

SOILS OF CORNWALL

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I. INTRODUCTION

The systematic survey of the soils of the country started in 1939 with the formation of the Soil Survey of England and Wales but twenty years passed before a Soil Survey centre was established at the regional sub-centre of the National Agricultural Advisory Service at Starcross and work began in Devon. Soil mapping from this centre has not extended far beyond the Exeter district but the soils of other parts of Devon have been studied from time to time to answer particular requests for information while observations have also been made at widely scattered localities in Cornwall. It is difficult, if not foolhardy, to attempt to describe the soils of an extensive tract of country without the information provided by the frequent inspection of the soil continuum involved when mapping soils at a moderately detailed scale. Thus this account deals primarily with the morphology, composition and genesis of only a few important soil types which are thought to be of considerable geographical extent in Cornwall and contiguous parts of Devon.

Previous work of the Soil Survey in Cornwall amounts only to the unpublished map and report of the soils of Rosewarne Experimental Horticultural Station, Camborne (Tapp and Findlay 1953). Otherwise the only modern accounts of soils in Cornwall are those by Combe and Frost (1956a, b) which describe in considerable detail the soils that overlie the serpentine of the Lizard peninsula and relate them to the principal types of heath communities. A summary of the early accounts of the agriculture of Cornwall is given by Stamp (1941) but, like more recent works, few include much useful information on the distribution of different soil types. Details of the soils given by the writers of the General Views of Agriculture, Fraser (1794) and Worgan (1811), are scant compared with those given by Vancouver (1808) for Devon and are largely repetitions of the observations made by Borlase (1758). The latter divided the soils of Cornwall into three types, "the black and gritty, the shelly,

slatty Soil, and the stiff reddish Soil, approaching more to the nature of Clay", the first being also known as "black grouan" from "growan" the Cornish name for gravel. A short description of the soils is usually given at the end of each geological memoir.

II. GEOLOGY, PHYSICAL FEATURES AND CLIMATE

Most of Cornwall lies on the southern limb of the broad Armorican synclinalorium with an east-west axis that crosses Central Devon. Culm Measure rocks are confined to the north-east of the county being replaced to the south-west by a succession of predominantly hard argillaceous rocks of Devonian and Pre-Devonian age, the outcrops of which are diversified by the post-tectonic granite masses with their girdles of thermally altered rocks. The granite bosses of Bodmin Moor, St. Austell Moor, Carnmenellis and Land's End are not the only expression of igneous activity. Serpentine and gabbro occur in the Lizard peninsula while outcrops of intrusive dolerites or greenstones are widely distributed, being found in the Mylor and Veryan Beds of the Pre-Devonian, the Upper Devonian slates and the Lower Culm Measures around Launceston. Moreover, extensive outcrops of spilitic lava are associated with the basic sills of the Upper Devonian.

The granite masses form the most prominent features of the relief and, although of lower elevation and smaller extent than Dartmoor, are similar reflections of the superior resistance of granite to denudation. Most of Bodmin Moor is between 750 and 1,000 ft. O.D. and includes substantial remnants of an upper erosion surface at 1,000 ft. surmounted by tor-crowned residuals, the highest of which, Brown Willy, rises to 1,375 ft. The other granite masses are considerably lower although the summit of Hensbarrow Downs, St. Austell Moor reaches 1,000 ft. and parts of Carnmenellis and Land's End rise above 800 ft. Apart from this major expression of differential weathering and erosion, the landscape is one of flat-topped interfluvies separating deeply incised valleys. Below the 1,000 ft. platform of Bodmin and Davidstowe Moors successive erosion surfaces are widespread, particularly those at 750 to 800 ft. and at about 400 ft. while summits between 200 and 300 ft. predominate in west Cornwall.

