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Chapter 15

SOILS

STUDY of the upland soils of the Reserve has been mainly directed towards a detailed 6-in. scale soil survey, to establish the varying types of ground-cover present in the region and the extent of their distribution. It has not been possible to complete a full soil survey of the area and, in particular, routine physico-chemical laboratory investigations are lacking. An investigation of the clay mineralogy of the soils has, however, been made. The organic soils or peat deposits have been studied extensively during the present survey in connection with the determination of the Post-glacial vegetational history of the region. These deposits are more fully described in Chapter 16.

In general the soils of exposed upland regions, such as the Moor House Reserve, have not received a great amount of attention by pedologists who usually work with agriculturalists and are more interested in farming land. Ecological studies of mountain regions have included examination of soils in connection with biological habitats of the mountain flora (*vide* Pearsall, 1950, p. 55 *et seq.*). The intensive interest taken in world food production caused by expanding populations and higher standards of living, has focused attention on marginal land and its development. Scientific work on this problem has already been started on the Moor House Reserve and the potential productivity of regions such as this have been described by Crompton (1958) and Cragg (1958). The only published account dealing with the upland soils of northern Britain is contained in the Scottish Soil Survey memoir on the Jedburgh and Morbattle region, south-east Scotland (Muir, 1956). Part of the area covered by this memoir consists of open upland fells having a similar type of peaty soil complex to the northern Pennines.

Soil Mapping

The Soil Survey of Great Britain use field maps of the standard 6-in. and 1 : 25000 scales and these are reduced to a scale of 1 : 63360 (1 in. to 1 mile) for publication. On this latter scale it should be possible to delineate an area of about five acres but areas smaller than this cannot be shown. The soils of the Reserve shown on the 1-in. scale would be a relatively simple picture. The western region of the escarpment and summit ridge would be shown to have a soil complex* surface cover of hill-peat and skeletal soils derived from the underlying Carboniferous rocks. All the ground to the east of the summit ridge would be mapped as hill-peat. This picture of the soil cover of the Reserve, though accurate at this scale, is of little use for detailed ecological and vegetational studies. Large scale plans have therefore been made by the Conservancy of the Rough Sike

*Any area where two or more types of soil are repeatedly present and change from one to the other in short distances is mapped as a soil complex.

enclosure (1 in. to 5 ft.) and the Greenhole enclosure (1 in. to 20 ft.) on which individual soil pockets and rock outcrops have been mapped. These plans give adequate detail to bring out the differing ecological environments over small areas of the Reserve which are of particular biological interest but the time involved in the construction of large scale plans limits the area of ground which can be covered on this scale. For the rest of the Reserve the soils have been surveyed on an intermediate scale of 6 in. to 1 mile. Much detail of soil variation can be shown on this scale but the complexity of the maps is such that they can not be reproduced at a smaller scale. A simplified soil map of the Reserve is included here (Fig. 19).

The principal functions of a soil survey are to identify and describe soil type and record their distribution on a map. Soils are identified in the field on the detailed morphology of their complete profile. Examination of soils over a region reveals that whilst each has an individual identity some are so much alike that they can be placed into the same primary category. The primary category, both for mapping and for classification, is the soil series. Though two soil series may be quite distinct their common boundary is often difficult to establish. Near their boundary soil series tend to merge together over a distance of some 20 yd. (Muir, 1956, p. 26), and no sharp break such as is found on geological boundaries is usually present in soils.

Soil Classification

The British Soil Survey have given a lead in the methods of soil classification in Britain. This authority groups soil series for mapping over large areas into soil associations. Each association is a cartographic unit containing soil categories developed on parent material derived from the same parent rock. Soils grouped together into an association generally occur in the same neighbourhood and have common properties imparted by the parent rock. Almost all the mineral soils of the Nature Reserve belong to a single soil association developed on till derived from Carboniferous sedimentary rock parent material; small areas of soil developed from other parent materials such as whin dolerite and Lower Palaeozoic rocks belong to other soil associations but are of almost negligible importance here. A different form of classification cutting across the sub-division into soil associations is the division of soils into major soil groups. In this way soil series are grouped according to their profile morphology into gleys, podzols, brown earths and organic soils. Soil series can then be grouped further into divisions, major soil groups and sub-groups according to the environments under which they have formed, and for the present purpose this is more useful.

The different horizons found in soils are identified for comparative purposes by a series of symbols. No standard method of numbering soil horizons has yet evolved in Britain, but the method used here is similar to that used by Robinson (1951, p. 84), with emendations suggested by the Soil Survey (*vide* Muir, 1956, p. 28). The symbols L, F and H refer to the three horizons or organic matter on top of the mineral soil as follows:

L—superficial layer of undecomposed plant litter.

F—superficial layer of partly decomposed plant litter with recognisable plant debris.

H—superficial layer of decomposed organic matter with few or no recognisable plant remains.

These three horizons make up the organic material, humus or peat layer, which forms the surface cover for most of the area of the Reserve. Over much of this region the superficial peat is over 1 ft. thick and is mapped as an organic soil. In these thick peat deposits the L, F and H layers cannot be recognised satisfactorily as the stratigraphy of the profile is normally complex and made up of bands of varying humification. The nomenclature is applicable to the superficial organic layers less than 1 ft. thick.

In the sub-division of mineral soil horizons the symbols A, B, C and D are used in the following way:

A—upper mineral part of the solum. The horizon of maximum biological activity and most subject to the direct influence of climate, plants and animals.

B—lower mineral part of the solum lying between the A and C horizons. It is characterised either by having a high content of sesquioxides or clay or by having a more or less blocky prismatic structure. It is frequently brightly coloured.

C—weathered rock or parent material from which the soil developed.

D—a stratum unlike the parent material of the solum but may influence profile development indirectly.

