 4.6 | 9 |
| B | 24–36 | 48 | 19 | 4.6 | 7 |
| C | 58–70 | 50 | 16 | 4.4 | 4 |

The most notable feature of the peaty gleyed podzol is the thin iron pan; the full mechanism of its formation is not known. Field evidence from this area shows that the prerequisite is a peaty surface layer waterlogged for most of the year. Iron mobilized in the anaerobic conditions beneath the waterlogged peat is thought by some workers to migrate through the upper part of the profile and re-oxidize at an anaerobic-aerobic interface. As the pan thickens and becomes continuous and impervious, it can hold up a perched watertable at some periods causing further gleying in the Eag horizon which eventually becomes grey.

Peaty gleyed podzols on the limestone plateau are strongly acid with a base saturation of less than 15 per cent in all horizons. They are less developed than similar soils on the thick drift of Fountains Fell and the pan is often thin and discontinuous. Like oligotrophic brown earths, the soils are usually developed in at least two superincumbent superficial deposits: a stoneless loam over shaly drift. They occur where drift is thickest and commonly on the tops of small hummocks, a feature of thick drift in Seaty Hill pasture (9064, 9164, 9065, 9165), on the western slopes of Great Close Hill (9066, 9067) and in dry valleys on Highfolds (8967).

In the Carboniferous Limestone area around Malham, soil development can be considered as a function of parent material in the following manner. Development likely to have taken place in the post-glacial period is shown by the full arrow (→) in the following sequence and that projected for a longer-term model by a broken arrow (- - →)

1. In insoluble residue of the limestone:
   Rendzina - - → Eutrophic brown earth - - → Mesotrophic brown earth.
2. In shallow drift or below a limestone outcrop:
   Quasi-permanent eutrophic and mesotrophic brown earths.
3. In deep drift:
   Mesotrophic brown earth ——→ Oligotrophic brown earth ——→ Peaty gleyed podzol.

The stages in the first sequence are retarded by the slow release of insoluble residue from the limestone. The soils on the limestone would hardly have developed beyond the rendzina stage since the Last Glaciation had limestone been the only parent material. Changes taking place in shallow drift are also slow. Eutrophic and mesotrophic brown earths are maintained by nutrient cycling, in spite of intense leaching. Insoluble residue adds to the depth of overlying material, preventing roots reaching the limestone and tapping the calcium.

Quasi-permanent brown earths adjacent to and below a limestone outcrop are from the flushing by calcium-rich water from the rock. As the present soil probably reflects an equilibrium between leaching and supply of calcium from upslope, it will remain in this stage until a change in climate alters the amount of leaching and/or the amount of calcium-rich water reaching the soil.

In the third sequence, the drift is so thick that weathering of the limestone no longer influences the upper part of the profile in which most pedological changes are taking place. When a fairly thick surface mat has developed, this accelerates accumulation of organic matter and the change from oligotrophic brown earth to peaty gleyed podzol.

Given sufficient time and stability of environmental conditions, the climax soil on the thick drift will be a peaty gleyed podzol and perhaps even peat. Although peat does not occur directly on the limestone in the Malham Tarn area, it does on Scar Close on the flanks of Ingleborough (Jones, 1965, Gosden, 1968). Possibly this formed directly on solid limestone, via a rendzina stage, but it may also have formed on drift later washed down into the grykes.

In the above discussion, soil development has been described in terms of the colonization of bare limestone and the building up of a soil cover. It should, however, be realized that the activity of man and his animals has also led to the stripping of soil from the limestone and there is evidence that, while some areas are being colonized, other areas of pavement have been denuded of soil since the Iron Age. Thus, there will be some areas in which the trends outlined above have been retarded and their direction even reversed.

## Soil-vegetation relationships on limestone

True calcicole vegetation occurs only on scree rendzinas and on thin ledge soils where addition of base-rich material from upslope and weathering of limestone *in situ* maintain a base-rich soil in spite of much leaching. On such sites, the main species are *Sesleria caerulea* and *Festuca ovina*, in association with *Briza media*, *Thymus drucei*, *Koleria cristata*, *Campanula rotundifolia*.