The climate of Cornwall is marked by high rainfall, mild winters and strong winds, with local variations being impressed by altitude and exposure. The range of mean annual temperature is low being, for example, 16° F. at Penzance (January 46° F.; July 62° F.) and 19° F. at Plymouth (January 43° F.; July 62° F.). Most of Cornwall has a mean annual rainfall of about 40 in. In a narrow strip along the northern coast the value is lower but it exceeds 40 in. on high ground, and reaches more than 60 in. on Bodmin Moor. Potential evapo-transpiration amounts to about 21 in. annually being about 17 in. for the summer half of the year (April to September) when the rainfall over much of Cornwall ranges from 16 to 20 in.

III. SOIL PARENT MATERIALS

The weathered debris from solid rocks normally provides the parent material for soil development; the establishment of plant and animal life on and within it initi-

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ates the differentiation of its upper part into a soil profile with demonstrably different layers or horizons. The soil profile at any site results from environmental and biotic factors acting on a particular parent material over a period of time. The influence of each factor is difficult to assess but it is clear that many of the main differences in soil characteristics to be found in Cornwall are related to differences in parent material. In the absence of glacial drifts, soil parent material is usually closely related to the underlying geological formation or parent rock although this is frequently mantled with a thin layer of locally transported rock waste or "head" resulting, for the most part, from mass-movement under periglacial conditions in the Pleistocene period. However, the well-known record of the Hawks Tor pit at 750 ft. on Bodmin Moor (Connolly *et al.* 1950) shows clearly that a phase of solifluction also occurred in early post-glacial times following the Alleröd climatic oscillation. At certain sites the head deposits thicken and Arkell (1943) records that they are often 40 ft. and sometimes 100 ft. thick.

Many of the head deposits show depositional layers of different composition within 3 to 5 ft. of the surface which influence soil profile development (Arkell 1943; Stephens 1961; Clarke 1963). On the Scilly Isles, Barrow (1906) records a relatively stone-free layer of silty material between the Main Head and the Upper Head which he relates to the wind-blown limon or loess of the Brittany coast. Subsequently Combe and Frost (1956b) have convincingly demonstrated the presence of several feet of loess mantling the Lizard serpentine which is not associated with solifluction deposits.

A striking feature of many sections of head is a discontinuity at about 20 in. from the surface between upper layers of friable consistency and crumb or blocky structure and lower layers of extremely compact or indurated material with a marked platy structure. In certain soil profiles the discontinuity is picked out by a thin pan-like seam of iron accumulation. Within the indurated zone, stones have characteristic silty sheaths on their upper surfaces which are absent from the lower parts of the stones. Indurated layers have been observed in head deposits derived from a variety of different rock types but they are particularly widespread in loamy granite head and are recorded from each of the mainland granite areas.

The origin of the indurated lower layers found in a wide range of soils in many parts of the world has been the subject for much controversy amongst pedologists but the explanation of Fitzpatrick (1956) seems most applicable to the soils of the South West. He suggests that the characteristics of the indurated substrata are inherited from the permafrost layer (permanently frozen ground) of the last phase of periglacial conditions, while the upper part of the profile represents the active layer subject to seasonal thaw. The platy structure and dense packing was maintained after slow melting of the laminae of clear ice between layers of mineral soil.

Stewart (1961) has drawn attention to other structures which are well developed in the "relict permafrost" layers in the neighbourhood of Aberystwyth. He describes a system of narrow vertical fissures with light grey margins forming a continuous polygonal network and suggests that the cracks developed by progressive desiccation

of a permanently frozen ground mass. Similar features are known to occur at one locality on Dartmoor and in the clayey head on the foreshore south of Bude. At the latter site, the bands of light grey colour associated with the fissures range in width from $\frac{1}{2}$ to 2 in. and have thin lines of iron accumulation on their outer margins. It should be recorded that a polygonal network of bleached fracture planes also characterizes the extremely compact horizons or "fragipans" found in many North American soils (Soil Survey Staff, U.S.D.A. 1960). The Americans believe however that fragipan horizons, with the features of the indurated layers described above, are developed by soil-forming processes and are not a legacy of events in the Pleistocene period.