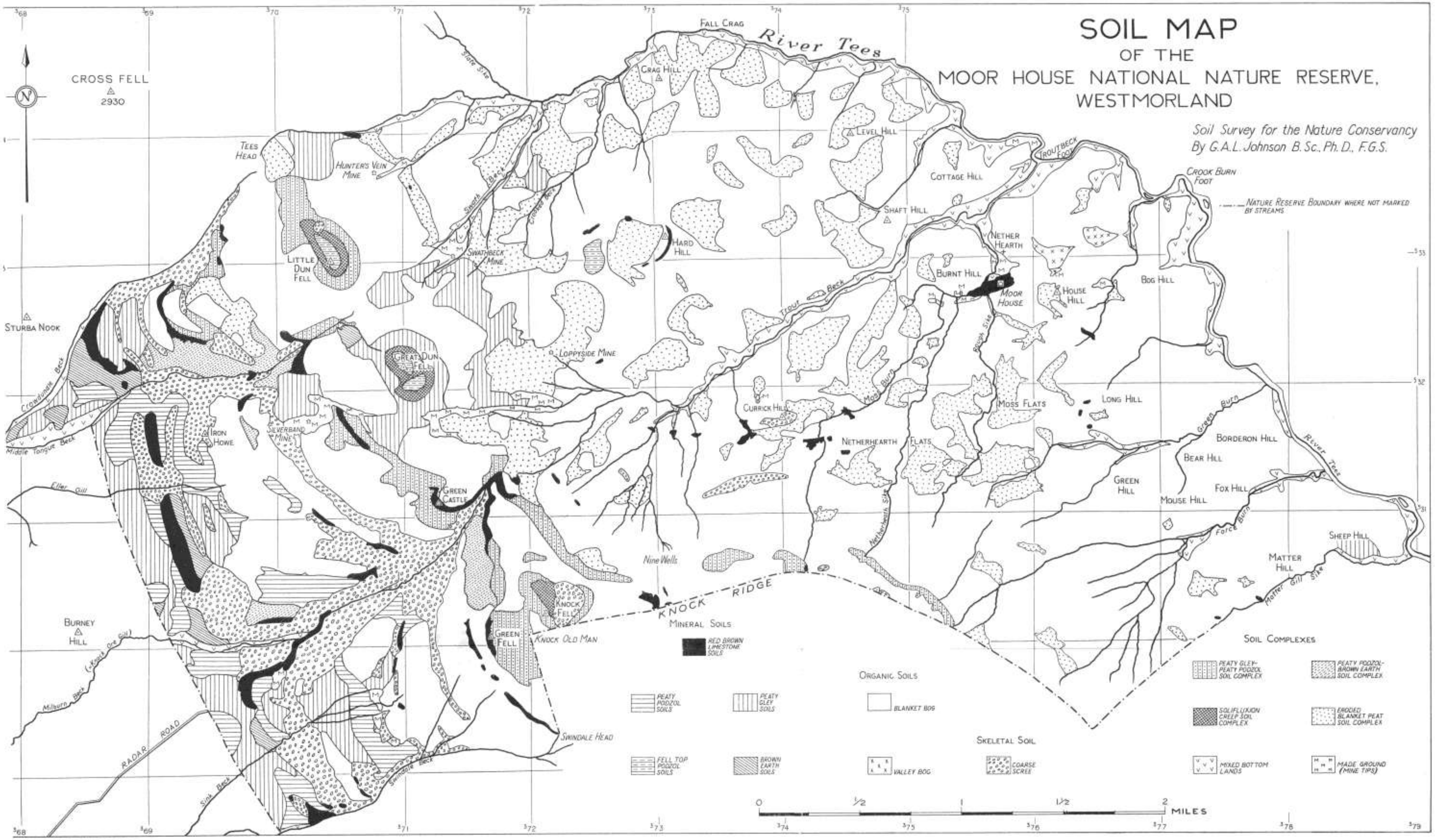
These divisions make up the main mineral soil horizons and can usually be identified without difficulty in soil profiles. All the horizons may or may not be present in any soil profile depending on the type of soil present and in many soils the individual horizons may be further divided into differing layers which are designated A_1, A_2, etc.

On the Reserve soils belonging to several major soil divisions are present including gleys, podzols, brown earths and organic soils, together with skeletal soils of several different types. Gley soils are developed under conditions of permanent or intermittent waterlogging which produces a grey or greenish colour in the mineral horizons often with ochreous mottling. The colours are secondary and normally mask colours inherited from the parent material. Well-drained soils occur in areas of the Reserve where waterlogging is absent. The soils are characterised by the presence of a uniformly coloured B horizon. Two important groups of these soils occur on the Reserve: the podzol group, with strongly differentiated mineral horizons, and the brown earth group in which each soil horizon merges with the one below. Organic soils are formed under waterlogged conditions and are normally developed on strongly gleyed mineral soils. Peat deposits over 12 in. thick are mapped as organic soils. Two types of organic soil deposits are found on the Reserve. On convex slopes and level ground organic soil or blanket-peat is developed, the formation of which is dependent on acidity, low summer temperature and waterlogging of the ground surface due to atmospheric moisture, ground-water springs, etc. In regions of concave relief basin-peat deposits are laid down under the influence of ground water. Basin-peat deposits form in lake basins and owing to the changing habitat caused by the gradual infilling of the basin, complex peat profiles are the rule. Organic deposits are described in detail in Chapter 16.

Thin soils derived from physically weathered material are termed skeletal soils. They are soils in the early stages of development and have ill-defined horizons in the solum. The character of the soils depends either on parent material or parent rock. In some localities the parent material is scree of sandstone, limestone or mixed rocks usually on steep slopes and in other places thin rubble over shattered rock. A peaty top may be present on the skeletal soils on the Reserve.

Areas where changes of soil type take place rapidly and repeatedly are mapped as soil

Fig. 19 opposite.



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soils of the Reserve began to form. The most usual surface deposit in the region is sandstone boulders on clay and sandy-clay. The impervious nature of this drift substrate led to widespread waterlogged soil conditions in the northern Pennines and peat deposits began to accumulate early in post-glacial times (p. 110). At the maximum period of peat-cover these organic soils seem to have spread throughout the area of the Reserve and to have completely covered the flat tops of the fells. 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. Since then widespread peat erosion has started which has already uncovered large areas of mineral soil, particularly on the higher slopes of the fells, and is still actively in progress (p. 145). At the present day the Reserve is mainly covered with peat deposits or organic soils which reach a depth of 12 ft. in some places on level ground. Elsewhere, where peat erosion has re-exposed mineral soils at the surface, tracts of immature and partly mature soil are present. Skeletal soils and soil complexes are of widespread occurrence and under present-day climatic conditions and active solifluxion soils occur on the higher slopes of the fells. Man's influence in the region has been mainly restricted to mining. Considerable areas of old mine dumps, washings, etc., are present in the region and large deposits of boulder fan have been caused by extensive hushing (working hydraulic open-cuts) in the area of the Reserve.