Clint rendzinas, more or less formed in drift, and eutrophic and mesotrophic brown earths poorer in bases than scree soils, also carry a partially calcicolous vegetation but with a smaller range of species. The dominant association of these soils is *Agrostis tenuis* with some *Festuca ovina*. The transition to deeper soils with more decalcified upper horizons is often marked by the appearance of *Anthoxanthum odoratum* and *Sieglingia decumbens*.

A generally calcicolous vegetation is maintained where the drift over limestone is thinner than 50 cm. (Bullock, 1964). On these soils the supply of nutrients from below is adequate. As mesotrophic brown earths deepen through weathering, calcifuge species enter the association unless lime is added to the surface.

On soils with limestone at depths greater than 50 cm., the plant associations are calcifuge and dominated by *Nardus stricta*, the characteristic species on oligotrophic brown earths. On this soil type, in particular, the plant association significantly influences the direction of its development. Because *Nardus* is unpalatable to the soil fauna in oligotrophic brown earths (see next Section), the residues break down slowly and a grass mat of more or less decomposed *Nardus* sheaths builds up. As this thickens, waterlogging results in a peaty H layer with incipient gleying beneath, giving an oligotrophic brown earth with surface gleying. The peaty humus then becomes pronounced, more moisture-loving species enter the association with *Carex binervis* and *Juncus squarrosus* indicating successive stages in the development of a peaty gleyed podzol.

## SOIL FAUNA AND SOIL FORMATION ON LIMESTONE

Wood (1964, 1967a, 1967b, 1967c) studied the distribution of soil fauna, particularly Collembola and Acarina, both between and within some soil types on the limestone. The soils and sites he studied (Figure 4) include a lichen-covered limestone block (L); a protorendzina under the cushion moss, *Grimmia apocarpa* (G); a protorendzina beneath various mosses (M); a skeletal soil under the prostrate moss, *Camptothecium sericeum* (I); a protorendzina under the cushion moss, *Tortella tortuosa* (II); a scree rendzina (III); a clint rendzina (P); a mesotrophic brown earth (IV); an oligotrophic brown earth with slight surface gleying (V); and an oligotrophic brown earth with strong surface gleying (VI).

During the early stages of soil formation on limestone (Sites L, G, M, I and II), there are few or no macrofauna such as Lumbricidae, Nematoda and Enchytraeidae, and animals are mainly confined to Collembola, Acarina, and a few other Arthropods made up mainly of Insecta, especially Coleoptera and Diptera. Occasionally woodlice (Isopoda) occur in protorendzinas under *Tortella tortuosa* where their droppings are a large part of the organic matter. Of the soil fauna studied by Wood, Acarina and Collembola had the largest mean population densities but densities were similar in the two moss sites (I and II) and the four grassland sites (III–VI).

In the deeper soils on limestone, macrofauna play an important part in soil development. Most scree rendzinas contain earthworms, mainly *Lumbricus festivus* and *Allolobophora chlorotica* and the population probably exceeds 100/sq. m. Woodlice (Isopoda) and land snails (Gastropoda) are also common and, with earthworms, thoroughly mix mineral and organic matter throughout the whole soil.

In mesotrophic brown earths, fauna are mainly active in the mull layer, where earthworms, with some Enchytraeidae and Nematoda, completely mix mineral and organic matter. Earthworms also burrow to depths in the soil, and the B horizon of most of the base-rich varieties also contains numerous casts. There may also be earthworms in the soil between limestone fragments. Mole (*Talpa*) activity is also conspicuously associated with this soil type.

Earthworms do not occur in the surface horizons of oligotrophic brown earths with gleying, partly because they are acid and seasonally waterlogged. Below 30 cm., earthworms, especially *Lumbricus terrestris* and *L. rubellus*, are active and casting from these species can be so great as to form a second mull horizon just above the limestone.

Nematoda and Enchytraeidae are common in oligotrophic brown earths but they are concentrated in the top 4 cm. Like Arthropoda, which show a similar vertical distribution, their main contribution to soil development is in the slow breakdown of the *Nardus* mat under the strongly acid conditions and most of the mineral part of soil is largely unaffected by fauna.