Although the geology of Cornwall is complex, most of the soils are developed on a limited range of soil parent materials. On the granites the parent material consists of locally derived head deposits of gravelly loam with a variable stone content. Sometimes the head has a bouldery upper layer, especially on the slopes below a tor where it may be expressed as a surface layer of large stones known as a "clitter". Occasional bands of less stony material with a high silt content suggest that loess has contributed to the solifluction deposits although its presence may be largely masked as a result of cryergic processes since its deposition.

The head often overlies granite *in situ* that has been deeply weathered or hydrothermally altered to an incoherent material readily dug with a spade. The feldspar phenocrysts may be hard and apparently little altered or soft and cheesy and easily cut with a knife. The soils and parent materials of the main areas of kaolinized granite have not been studied. Moreover, little is known of the extent to which petrological differences in the granites are reflected in the nature of the head so that, in this paper, the soil parent material is regarded as being similar on all the mainland granite masses.

On the slates, shales and sandstones of Pre-Devonian, Devonian and Carboniferous age it is often difficult to decide in a soil pit whether the soil has developed on material weathered directly from the underlying rock or on transported material. In many instances solid rock is encountered at less than 3 ft. from the surface but elsewhere 2 or 3 ft. of earthy material overlie a layer of shattered rock debris. Some of the soils on slates have a very high content of quartz stones or "spar" which cannot be accounted for by the vein-quartz in the rock below and suggests loss of fine earth from the weathered material (Reid 1907).

IV. SOILS

From the evidence of scattered observations it can be said that inherently acid, well drained soils of the brown earth group occupy much of the county. They occur on the weathered debris of a wide variety of rock types including slate, shale, sandstone, granite, dolerite and serpentine, the chief differences being related to the nature of the parent material. Poorly drained,¹ surface-water gley soils are only extensively

¹ The recognition of soil drainage classes is based on the colour patterns of the horizons in a soil profile. In general terms, freely drained soils are uniformly coloured with shades of brown whereas poorly drained soils show grey colours with associated reddish brown or ochreous mottles.

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developed on the Culm shales in the north-east of the county where drainage impedance is caused by the slow permeability of both the clayey subsoil layers and the shale substratum. Ground-water gley soils are confined to the narrow strips of alluvium bordering streams and to the margins of the valley bogs of the granite basins.

Soils with a thin surface layer of amorphous peat overlying a thin iron pan are characteristic of the upland moorlands. They are known as peaty gleyed podzol soils and are especially extensive on Bodmin Moor but also occur sporadically on other granite areas and uplands like St. Breock's Down and Davidstowe Moor. Blanket bog, developed widely on the high plateaux of Dartmoor above about 1,500 ft., is virtually absent from the lower uplands of Cornwall, being found only locally on Bodmin Moor. The group of organic soils or peats is only represented by the valley bogs of the basins and valley floors on Bodmin and St. Austell Moors.

Calcareous rocks occupy extremely limited areas so that naturally calcareous soils, containing more than 2 per cent. calcium carbonate, are uncommon. One of the most important calcareous parent materials is the blown shell sand forming the "towans" on the north coast.

In the descriptions that follow an outline is given of some important soils associated with broad groups of parent rocks. Many of the profiles described are from woodlands or semi-natural moorlands where the influence of man is less pronounced than on farmed land. The description of soil profiles involves the use of a number of specialized terms, many of which are defined in the Soil Survey Field Handbook (Soil Survey Staff 1960) while the symbols used to designate particular soil horizons are explained in the Appendix.