Blanket-peat is the dominant soil to the east of the summit ridge on the Nature Reserve up to the 2500 ft. contour. To the west of the ridge peat deposits are also extensive on the more level ground but are generally absent on the frequent steeper slopes. Peat thickness varies up to 12 or 13 ft. on the flat but average thicknesses are about half this. Details of the stratigraphy of peat deposits are given elsewhere (p. 135) but everywhere consist of ombrogenous blanket-bog overlying soligenous and spring-bog peat. Flushed peats due to calcareous, ferruginous and peaty waters flowing over the bog surface are fairly widespread over the Reserve (p. 140). Basin-peat deposits or valley-bogs occur below House Hill in two small peat-filled drift-dammed lakes. The higher basin called the Upper Valley Bog (p. 147) contains nearly 9 metres of fen- and bog-peat which began to accumulate about 8000 years ago. The Lower Valley Bog (p.135) is smaller but appears to contain the same sequence of peats as the upper bog. Small shallow peat-filled hollows occur at other places on the Reserve but do not contain deposits very different from the surrounding blanket-peat. Peat deposits are described in greater detail in Chapter 16.

In some areas of better drainage, where thick blanket-peat cover is absent, mineral soils of the peaty-podzol group are developed. On the Reserve these areas occur mainly on the higher slopes to the east of the summit ridge and on the western escarpment where they are probably best developed (Fig. 19). These soils have a conspicuous B horizon frequently with a thin iron-pan at the top. They are typical podzolised soils and have the characteristic light grey coloured sandy leached horizon towards the top of the solum. Soils of this type occur on gentle slopes and rounded crests in areas devoid of thick peat cover particularly where the presence of much sandstone debris allows lighter soils to form. Where drainage is to some extent impeded gleyed peaty-podzol and peaty-gley soils are developed and are characterised by conspicuous ochreous mottling in the B. horizon. These gleyed soils, particularly the peaty gleys, are widespread throughout the Reserve in areas of light peat cover. They differ from the permanently waterlogged gleys found below deep blanket-peat by the presence of iron mottling in the B. horizon.

Skeletal soils are of common occurrence in upland regions and occur often on the Reserve in areas free of blanket-peat cover. On steep slopes, particularly below sandstone outcrops, large areas of scree occur on the western escarpment and to a lesser extent to the east of the summit ridge (Fig. 19). These screes form skeletal soils normally of sandstone debris but sometimes of limestone or whin dolerite and sometimes of mixed parent rocks. Other thin and skeletal soils form on drift-free outcrops of limestone, sandstone and whin dolerite. Of these, red-brown limestone soils are most common on the Reserve and are derived from thin drift material altered by contact with the underlying limestone; straight skeletal limestone soils are rare.

The exposed crest and upper slopes of the summit ridge are at the present day subject to a winter climate sufficiently severe to produce solifluxion soils. Two types of soil are at present being formed during the winter months in this region. Unstable solifluxion soils, or creep soils, form on sloping ground and stable solifluxion soils, or polygon soils, form on horizontal or almost horizontal surfaces. The details of solifluxion phenomena present in this area are described in Chapter 14 but the soils produced under these conditions are the concern of this chapter. The unstable creep soils are uniformly bright orange-brown in colour and tend to have coarse material concentrated at the top of the profile and finer material below. They form on slopes which are subject to soil creep owing to summer rain wash and winter solifluxion. The more stable polygon soils occur on the bare flat or almost flat tops of the high fells. Stone polygons are abundant in these areas and though many may date from late-glacial or early post-glacial times others are in active formation at the present time (p. 110). As with the creep soils coarse material is normally concentrated at the surface, with flaggy boulders often standing on end out of the ground, and finer material concentrated below. Beneath the stones there is normally a thin layer of light coloured leached sand overlying a bright coloured yellow-brown B horizon. Thin iron-pan is sometimes developed at the top of the B horizon. These are thus leached soils belonging to the podzol group.

The Moor House Soils

Organic soils, in the form of hill-peat deposits, cover some 70% of the Nature Reserve and being so dominant in the region they are described separately in Chapter 16. The following paragraphs are devoted to details of the mineral soils of the Reserve. Six major mineral soil divisions, all derived from Carboniferous parent material, are present in the region: the gleys, podzols, brown earths, red-brown limestone soils, skeletal soils, soil complexes and solifluxion soils. These groups will be described in this order.

Gleys: Two important types of gleyed mineral soil occur on the Reserve, those with thick peat cover and those with thin peat cover. These soils are normally peaty-gleys though small areas of non-peaty-gley have been mapped in the region. The soils mapped as peaty-gleys have by definition an H layer of superficial peat 12 in. or less in thickness; gley soils overlain by more than 12 in. of peat are mapped as organic soils (p. 114). In general gley soils develop under conditions of permanent or intermittent waterlogging and have grey or greenish-grey coloured mineral horizons with conspicuous ochreous mottling in some cases (Colour Plate 3). Peaty-gleys occur on gentle slopes and level slopes in areas of impeded drainage. They vary from immature gley soils with little indication of horizon development to well developed gley soils. They are mainly restricted to the western escarpment and upper slopes of the summit ridge on the Reserve but occur in small areas throughout the region.

The generalised peaty-gley soil profile is as follows:

Vegetation—Eriophoretum with *Juncus* spp.

Horizon	Depth or thickness	
L	Trace	Litter.
F	Trace	Partly decomposed litter.
H	6″	Very dark brown peat.
A_{1g}	0–2″	Dark brown coloured sandy loam. Mixed organic and mineral layer with many roots. Up-ended sandstone boulders normally present and often rotten.
A_{2g}	2–5″	Pale buff-grey coloured friable loam with sandstone boulders and pebbles; few roots. Sharp change into
B_{2g}	5–16″	Light greyish-buff coloured stiff stony clay with much ochreous mottling. Some sandstone boulders and many pebbles of sandstone and other rocks. Dries with strong blocky structure. Grades downwards into
C_g	16″+	Grey and blue-grey coloured clay with sandstone pebbles and boulders. Ochreous mottling less than horizon above and decreasing downwards.