Wood (1964) did not sample peaty gleyed podzols but fauna will probably be distributed in them as in oligotrophic brown earths with surface gleying.

## SOILS ON DRIFT SOUTH OF THE TARN

South of the Tarn and east of Black Hill there is an extensive kame complex marked by ridges of variously sorted sands and gravels (Clark, 1967). Between the ridges are more extensive areas of acid drift mainly from Silurian shale but with some Millstone Grit, limestone and loess-like material. The soil pattern is complex and several types are present.

On the largely limestone derived kame ridges, the soils are eutrophic, mesotrophic and oligotrophic brown earths similar to those on limestone but more gravelly. Areas next to the kame ridges can also carry well-structured eutrophic and mesotrophic brown earths because of flushing by base-rich water from the kame deposit.

The most widespread soils are oligotrophic brown earths with surface gleying and peaty podzols in the acid drift, carrying mainly a *Nardus* and *Deschampsia flexuosa* grassland association. A laminated to peaty mor overlies a more or less grey, humus-stained horizon grading into a rust-mottled, yellowish brown horizon and eventually into a freely drained yellowish brown horizon similar to that of acid limestone soils. Their structure, however, tends to be more prismatic than in the acid limestone soils.

Some hollows in the relief have non-calcareous surface-water gley soils, often associated with finer-textured drift. The profile consists of a thin acid mull A horizon over 15 cm. of yellowish brown silty clay loam with grey mottles and grading into a thick (50 cm.) yellowish brown Bg horizon with common grey mottles in the top, decreasing to few with depth and a weakly developed prismatic structure.

## Soils on millstone grit, yoredale shales and associated drifts of fountains fell

The survey of the soils of Fountains Fell revealed the complexity of the soils especially in peaty areas where differential growth, erosion and slumping has produced an extremely intricate pattern. Without landmarks such as field boundaries to act as references when drawing soil boundaries, attempts were made to plot the soil pattern from aerial photographs. Unfortunately, tonal patterns did not correspond well to the distribution of individual soil types. However, further photography at a more favourable season or with different film might well have given more useful results.

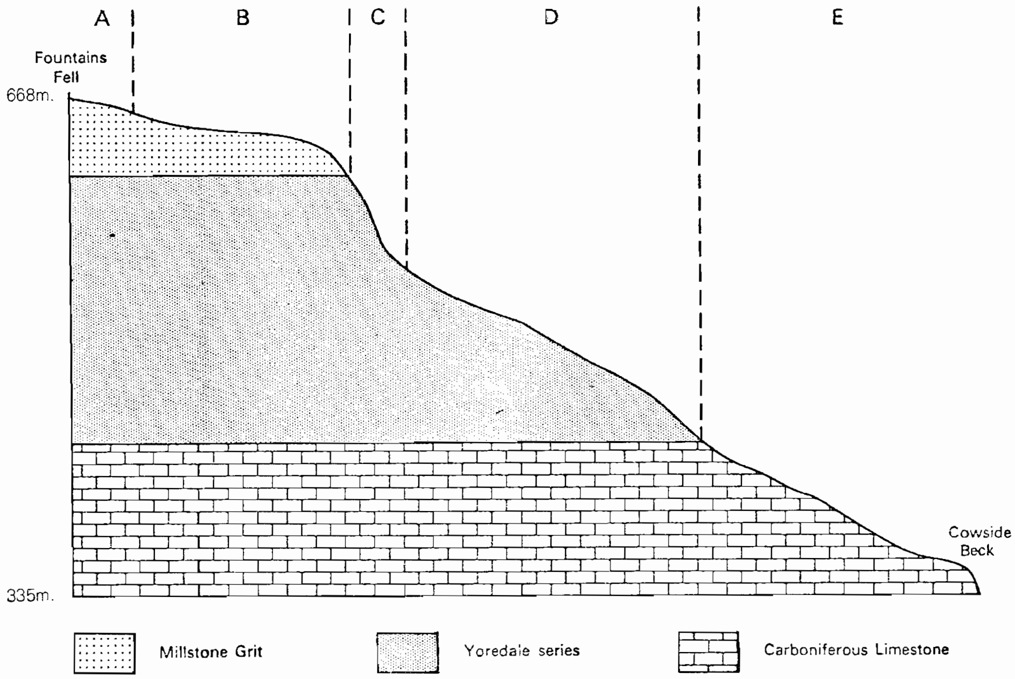
For the purpose of this discussion, the western slope of Fountains Fell is divided into five landscape/soil parent material units, each containing one or two principal soil types and several subsidiary ones (Figure 5). The following are the units distinguished:

A—summit area of the Millstone Grit plateau
B—lower slopes of the Millstone Grit plateau
C—steep slopes on shale
D—shallow middle slopes on boulder clay and bedded slope deposits
E—lower limestone slopes

### *Summit area of the Millstone Grit plateau*

Above 654 m., and especially near the summit and old colliery sites, podzols have formed under a cover of *Nardus stricta*. They generally have thick eluvial horizons and deep, diffuse B horizons of iron and humus accumulation. In many of the soils the Bhfe horizon occurs between weathering Millstone Grit blocks. Although normally coarse textured, there are small areas of gritty clay (e.g. 866717), which may be associated with old spoil heaps but may be remnants of a drift deposit.

The other main soil type of this area is peat under *Eriophorum vaginatum*, now seriously eroded so that mounds are separated by erosion channels, which can be strewn with Millstone Grit debris or have a floor of peaty silt. In both cases they often have no vegetation. Smaller areas of other soils include peaty gley soils and peat rankers.




| Zone | Elevation | Landscape/soil parent material | Soil types |
|---|---|---|---|
| A | 654 m.+ | Summit area of the Millstone Grit plateau | Peat, Podzols (Peaty Podzols*, Peaty Gleys and Peat Rankers) |
| B | 594–654 m. | Lower slopes of Millstone Grit plateau | Peat, Peat Rankers (Podzols, Peaty Gleys) |
| C | 562–594 m. | Steep shale slopes | Podzolized Brown Earths, Mesotrophic Brown Earths, Surface Water Gleys (Peat) |
| D | 439–562 m. | Boulder clay of the middle slopes | Peat, Peaty Gleys, Peaty Gleyed Podzols (Surface Water Gleys) |
| E | 335–437 m. | Lower limestone slopes | Rendzinas, Mesotrophic and Oligotrophic Brown Earths, Peaty Gleyed Podzols |

* Soils shown in brackets occupy a very small area of each zone.

FIG. 5.
Main landscape/soil parent material units of Fountains Fell.

The following profile is representative of a podzol under *Nardus stricta*.

*Profile 6. Podzol*
Locality: Fountains Fell (866714).
Altitude: 660 m.
2–0 cm.: Grass mat composed mainly of *Nardus* sheaths.

| | |
|---|---|
| 0–10 cm.: A | Black (5 YR 2/1) organic matter with abundant bleached mineral grains. Fine subangular blocky structure. Abundant fine and medium roots. Common fragments of Millstone Grit. Sharp boundary to: |
| 10–15 cm.: AE | Brown (7·5 YR 5/2) coarse sandy loam with abundant bleached grains. Single grain structure. Loose consistency. Abundant fine and medium fibrous roots. Abundant bleached fragments of Millstone Grit. Merging boundary to: |
| 15–21 cm.: Ea | Very dark grey (5 YR 3/1) coarse sandy loam. Single grain structure. Loose consistency. Common fine fibrous roots. Clear boundary to: |
| 21 cm.+: Bfe/C | Millstone Grit fragments with dark reddish brown (5 YR 3/2) loamy material between. |

Table 6. *Characteristics of podzol*

| Horizon | Depth (cm.) | Loss on ignition (%) | Silt (%) | Clay (%) | pH |
|---|---|---|---|---|---|
| A | 2–8 | 81 | — | — | 3.7 |
| AE | 11–13 | 3 | 20 | 12 | 4.3 |
| Ea | 17–19 | 4 | 17 | 14 | 4.4 |

*The lower slopes of the Millstone Grit plateau*

South and south-east of the Fountains Fell summit, the main soil on the Millstone Grit is peat. Peat rankers on Millstone Grit pavement are also common.