1. Soils on the Devonian and Pre-Devonian Slates.

The soils on the slates are predominantly brown earths with free soil drainage. The substratum of hard, argillaceous rocks rarely seems to impede water movement and, despite the moderately fine texture of many of the soils, poorly drained soils are uncommon even on flat or gently sloping sites. On similar rocks in South Devon, where the distribution of soils is better known, gleyed brown earths and surface-water gley soils are confined to occasional low-lying areas of subdued relief and local foot-slope sites. Apart therefore from limited areas of surface-water gley soils, the regional pattern of brown earths is only interrupted by uplands like Davidstowe Moor and St. Breock's Down where the soils are peaty gleyed podzols. The latter moorland, although associated with the outcrop of Staddon Grits, includes appreciable areas where slate is the main source of the soil parent material.

Profiles of brown earths examined at a variety of geomorphological sites overlying slates of different geological age show only a limited range of characteristics. Particular attention was paid to woodland soils and profiles were studied at Bishop's Wood, near Truro, several woodlands near Bodmin, including Dunmere Wood and Great Grogly Downs, and in woods near Gweek, Helston. The following generalized

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profile description of a woodland soil may be regarded as representative of the kind of brown earth occurring widely in Cornwall and South Devon.

L		Thin litter resting directly on mineral soil.
A	0-2 in.	Dark brown (7.5 YR 3/2) ¹ humose loam (mull humus); strong, fine crumb structure; very friable; narrow boundary.
A/(B)	2-10 in.	Brown (7.5 YR 4/4) to strong brown (7.5 YR 5/6) clay loam; slightly stony with small slate fragments; moderate, medium crumb structure; very friable; merging boundary.
(B)	10-20 in.	Strong brown (7.5 YR 5/6) clay loam; slightly stony; moderate, medium crumb structure; very friable, aggregates ruptured by very small force; extremely abundant fine and very fine pores; merging boundary.
(B)/C	20-30 in.	Yellowish brown (10 YR 5/8) clay loam; stony with small slate fragments; weak, very fine sub-angular blocky structure; friable; merging boundary.
C	30-35 in. +	Small slate fragments dominant; matrix of light olive-brown (2.5 Y 5/4) loam.

Such a profile under woodland may have an extremely low base status and a strongly acid reaction, a pH value of about 4.0 at the surface increasing to only 4.5 at 3 ft.

Apart from a thin layer of fresh, undecomposed litter, the profile described lacks a superficial layer of unincorporated organic matter. The humus form is known as mull and results from intimate mixing of dispersed humic substances with the thin uppermost layer of mineral soil, organic residues having been completely decomposed and humified. A mull humus form is not diagnostic of the type of soil formation as apparently identical soils under woodland may have a moder humus consisting of fresh litter overlying a 1 to 2 in.-thick horizon of black and crumbly, amorphous organic matter (H layer) which rests on the surface of the mineral soil. The H layer consists mainly of the droppings of small animals like mites and spring-tails that, in the absence of earthworms, are often chiefly responsible for the breakdown of plant litter. Below the H layer there is sometimes a 1 in.-thick bleached seam above an equally thin seam of reddish brown colour, a sequence of narrow horizons analogous with that described by Avery (1958) as a "micro-podzol" in beechwood soils on the Chiltern Hills. On agricultural land the surface horizons have been mixed and changed by cultivation and the increased biological activity associated with the addition of fertilizers and manures. In this case, the organo-mineral A horizon is of the dark brown colour indicative of well-incorporated organic matter and commonly extends to a depth of 10 or 15 in. before merging to strong brown, sub-surface horizons which can be matched with those of neighbouring woodland soils. (cf. Tapp and Findlay 1953.)

¹ Soil colours are described and named using the names and symbols of the Munsell Soil Colour Chart which provides a standard notation for colours.

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A characteristic feature of the soil is the bright orange-brown colour (strong brown) which, under woodland, extends to within a few inches of the surface. It is usually possible to distinguish a slightly redder (B) horizon between about 10 and 20 in. from the surface but the difference in colour between this horizon and the A/(B) horizon above is only slight. The uniform composition of the clay fraction, as illustrated by the silica-sesquioxide ratios for a profile in Bishop's Wood (Table 1), shows that there has been no differential eluviation of iron and aluminium sesquioxides. Strong brown-coloured soils lacking evidence of podzolization are widespread in other parts of Highland Britain under high rainfall conditions and their development is considered briefly in the short discussion at the end of the paper.