Under blanket-peat, where the peat cover is over 1 ft. thick, a rather different type of gleyed soil is commonly developed (Colour Plate 4). This gleyed mineral soil differs from the peaty-gleys by the presence of a uniformly coloured grey or greenish-grey solum frequently without ochreous mottling. It is not shown on the soil map (Fig. 19) although it is present below blanket-peat over most of the area of the Reserve. Regions in which this soil occurs are mapped as blanket-peat and it is owing to this overlying deposit that this particular type of gley is developed. Under deep blanket-peat the mineral substrate is kept in a permanently waterlogged state and strongly reducing conditions are developed. The persistent reducing conditions are evidenced by the greenish-grey colour of the solum and the lack of ochreous mottling. In regions of thinner blanket-peat or where there is drainage such that waterlogging is reduced or absent during dry periods ochreous mottling becomes conspicuous and the soils grade towards the peaty-gleys. A similar variation in gleyed soils has been described by Crompton (1952, p. 285) in upland sites of poor or very poor drainage. The sub-blanket-peat gley-soils become important on the Reserve in areas of peat erosion where the thickness of peat is reduced and in some places removed altogether. Generally eroding peat areas do not expose the mineral substrate near the surface over large regions and the sub-blanket-peat gley soils thus form part of a soil complex in which blanket-peat and sub-blanket-peat gleys are the two important constituents. The parent material for the sub-blanket-peat gleys is similar to the peaty-gleys and consists of solifluxion deposits and colluvium derived from the local Carboniferous rocks. Where the sub-blanket-peat gleys are exposed near the surface in eroding peat areas an enriched type of blanket-bog vegetation including *Juncus* spp. and *Polytrichum* spp. is normally present, and with thickening peat deposits some form of Callunetum or Eriophoretum becomes widespread. On blanket-peat ombrogenous blanket-bog vegetation is developed throughout the region (p. 132). The generalised profile description of gleyed mineral soil, sub-blanket-peat gley, below the blanket-peat deposits of the Reserve is as follows:

PLATE 1
Red-brown limestone soil developed over the Five Yard Limestone, Belbeaver Rigg. Limestone below profile is *in situ*.

PLATE 2
Immature red-brown limestone soil over the Great Limestone, Knock Ridge. Light coloured patches in the solum have little enrichment in iron oxides which tends to be concentrated along root channels and other drainage lines. Limestone *in situ* at the base of the profile.

PLATE 3
Peaty gley soil profile with thin L-H horizons. Strong ochreous mottling in the B_{2g} horizon, Knock Fell.

PLATE 4
Peaty gley soil profile developed below thin blanket peat cover, Knock Ore Gill.

PLATE 5
Thin blanket-peat gley soil overlying D horizons and weathered shale above the Great Limestone, Knock Ridge. The iron pan D_1 is developed at the interface between the B_{2g} horizon of the solum and the D_2 horizon formed of weathered shale *in situ*.

PLATE 6
Skeletal red-brown soil developed above the Whin Sill, quartz dolerite, western side of Knock Fell. The Whin dolerite boulders show spheroidal weathering.

Note: White rule equals 6 inches.

Vegetation—Eriophoretum or Callunetum.

Horizon	Depth or thickness	
		Blanket-peat—superficial peat between 1 ft. and 12 or more feet thick.
A_{1g}	0–2″	Dark brown coloured sandy mixed organic and mineral layer with some sandstone boulders and pebbles. Rotten sandstone pebbles and boulders are frequently present.
A_{2g}	2–5″	Pale buff-grey coloured clay with few sandstone boulders. Sharp change into
$B_{2g}C$	5–10″	Light grey coloured stony clay with sandstone pebbles and boulders. The clay is firm when moist and dries with blocky structure. Low organic content. Merges with
C	10″+	Light grey and blue-grey coloured stony clay with sandstone pebbles and boulders. Unaltered solifluxion deposit parent material.

The superficial blanket-peat varies considerably in composition and thickness (Fig. 25) and is usually permanently waterlogged. The top mineral horizon is a mixed organic-mineral layer normally sandy and often containing rotten sandstone boulders. Root channels formed by the initial peat forming vegetation are usually present in the A horizons though no living roots occur. The A_{2g} horizon has the palest colour of all the horizons in the profile. Its composition is normally less sandy than the overlying and underlying horizons and it may consist of firm clay with little or no sandy or stony material. There is a sharp change from this to the underlying little-altered and unaltered stony clay solifluxion deposits which form the parent material of these soils. The B horizon sometimes has reducing conditions indicated by green colouration on pebbles and boulders.

Owing to the mobility of the head or solifluxion deposits during their formation these drifts can be found overlying all other forms of sub-strata. The mineral soils which are developed from thin solifluxion drift parent material have important D horizons formed by the underlying substrate. This horizon though unlike the material from which the solum has developed may influence the solum indirectly. Gley soils with this type of solum development occur on Carboniferous shale outcrops in some parts of the Reserve and can be seen particularly well on Knock Ridge (Colour Plate 5). The following profile can be seen overlying shales above the Great Limestone in this region:

Vegetation—Eriophorum dominant.

Horizon	Depth or thickness	
		Blanket-peat 18 in., dark brown coloured with *Eriophorum* and *Sphagnum* remains.
A_{1g}	0–2″	Dark brown coloured sandy loam with roots. Mixed organic and mineral layer. Grades downwards into
B_{2g}	2–5″	Pale grey and blue-grey coloured stiff clay with sandstone pebbles and boulders. Ochreous mottling very slight or absent.
D_1	5–7″	Bright orange coloured iron pan with irregular top surface. Upper crust indurated and more rusty coloured than the main pan horizon which is of clay consistency. Fairly sharp junction at the base with
D_2	7–12″+	Dark grey coloured rotten Carboniferous bedrock shales showing good bedding.

This soil profile consists essentially of a thin blanket-peat gley overlying D horizons. The iron-pan D_1 is developed at a natural discontinuity or interface between the B_{2g} horizon of the solum, which has formed from solifluxion drift parent materials, and the D_2 horizon formed of rotten bedrock shales *in situ*. The horizon was found to be very moist even during a dry summer spell and is almost certainly a plane of water percolation between two impervious or semi-impervious strata. In the soil profiles of this type the overlying gley soils have been little affected by the underlying D horizons. Elsewhere on the Reserve soils of similar history have D horizons which are of considerable importance in solum development (p. 125).

Podzol Soils: Two types of podzol are present on the Reserve—the peaty gleyed podzol and the felltop podzol. The peaty gleyed podzol occurs in the blanket-peat zone in areas of better than average subsoil drainage. Sloping ground is the characteristic environment for these soils on the Reserve with the angle of slope for their development dependent on the degree of lightness of the solum. A frequently waterlogged acid peaty surface is necessary for the formation of these soils. Peaty podzols are restricted to the upper slopes of the summit ridge and to the western escarpment of the Reserve. The parent material consists of grey coloured stony clay with many sandstone pebbles and boulders and is thus similar to the parent material of the widespread gleyed soils. The generalised peaty gleyed podzol profile is given below:

Vegetation—*Juncus* spp., *Carices* and *Polytrichum* sp.