As in the area around the summit, the peat, under *Eriophorum vaginatum*, is strongly eroded giving a landscape of mounds with steep scarred sides, separated by channels of Millstone Grit debris or peaty silt, either free from vegetation or with a sparse cover of *Deschampsia flexuosa* and *Nardus stricta*. The following profile description and analytical data refer to this landscape unit but are also representative of peat in Units A, C and D.

*Profile 7. Peat*

| | |
|---|---|
| Locality: | Fountains Fell (869708). |
| Altitude: | 650 m. |
| Slope and aspect: | 1° SE. |
| 0–12 cm.: Peat 1 | Black (5 YR 2/1) peat with few undecomposed plant remains. Common fine fibrous roots. Merging boundary to: |
| 12–25 cm.: Peat 2 | Dusky red (2·5 YR 2/2) amorphous peat. Few distinguishable plant remains. Few fine fibrous roots. More massive structured than horizon above. Common fungal incrustations. Merging to: |
| 25–85 cm.: Peat 3 | Dark reddish brown (5 YR 2/2) amorphous peat. Massive structure. Slight addition of mineral matter in lower part. Sharp boundary to underlying mineral matter. |

Table 7. *Characteristics of peat*

| Horizon | Depth (cm.) | Loss on ignition (%) | pH |
|---|---|---|---|
| Peat 1 | 5–10 | 91 | 3.7 |
| Peat 2 | 15–20 | 97 | 3.7 |
| Peat 3 | 50–60 | 78 | 3.8 |

Fairly large areas of Millstone Grit pavement occur near the edge of the plateau, especially to the south-west, on which peat rankers have developed beneath a heath-shrub vegetation, e.g. *Calluna vulgaris* and *Vaccinium myrtillus*. These consist of a thin peaty top directly on solid Grit. The following profile and analytical data are representative.

*Profile 8. Peat ranker*

Locality: Fountains Fell (869709)
Altitude: 630 m.
Slope and aspect: 2° S.
0–10 cm.: A — Black (5 YR 2/1) amorphous organic matter with abundant roots of various sizes. No clear structure. Few coarse mineral grains near the junction with underlying rock.
10 cm.+: C — Millstone Grit.

Table 8. *Characteristics of peat ranker*

| Horizon | Depth (cm.) | Loss on ignition (%) | pH |
|---|---|---|---|
| A | 4–8 | 96 | 4.0 |

Also towards the edge of the plateau but more to the south-east, thin rankers composed of mixed peat and Millstone Grit debris occur mainly beneath *Vaccinium myrtillus*. Small areas of peaty gley soil occur as in Zone A.

*Steep shale slopes*

Above 562 m. there is a sharp rise to the Millstone Grit plateau traversing bands of Yoredale limestones and shales. As soil formation on Yoredale limestones is essentially similar to that on Great Scar limestone, only soils developed on the shale bands are described here. There are three main types, a podzolized brown earth, a mesotrophic brown earth and a surface-water gley soil.

Immediately below the Millstone Grit, shallow podzolized brown earths, less than 30 cm. deep, are on shales and more sandy beds, which may be Yoredale sandstone or a sandy facies of Yoredale shales. The soils carry a heath-shrub vegetation, and are particularly well exposed where tributaries of Darnbrook Beck have deeply incised valleys.

*Profile 9. Podzolized brown earth*

Locality: SE slope of Fountains Fell (876712).
Altitude: 592 m.
Slope and aspect: 15° SE.

| | |
|---|---|
| 0–7 cm.: A | Black (5 YR 2/1) organic matter containing small amounts of mineral matter. Moderately developed crumb structure. Friable consistency. Abundant fine and medium, mainly *Calluna*, roots. Merging boundary to: |
| 7–10 cm.: B1 | Brown (7·5 YR 5/2) silt loam with weakly developed sub-angular blocky structure. Friable consistency. Common fine and medium fibrous roots. Few shale fragments. Merging boundary to: |
| 10–13 cm.: B2 | Dark reddish brown (5 YR 3/3) loam with common shale fragments. Strongly developed fine to medium subangular blocky structure. Friable consistency. Common fine fibrous roots. Merging boundary to: |
| 13 cm.+: C | Grey shale. |