Although little soil mapping has been done on the slates of either Devon or Cornwall it is probable that the soil individuals represented amongst the freely drained brown earths would form a relatively small group of soil series.¹

Few of the soils are sandy and most are of moderately fine texture (silty clay loam, clay loam) or loamy (silt loam, loam) and usually have a high silt content; some soils have the mechanical composition of a clay (>40 per cent. of material with an equivalent surface diameter of <2 μ) although being finely structured, friable and porous and lacking the intractability normally associated with clay soils. The clay content is fairly constant in all horizons, no soils being recorded in the field with the morphology of a *sol lessivé* (Duchaufour 1960) in which a pale-coloured Eb horizon depleted of clay overlies a Bt horizon containing illuviated clay in the form of well marked clay skins observable with the naked eye or lens. However, in one profile similar to that described above, some accumulation of clay with strong optical orientation is seen when thin sections of the strong brown horizon between 15 and 20 in. are examined under the polarising microscope. These accumulations are absent from thin sections of the (B) horizons of other soils with a very similar field morphology.

Little information is available on the distribution and local variation of soils belonging to the sub-group of gleyed brown earths but they may be typified by certain imperfectly drained soils occurring in patches on the Upper Devonian slates at the Ellbridge Experimental Horticultural Station in the Tamar Valley. The profile consists of a surface horizon of dark brown, silty clay loam merging to a (B)(g) horizon of brownish yellow, silty clay with slightly greyer ped faces and weak ochreous mottling within aggregates. In the surface-water gley soils, evidence of extended periods of waterlogging is provided by the well developed, light grey faces of subsoil fissures and the prominent orange-brown mottles within peds. The surface horizon is greyer than that of a brown earth and under old pasture typically shows reddish brown staining on ped faces and rusty tubes around root channels, the surface being overlaid by a thin matted layer of dead and living roots.

¹ A soil series is the principal mapping unit used in detailed soil survey and included soils with the same kind and arrangement of horizons in the profile developed from similar parent material.

TABLE 1: *Composition of the clay fraction in representative soils of the South West*

Genetic Type	Soil Series	Parent Material	Locality	Depth in.	Horizon	SiO ₂ : Fe ₂ O ₃ : Al ₂ O ₃			Molecular Ratios			
						%	%	%	SiO ₂ /Fe ₂ O ₃	SiO ₂ /Al ₂ O ₃	SiO ₂ /R ₂ O ₃	Al ₂ O ₃ /Fe ₂ O ₃
Brown earth	Unnamed	Slaty head overlying Grampound Grits, Lower Devonian	Bishop's Wood, Truro. (SW 825478)	2—10	A/(B) ₁	45.3	14.4	32.5	8.0	2.4	1.9	3.4
				10—15	A/(B) ₂	45.0	13.5	33.7	8.1	2.3	1.8	3.7
				15—20	(B)	43.2	16.4	33.1	6.7	2.2	1.7	3.0
				20—27	(B)/C	44.7	14.1	33.8	8.1	2.3	1.8	3.6
				27—36	C	48.7	11.1	31.6	11.7	2.6	2.1	4.5
Brown earth	Moreton-hampstead	Granite head	Burnicombe Down, Bridford, Devon. (SX 804871)	0—9	A	47.5	16.7	32.6	7.5	2.5	1.9	3.2
				9—12	A/(B)	46.0	18.0	34.5	7.0	2.3	1.7	3.1
				12—22	(B)	43.7	16.3	38.4	7.3	1.9	1.5	3.8
				22—30	C	46.0	12.7	39.7	9.6	2.0	1.6	4.9
Peaty gleyed podzol	Hexworthy	Granite head	Hensbarrow Downs, St. Austell. (SW 998576)	0—3	A	55.9	3.2	32.1	44.5	3.0	2.7	15.0
				3—5	Eag	54.6	3.4	33.0	40.9	2.8	2.6	14.5
				5—9	(B)	46.8	16.7	28.0	7.2	2.8	2.0	2.5
				9—15	C	49.3	12.9	29.2	9.7	2.9	2.2	3.4