Horizon	Depth or thickness	
L		Trace.
F	1″	Partly decomposed litter.
H	8″	Very dark brown peat.
A	0–4″	Dull light grey-buff coloured sandy clay loam with rotten sandstone pebbles and boulders. Horizon becomes paler downwards. Many roots concentrated into a mat at the sharp lower boundary.
B_{1h}	4–4½″	Bright orange-brown coloured indurated iron-pan. Hard and cemented with dark upper surface which is not penetrated by roots. Very conspicuous in the solum where it forms a persistent but undulating horizon.
B_2–C	4½–9″	Yellow and buff mottled stiff stony and sandy clay with sandstone pebbles and boulders. Merges downwards into
C	9″+	Grey and blue-grey stony clay solifluxion deposits parent material.

Peaty gleyed podzols of this type have been recorded by Crompton (1956) from northern England who in his paper initially described this soil group. He regards the factors essential to the formation of these soils as the presence of an acid peaty surface generally waterlogged and reasonably good subsoil drainage (*ibid.* p. 159). The most striking feature of the soils is the very hard cemented iron-pan often with a mat of roots lying on its upper surface. This pan tends to form best in lighter sandy soils and in soils of heavier texture a narrow zone of rusty or strong rusty mottling occurs in the place of the iron-pan. Both types of pan are present in the peaty gleyed podzols of the Reserve. Above the iron-pan the A_2 horizon is always a dull light grey-brown in colour and there is normally no accumulation of humus at the base such as is found in other podzols. Below the pan a thin diffuse iron rich horizon (B_2) is normally present but may show indications of gleying and may be absent. Superficial peat is always found overlying the

solum and normally includes a well developed H horizon. The thickness of overlying peat varies between 2 and 10 in. in the region about the Reserve. In this area the peaty gleyed podzols are found in scattered small tracts and they do not form an important soil group.

A normal podzol soil is also present in some restricted areas on the Reserve but is restricted to level ground on sandstone outcrops at or near the top of the fells. The geological structure gives a gentle eastwards dip to the strata of this region and during weathering processes allows wide, almost level, tracts of country to form on the upper surface of thick sandstone bands. On low ground these are extensively drift covered and blanket-peat and gleyed mineral soils are found. Higher on the slopes of the fells, however, these areas are mainly drift free except for thin solifluxion deposits. An abundance of shattered sandstone, much of it rotten in many cases, incorporated in the surface soils causes them to be light and sandy and allows podzols to develop. These are called felltop podzols in this work and occur on the flat tops of Great Dun Fell, Little Dun Fell, Cross Fell and Knock Fell on the summit ridge and also on the top of Hard Hill. They are found overlying the outcrops of three thick sandstone bands: Quarry Hazle, Coal Sills and the Dun Fell Sandstone. An interesting profile through one of these soils was recorded during the excavations of the foundation of the most north-westerly radio-mast on Great Dun Fell in June 1957. A large pit over 9 ft. deep was dug on this occasion which gave the following section:

Vegetation—grasses including *Deschampsia flexuosa* and *Festuca ovina* and lichens.

Horizon	Depth or thickness	
L–F	1″	Black litter and partly decomposed litter with many roots.
A_1	0–½″	Black coloured sandy mixed organic and mineral layer.
A_2	½–4″	Light grey-brown coloured leached sandy clay with many angular sandstone pebbles and boulders.
B_{1h}	4–8″	Black coloured humus horizon containing angular sandstone pebbles and boulders. Sharp boundary at the base with
B_{1Fe}	8–11″	Strong brown coloured iron-pan with sandstone pebbles and boulders. Merging downwards into
B_2	11–19″	Yellow clay with fragments of rotten micaceous sandstone. Merging downwards into
C	19–40½″	Yellow-grey coloured clay with fractured sandstone and flagstone fragments.
	40½–6′ 1″	Yellow-buff coloured soft rotten micaceous flags.
	6′ 1″–9′ 1″	Yellow-buff coloured massive medium-grained sandstone, the top of the Dun Fell Sandstone.

Soil pits dug on Little Dun Fell and Hard Hill (Fig. 21) have proved very similar soil sections in these regions and the felltop podzols seem to be a soil which is characteristic of well-drained sandstone outcrops devoid of deep drift. The soils are normal podzols and have a well developed humus layer B_{1h} at the base of the A_2 horizon. The incipient iron-pan below this is normally friable and not indurated and cemented as is found in the peaty gleyed podzols. The A_0 horizon of superficial mull is normally black coloured and thin usually being only 1 or 2 in. thick. The light sandy texture and free drainage of these soils is brought about by the abundance of rotted sandstone in the solum and is an important factor in their formation. This concentration of sandstone