Table 9. *Characteristics of podzolized brown earth*

| Horizon | Depth (cm.) | Silt (%) | Clay (%) | pH |
|---|---|---|---|---|
| B1 | 7–10 | 46 | 20 | 4.0 |
| B2 | 10–13 | 39 | 18 | 4.4 |

Mesotrophic brown earths of variable depth have developed on shale where a limestone band occurs immediately upslope. Here, drainage water from the limestone continually supplies calcium to the shale soils below.

The high calcium content helps to maintain a good structure in the upper horizon, giving good drainage, unusual in clay soils under high rainfall.

Because of the flushing effect, these soils carry an *Agrostis-Festuca* association typical of the adjacent Yoredale limestone soils.

*Profile 10. Mesotrophic brown earth*

| | |
|---|---|
| Locality: | SE slope of Fountains Fell (875708). |
| Altitude: | 575 m. |
| Slope and aspect: | 20° SE. |
| 1–0 cm.: | Mat composed of *Festuca-Agrostis* roots. |
| 0–24 cm.: A | Very dark grey (10 YR 3/1) clay. Strongly developed fine crumb structure. Friable consistency. Intimate organic matter. Abundant fine fibrous roots. Common earthworms. Merging boundary to: |
| 24–49 cm.: B | Dark greyish brown (10 YR 4/2) clay. No structure apparent. Few fine fibrous roots decreasing to rare with depth. Common angular fragments of shale. Some earthworm activity. |
| 49 cm.+: C | Weathering shale. |

Table 10. *Characteristics of mesotrophic brown earth*

| Horizon | Depth (cm.) | Silt (%) | Clay (%) | pH |
|---|---|---|---|---|
| A | 6–18 | 35 | 50 | 5.6 |
| B | 28–44 | 44 | 54 | 6.1 |
| C | 54–64 | 38 | 52 | 6.6 |

Slightly gentler slopes have more poorly drained soils. The presence of *Juncus effusus* and *Juncus articulatus*, in particular, in areas of shale soil indicate a surface water gley soil with much organic matter intimately mixed with mineral matter over strongly mottled horizons. Good examples of surface water gley soils occur along the Pennine Way (878710).

*Profile 11. Surface-water gley soil*

| | |
|---|---|
| Locality: | SE slope of Fountains Fell (875707). |
| Altitude: | 574 m. |
| Slope and aspect: | 15° SE. |
| 1–0 cm.: | Mat of *Juncus* and grass roots. |
| 0–14 cm.: A(g) | Very dark grey silty clay (2·5 Y N3). Weak crumb structure. Humose. Abundant fine fibrous roots. Few strong brown (7·5 YR 5/8) concretions. Clear boundary. |
| 14–29 cm.: B1g | Yellowish brown (10 YR 5/8), slightly predominant, and grey (5N) silty clay. Angular blocky structure with grey structure faces. Few fissures. Few fine fibrous roots. Merging boundary to: |
| 29–59 cm.: B2g | Yellowish brown (50 per cent) (10 YR 5/6) and grey (50 per cent) (4N) silty clay. Weak prismatic structure. Common shale fragments. Clear boundary to: |
| 59 cm.+: C | Black (10 YR 2/1) and dark greyish brown (10 YR 3/2) silty clay. No structure apparent. Very abundant fragments of shale. |

Table 11. *Characteristic of surface water gley soil*

| Horizon | Depth (cm.) | Silt (%) | Clay (%) | pH |
|---|---|---|---|---|
| A(g) | 4–9 | 30 | 53 | 5.9 |
| B1g | 17–24 | 28 | 40 | 6.4 |
| B2g | 39–49 | 31 | 43 | 6.5 |
| C | 64–71 | 46 | 30 | 6.5 |

There is also peat on steep slopes, especially the upper parts, where slumping from the Millstone Grit plateau has occurred.