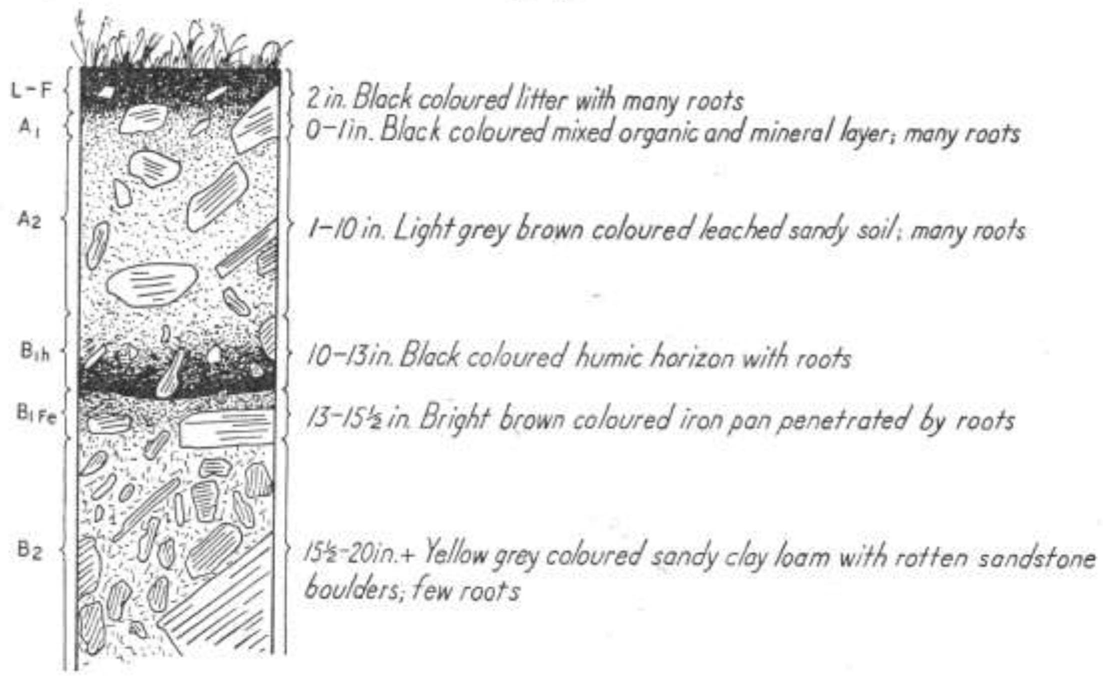

Fig. 21. Generalized felltop podzol soil profile, Hard Hill.

at the surface was brought about by severe late-glacial and post-glacial solifluxion which is thus an important factor in their history of formation. The effect of present-day solifluxion on these soils is only important in regions which have a discontinuous mantle of vegetation. The solifluxion soils are described in a later paragraph (p. 129).

Brown Earth Soils: These soils are characterised by the presence of a uniformly coloured B horizon and horizons which merge one with the other in the solum. They occur mainly on freely drained slopes under conditions of better drainage than the peaty podzols. Brown earth soils also form on flushed slopes particularly below limestone outcrops where base rich water drains over the sloping ground. Soils of this type are restricted to steep slopes on the western escarpment and summit ridge of the Reserve (Fig. 19). They cover areas of only small extent and are not of importance in the region. The generalised brown earth soil profile found on steep slopes on the Reserve is as follows:

Vegetation—mainly grasses.

Horizon	Depth or thickness	
L–F	1″	Black coloured undecomposed and partly decomposed plant litter with many roots.
A–B	0–12″+	Orange-brown coloured stiff stony clay undifferentiated into horizons. Many sandstone pebbles and boulders.

The slopes on which these brown earth soils are found obtain soil enrichment by wet and dry flushing. They are particularly well developed below outcrops of the thicker bedrock limestone bands where base rich water can drain over the ground surface and fine-grained mineral particles tend to be carried down with the solutions. The brown earth soils are well developed below the Melmerby Scar Limestone low down on the western escarpment. Rather similar looking orange-brown soils but of lighter texture than the brown earths occur on steep slopes high on the summit ridge of the escarpment.

These soils belong to the creep soils complex and have a structure indicative of solifluxion movement. They are described under solifluxion soils (p. 129). Other soils superficially similar to the brown earths on the Reserve include the skeletal soils developed on limestone and whin dolerite outcrops. The soils are normally very immature and are described elsewhere (pp. 128, 129).

Red-Brown Limestone Soils: On level and more gently sloping parts of limestone outcrops red-brown coloured clay-loam soils develop which are distinctive and have a pH between 5·5 and 5·8. These soils often occur on a typical hummock-hollow limestone surface and the depth of soil is thus variable. Up to a foot or more of soil may be present in the hollows while the hummocks expose bare limestone or are covered by only a few inches of soil. The clay-loam soils are well drained owing to the presence of underlying porous limestone and are most fertile. On the Reserve to the east of the summit ridge the small tracts of limestone soil form brilliant islands of verdant vegetation surrounded by wide areas of dark blanket-bog (Fig. 19).

The mode of development of the red-brown limestone soils is of some interest as when well developed they show many of the characters of terra rossa soils (Colour Plate 1). The soil profile is relatively simple and consists of a variable depth of red-brown coloured clay loam, sometimes modified in colour by the admixture of humus in the upper horizon, and passing downwards abruptly into bedrock limestone without any marked zone of transition. Soils of this type are called red-brown limestone soils by Robinson (1951, p. 423) who restricts the term terra rossa to the red limestone soils of the Mediterranean region. The exact method of formation of these soils has been the subject of much speculation (*ibid.* p. 424 *et seq.*) particularly the origin of the abundant iron oxide which colours the solum.

In the northern Pennine region the presence of limestone outcrops in different stages of exposure from below drift deposits allows the examination of every stage in the formation of red-brown limestone soils. In some regions small bare outcrops of limestone with thin skeletal soils occur in the bottom of sink holes often surrounded by deep blanket-peat or solifluxion deposits or both. In all cases the removal of superficial peat and solifluxion deposits appears to be mainly due to free underground drainage into the underlying limestone although normal sub-aerial erosion may have produced the initial thinning of the drift cover. Underground limestone drainage carries away not only water but organic and mineral matter from above the limestone. This erosion thins the superficial drifts, allows better drainage conditions to develop and allows the formation of red-brown limestone soils to begin. Initially the limestone is covered by thin drift deposits similar in all ways to the parent material of the widespread gleyed soils of the Reserve. This deposit undergoes chemical and biological changes, partly due to the underlying limestone, and changes into the local red-brown limestone soils. During this period the limestone acts as a D horizon to the solum and appears to influence the development of the solum directly.

As a consequence of the free drainage conditions produced over limestone outcrops during the initial stages of red-brown limestone soil formation the ground cover begins to dry out periodically during the summer months. During these dry periods moisture appears to migrate towards the ground surface from the underlying bedrock limestone, owing perhaps to capillary action, and carries with it soluble bases. In this way the limestone D horizon has an important influence on profile development.

All stages from little altered gleyed drift to quite sizeable tracts of red-brown limestone soil are present on the Reserve. The intermediate stages have not been examined in detail but there is evidence of leaching in the upper part of the solum and concentration of sesquioxides in the lower horizons—apparently a process analogous to podzolisation. Enrichment in iron oxides appears to develop along root channels and other drainage lines characteristically leaving patches of little altered material in the solum. A typical profile of immature red-brown limestone soil is shown on Colour Plate 2, and the profile from this site is detailed below:

Vegetation—Carices, grasses, *Polytrichum* sp.

Horizon	Depth or thickness	
L–F	½″	Black coloured litter and many roots.
A	0–3″	Dark purple-brown coloured clay loam with irregularly distributed areas of lighter grey coloured soil. Crumb structure, many roots, fairly high organic content towards the top. Sharp junction with
B_1	at 3″	Bright orange-brown coloured iron-pan. Very thin (c. ⅛″) horizon and irregular in the solum.
B_2	3–7″	Dull yellow-brown coloured clay with crumb structure. Very irregular base.
	7–9″	Dark brown coloured soft clay with crumb structure containing limestone blocks and fragments. Probably has considerable organic content.
D	9″+	Bedrock limestone with joints filled with dark brown coloured soft wet clay.