*Boulder clay and bedded slope deposits of the middle slopes of Fountains Fell*

Between 439 and 862 m., the southern slopes of Fountains Fell are more gentle and thick deposits of boulder clay and bedded re-worked boulder clay clothe the solid formation. Most is fine textured, except on islands of Yoredale Limestone and against Darnbrook Beck where there is a greater sandstone influence, giving rise to better drained soils. Elsewhere on these middle slopes, soils are poorly drained with a variable thickness of peat.

Three main soil types have been recognized here, peat, peaty gley soils, and peaty gleyed podzols. All carry cotton grass moor and are strongly acid.

Soils are classed as peat where it is >36 cm. thick and these are most widespread here. Above about 472 m., it is much eroded, exposing drift in places, but there are also smaller areas of active peat growth under *Sphagnum*.

Peaty gley soils are in fine textured drift and consist of up to 36 cm. of peat overlying a grey clay or clay loam with mottling in old root channels.

*Profile 12. Peaty gley soil*

| | |
|---|---|
| Location: | S slope of Fountains Fell (879699). |
| Altitude: | 472 m. |
| Slope and aspect: | 4° S. |
| 7–5 cm.: | Mat composed of many grass and few woody roots. |
| 5–0 cm.: | F layer. Partly decomposed mat. |
| 0–8 cm.: Peat 1 | Black (5 YR 2/1) humus containing few decomposed plant remains. No mineral matter. White fungal incrustations. Merging boundary to: |
| 8–18 cm.: Peat 2 | Dark reddish brown (5 YR 2/2) amorphous peat. Few distinguishable plant remains. More massive than horizon above. Common fungal incrustations. Sharp boundary to: |
| 18–29 cm.: A | Dark grey (4N) silty clay loam. No structure apparent. Friable consistency. Few small stones. Very abundant old root channels. Few living roots. Merging boundary to: |
| 29–49 cm.: Bg | Dark grey (4N) silty clay with strong brown (7·5 YR 5/6) mottles mainly associated with root channels. Some light grey (10 YR 7/1) weathered sandstone. Very sticky. Abundant old root channels. Few living fibrous roots. |
| 49 cm.+: Cg | Dark grey (4N) gritty clay loam. Abundant stones of various sizes and in various stages of decomposition. Few mottles associated with old roots channel. |

Table 12. *Characteristics of peaty gley soil*

| Horizon | Depth (cm.) | Silt (%) | Clay (%) | pH | Organic matter (%) |
|---|---|---|---|---|---|
| Peat 2 | 11–14 | — | — | 3.5 | 80 |
| A | 21–27 | 30 | 39 | 4.0 | 5.3 |
| Bg | 33–47 | 31 | 42 | 6.0 | 3.4 |
| Cg | 53–58 | 33 | 42 | 7.2 | 1.5 |

Peaty gleyed podzols are developed in patches of slightly coarser textured drift. Thin iron pans are more strongly developed than on the same type of soil on the limestone plateau, presumably partly because the peat is thicker.

*Profile 13. Peaty gleyed podzol*

| | |
|---|---|
| Location: | SE slope of Fountains Fell (879697) |
| Altitude: | 440 m. |
| Slope and aspect: | 4° SW |
| 18–12 cm.: Peat 1 | Black (2·5 Y 2/1) peat. Weak, fine crumb structure. Common fine fibrous roots. Stoneless. Merging boundary to: |
| 12–0 cm.: Peat 2 | Dusky red (2·5 YR 2/2) peat. Subangular blocky structure (dry). Common fine fibrous roots. Stoneless. Merging boundary to: |

| | |
|---|---|
| 0–5 cm.: A | Reddish brown (5 YR 3/2) silt loam. No structure apparent. Friable consistency. Few stones. Few fibrous roots. Merging boundary to: |
| 5–14 cm.: AE | Dark brown (10 YR 3/3) silt loam. No structure apparent. Friable consistency. Few stones. Abundant old root channels. Sharp boundary to: |
| 14–15 cm.: Bfe | Thin iron pan. |
| 15–52 cm.: B | Yellowish brown (10 YR 5/4) silty clay loam with light grey (10 YR 7/2) flecks. No structure apparent. Common stones. Rare old root channels. Merging boundary to: |
| 52–82 cm.: C | Dark greyish brown (dominant) (10 YR 4/2) with patches of very dark greyish brown (10 YR 3/2), clay. Plastic. Stone content increasing with depth, mainly limestone. |