The irregular patches of light grey coloured soil are frequently present in the upper part of immature red-brown limestone soils. In many cases they seem to represent pockets of unaltered parent material. The very thin iron-pan mentioned in the soil profile above is an unusual feature in these limestone soils but seems to occur in relatively deep profiles. The B_2 horizon is dull yellow-brown in colour for most of its thickness but at the base changes to a soft brown coloured soft clay which contains fragments of hard limestone. Earthworms are conspicuous in this part of the solum and the soil has well developed crumb structure; the darker colour of this horizon seems to be due to the presence of organic material. This dark brown coloured horizon is found overlying the limestone in many areas where immature red-brown limestone soils occur.

Time seems to be an important factor in the formation of mature red-brown limestone soils for a gradual change takes place in the profiles towards bright coloured orange-brown and red-brown horizons which ultimately spread throughout the profile (Colour Plate 1). During this period of soil development increasing quantities of iron oxide are concentrated in the solum which gives the profile the characteristic colour. A typical mature profile in the red-brown limestone soils is given below:

Vegetation—Grasses, *Thymus*.

Horizon	Depth or thickness	
L–F	½″	Thin litter and many roots.
A–B	0–6″	Brown or dark yellow-brown coloured clay loam with good crumb structure. Not divided into horizons. Fragments of hard limestone towards the base and rests on bedrock limestone.
D	6″+	Bedrock limestone with open joints infilled with soft yellow-brown clay.

The concentration of iron oxide in the A and B horizons of the solum in these soils is brought about by solutions migrating upwards from the underlying limestone. The local bedrock limestones have been found to contain variable quantities of iron minerals including pyrite which is sometimes visible in the rock (p. 71). The source of iron oxide in these soils is therefore clear and the mechanism whereby these salts are concentrated in the solum could be based on capillary action during periods of summer drought. At these periods ground water stored in the limestone appears to become available to the overlying soil in the form of ascending moisture. Support for the theory that the main process in red-brown limestone soil formation is concerned with the action of iron-rich water on locally derived clays is afforded by examination of the clay infilling the joints of some of the larger limestone bands. Cores recovered from boreholes show that some of the thicker limestones contain large open joints which may be partly filled with soft orange-yellow coloured clay. These clay-filled joints are conspicuous in some quarries. The clay infilling in the joints formed underground by the accumulation of insoluble material, mainly ferriferous clay from the vicinity of the limestone, and under the influence of ground water in the limestone. The resulting clay gives similar analysis curves to the red-brown limestone soils (Fig. 22, C and D).

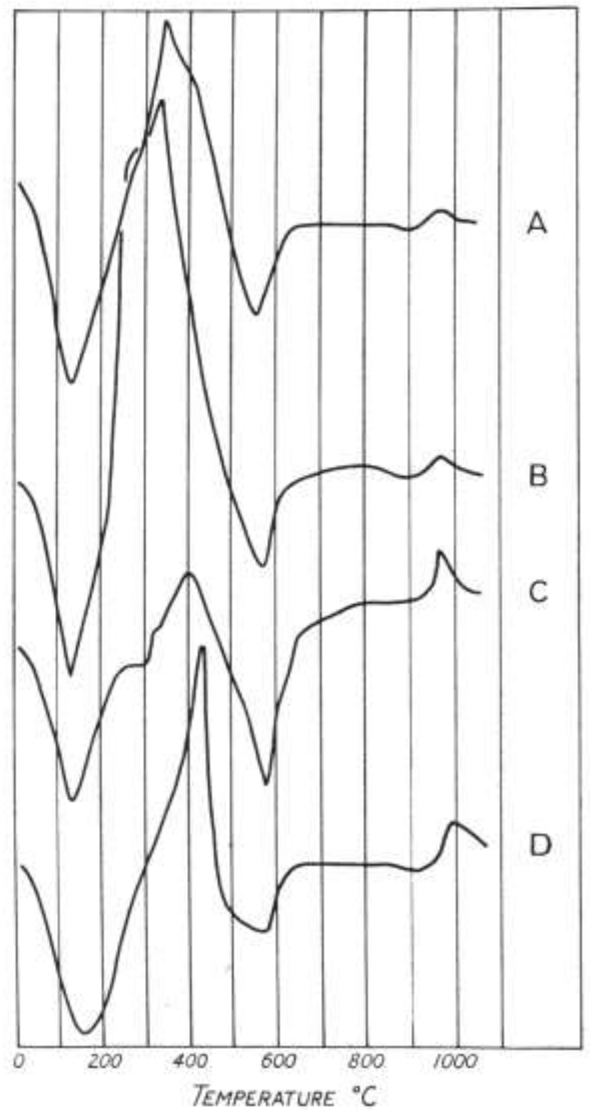

Fig. 22. Differential thermal analysis records of red-brown coloured soils and joint clay.

A Red-brown Whin dolerite soil, Knock Ore Gill.
B Red-brown tuff soil, Greatdale.
C Joint clay from the Great Limestone, Bowes, north Yorkshire.
D Red-brown soil developed on the Four Fathom Limestone, Hard Hill.

The mineral composition of the red-brown limestone soil is initially dependent on the drift parent material and the primary parent material is thus the rocks of the local Carboniferous succession. Clay micas of the illite group are dominant in the argillaceous Carboniferous rocks p. 72) and these clays occur in the limestone soils. The conspicuous change which takes place during the formation of the red-brown soils is the addition of iron salts. The iron rich material was for many years regarded as being partly made up of amorphous iron oxides which was identified by the presence of a sharp exothermic peak at about 320°C on D.T.A. records. Recent work by Taylor (1959) has shown that this exothermic peak in soils is due to organic compounds and that the iron salts present are in the form of crystalline iron minerals.

Skeletal Soils: Skeletal soils form an initial stage in soil formation when unaltered rock fragments are dominant in the solum. Two types of skeletal soil are present on the Reserve—very stony scree soils made up of a mass of angular rock fragments of all sizes and thin immature fine-grained soils, sometimes approaching straight soils,* developed over bedrock. These soils occur throughout the region of the Reserve but the scree soils in particular are mainly concentrated on the western escarpment and the summit ridge (Fig. 19). Thin fine-grained skeletal soils are developed over limestone, whin dolerite and sandstone outcrops but rarely form anything but small areas of soil. Of these soils those developed on limestone are the most extensive and form an important series of biological environments in the region.

The skeletal scree soils characteristically occur on sloping ground below bedrock outcrops (Plate III). Large boulders with finer rock fragments are normally concentrated at the surface overlying a little leached brown coloured sandy loam soil. The most extensive screes found on the Reserve are composed of sandstone debris lying below sandstone outcrops; the Smiddy Ganister, Six Fathom Hazle and Dun Fell Sandstone form particularly widely developed screes. Pockets of vegetation occur among these scree soils which are otherwise devoid of plant cover. *Rhacomitrium* sp. and *Lycopodium* sp. are two plants which occur regularly among sandstone screes high on the fell sides. Other less widespread screes are formed almost exclusively of limestone fragments and occur below limestone crags. These screes are restricted to the western escarpment and are particularly well developed below cliffs of the Great Limestone at Green Castle above Knock Ore Gill. Other screes of this type occur below the outcrop of the Melmerby Scar Limestone near the foot of the escarpment. Reddened base-rich clay soils normally occur below the surface limestone blocks on these screes and pockets of limestone type vegetation are often developed. Whin dolerite screes are restricted to a few places below high dolerite cliffs on the western escarpment and do not cover large tracts of country. Screes composed of mixed rocks, sandstone, limestone and dolerite occur in some places on the escarpment and locally cover large areas of slope.

Skeletal soils developed on limestone outcrops are of considerable interest in the region owing to the distinct flora which they support. In small pockets on the limestone dark coloured grey and black soils containing fragments of unweathered limestone occur in some places and are covered by typical limestone vegetation. These soils are skeletal rendzinas and have some of the highest pH values recorded on the Reserve; values up to pH 8 have been found. They are not of widespread occurrence in the region and are found only in small pockets on the steep face of a limestone outcrop. Of more common occurrence on the Reserve are the red-brown limestone soils which form on level or gently sloping limestone outcrops throughout the region. Though often thin and immature the limestone soils are not regarded as skeletal and they have thus been described in a previous section (p. 125). Sandstone outcrops may have thin dark coloured sandy-humic skeletal soils developed in small pockets but they are not widely developed in the region.

Fertile, red-brown, thin and skeletal soils, rather similar in appearance and texture to the red-brown limestone soils, occur on some outcrops of igneous rock on the Reserve.

*Straight soils have a solum which has developed directly from the underlying bedrock formations.

Soils of this type cover a very small area of ground and are associated with outcrops of the Great Whin Sill (p. 84) and Lower Palaeozoic tuffs of Ordovician age (p. 7). Small patches of immature clay loam soil occur on exposures of the Whin Sill both on the western escarpment (Colour Plate 6) and in the Tees Valley but are nowhere of significant extent. Blanket-peat deposits cover the Whin outcrop over most of the Reserve. Outcrops of tuffs are restricted to the Cross Fell Inlier at the foot of the western escarpment and tuff derived soils only occur on the Reserve in Great Dale near the junction of Middle Tongue Beck and Crowdundle Beck; small patches of red-brown coloured fertile soil occur here on outcrops of tuff. The Whin and tuff soils are similar in appearance and texture and their analysis curves are much the same (Fig. 22, A and B). Their similarity to the red-brown limestone soils also extends to the analysis curves which are readily comparable (Fig. 22). This general similarity of the red-brown coloured soils on limestone and igneous outcrops may reflect similar modes of formation.

Soil Complexes: Any area where two or more types of soil are repeatedly present and change from one to the other in short distances is mapped as a soil complex. Large tracts of ground are covered with variable soils of this type on the Reserve—the most widespread being those associated with areas of eroding blanket-peat (Fig. 19). Here small areas of blanket-peat, bare eroded peat, bare gleyed soil and peaty gleyed soil occur repeatedly over wide tracts of ground. The eroding process leads towards the removal of blanket-peat and the establishment of peaty gley soils recolonised or partly recolonised by vegetation. The proportion of blanket-peat to peaty gley soil in an area of eroding peat soil complex is, subject to other local factors, largely dependent on time. Another widespread soils complex has been called moor edge complex and occurs along the sides of moorland streams. The complex consists of areas of the following soils: blanket-peat, flushed blanket-peat, peaty and sandy alluvium and thin peat on alluvium. This complex can be mapped on the 6-in. scale maps as a narrow band on either side of the larger streams and it is a persistent feature in areas of peat moor. In the vicinity of larger streams a rather different soil complex made up of alluvium, peaty alluvium, blanket-peat and areas of bare drift and bedrock is found which has been mapped under the standard pedological unit called "mixed bottom lands" (Fig. 19). Numerous other small areas of different soil complexes occur on the Reserve but are restricted to few occurrences and small patches. An exceptional man-made soil complex which is extensive in the region is formed by the mine tips and ore taillings which in some areas cover wide areas of ground. These exceedingly variable tip deposits have been mapped under the name "made ground" (Fig. 19).

Solifluxion Soils: Two types of solifluxion soil have been recognised in the northern Pennine region, stable soils which occur on generally level ground and creep soils which are found on high altitude slopes. Stable solifluxion soils are well developed on the flat fell tops on the Reserve and are characterised by the presence of a superficial layer of stones extruded from below by frost action. In some areas rain wash has removed the finer materials and left a thick deposit of stones and boulders over the surface of the ground which is called a blockfield (p. 109). Where coarse and fine material is present at the surface on even ground at high level stone polygons are frequently conspicuous (p. 110). The larger polygons seem to date from late-glacial or early post-glacial times and have been preserved below blanket-peat until re-exposed at the surface owing to peat erosion at the present day. These polygons are active under present day climatic conditions. The soils of stable solifluxion areas are often podzolised and have been described in a previous section under the name felltop podzols (p. 123).

Creep soils occur on sloping ground where soil-wash and soil-creep are active. Soil movement takes place particularly in the early spring when the thawing of the ground liberates much water which saturates the soil and causes it to flow down hill as mud. A superficial layer of stones extruded from below by frost is present above creep soils as well as the stable solifluxion soils. The surface stones are unstable and tend to move down the slope as do larger boulders which are called gliding-blocks (p. 111). The creep soils are orange-yellow in colour and do not develop horizons in the solum. In appearance they are very like the brown earth soils which occur on similar slopes at lower altitudes.