Table 13. *Characteristics of peaty gleyed podzol*

| Horizon | Depth (cm.) | Silt (%) | Clay (%) | pH | Organic matter (%) |
|---|---|---|---|---|---|
| Peat 2 | 10–3 | — | — | 3.5 | 78 |
| A | 1–3 | — | — | 3.5 | 35 |
| AE | 6–12 | 29 | 29 | 3.7 | 9 |
| B | 22–32 | 34 | 44 | 4.4 | 1 |
| C | 57–62 | 32 | 41 | 6.8 | 1 |

Table 14. *Ecological characters of soils of the Malham Tarn area*

| Soil type | Parent material | Elevation (m.) | Acidity | | Dominant species |
|---|---|---|---|---|---|
| | | | Surface pH | Subsoil pH | |
| Scree rendzina | Limestone | 335–439 | 6.5–7.5 | 7.5–8.0 | *Sesleria caerulea, Festuca ovina* |
| Clint rendzina | Thin drift over limestone | 335–439 | 4.8–6.5 | 7.5–8.0 | *Festuca ovina, Sesleria caerulea* (Agrostistenuis) |
| Mesotrophic brown earth | Drift over limestone and Yoredale shales beneath limestone outcrop | 335–594 | 4.5–6.5 | 5.0–6.5 | *Festuca ovina, Agrostis tenuis* |
| Oligotrophic brown earth | Thick drift over limestone | 335–439 | 3.7–5.0 | 4.0–5.0 | *Nardus stricta* |
| Peaty gleyed podzol | Thick drift over limestone | 335–439 | 3.7–5.0 | 4.0–5.0 | *Nardus stricta, Carex binervis* |
| Iron podzol | Millstone Grit | 594–668 | 3.7–4.5 | 3.9–4.5 | *Nardus stricta* |
| Peat ranker | Millstone Grit | 594–668 | 3.5–4.5 | — | Shrub heath, e.g. *Calluna vulgaris* and *Vaccinium myrtillus* |
| Peat | Millstone Grit and shale-derived boulder clay | 439–668 | 3.5–4.5 | 3.8–5.0 | *Eriophorum vaginatum* |
| Podzolized brown earth | Yoredale sandstone? and Yoredale shale | 562–594 | 3.8–4.5 | 4.0–5.0 | Shrub heath, e.g. *Calluna vulgaris, Vaccinium myrtillus* |
| Surface-water gley | Yoredale shale | 549–594 | 4.5–6.0 | 5.0–6.5 | *Juncus effusus, J. articulatus* |
| Peaty gley soil | Shale derived boulder clay | 439–562 | 3.5–5.0 | 4.0–6.5 | *Eriophorum vaginatum* |
| Peaty gleyed podzol | Mixed drift on Silurian and Yoredale shales | 439–562 | 3.5–4.5 | 4.0–6.5 | *Eriophorum vaginatum* |

Apart from the rendzinas and mesotrophic and oligotrophic brown earths on islands of Yoredale Limestone in this zone, small areas of non-calcareous surface water gley soil occur in New Pasture north-west of Darnbrook House, and near the foot of Zone C. Bedded slope deposits are also well exposed in Darnbrook and as the movement of slope material postdates the deposition of glacial deposits, the soils on them must be quite young. However, in terms of soil development, both the original and re-worked boulder clay often carry similar soils.

### *Soils on lower limestone slopes of Fountains Fell*

The soils developed here resemble those on limestone discussed earlier, but around the farmsteads most soils under leys have been limed more than those of the limestone plateau and so are less likely to regress to more acid types. It is noticeable however, that where oligotrophic brown earths and peaty gleyed podzols occur, little attempt has been made to improve them and these areas are not given over to hay meadows.

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