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Peaty gleyed podzol soils are not commonly found on slaty parent materials in Cornwall except on upland sites under semi-natural vegetation. Of the two profiles examined in detail, one is on the Slaughterbridge phyllites of Davidstowe Moor (c. 950 ft.), the other being from slaty head on St. Breock's Down at about 550 ft. The latter profile under a wet heath vegetation is more typical of the group and has the following sequence of horizons.

L and F		Absent or very thin.
H	6-0 in.	Very dark brown (10 YR 2/2) amorphous peat ; strong fine angular blocky structure ; greasy ; pH 4.0 ; narrow boundary.
Eag	0-2 in.	Dark grey-brown (10 YR 4/2) loam with paler patches of light brownish grey and common ochreous and rusty mottles ; stony ; weak, fine angular blocky structure ; friable ; mat of roots above the pan ; pH 4.4 ; sharp, irregular boundary.
Bfe	At 2 in.	Thin, irregular iron pan.
(B) ₁	2-8 in.	Strong brown (7.5 YR 5/6) clay loam ; slightly stony ; moderate, fine crumb structure ; very friable ; pH 4.4 ; merging boundary.
(B) ₂	8-20 in.	Reddish yellow (7.5 YR 6/6) silt loam with patches of dark brown to black staining ; stony ; weak, fine crumb structure ; very friable ; pH 4.8 ; narrow boundary.
C ₁	20-80 in.	Stone dominant, mainly small fragments of light reddish brown and greenish grey slate with their long axes horizontal ; matrix of reddish yellow to light brown silt loam ; stones have sheaths of fine earth on their upper surfaces.
C ₂	80 in. +	Bedded slate.

On the flat upland plain of Davidstowe Moor under wet grassland with rush the surface soil consists of a dark, brown, humose, silt loam showing rusty mottling ; it has probably resulted from the mixing by cultivation of a thin superficial layer of amorphous peat and the underlying mineral soil. A thin seam of light brownish grey, silt loam overlies the discontinuous thin iron pan occurring at a depth of 10 in. Below the iron pan, a horizon of strong brown, silt loam extends to 15 in. and has a narrow boundary to the C horizon of light olive-brown, slaty silt loam. The results of mechanical analyses of samples from this profile show that the soil is low in clay (12-15 per cent.) but especially high in the 0.05-0.002 mm. silt fraction (72-75 per cent.). These figures, together with those for a brown earth sampled on a similar parent material near Camelford Station, suggest that the phyllites give more silty weathering products than the bulk of the slaty rocks.

A profile of quite unusual morphology was examined in a mixed deciduous wood on slaty head overlying rocks of the Mylor series near Carclew. Below a surface layer of raw humus, characterized by a relatively thick F horizon of matted and only partly decomposed litter, the profile showed the following sequence of horizons :

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- 0-6 in. Dark grey (10 YR 6/1) silt loam ; stony ; weak, medium angular blocky structure ; friable ; pH 4.1 ; narrow, irregular boundary.
- 6-12 in. Light brownish grey to light grey (2.5 Y 6/2-7/2) silt loam ; stony ; structureless, massive ; firm, brittle ; few pores ; pH 4.4 ; sharp irregular boundary.
- At 12 in. Thin, irregular iron pan.
- 12-18 in. Light olive-grey (5 Y 6/2) silt loam with much strong brown mottling ; stony ; weak, very fine sub-angular blocky structure ; firm ; pH 4.9 ; sharp, irregular boundary.
- At 18 in. Very thin, very irregular iron pan, more weakly developed than that above.
- 18-24 in.+ Pale brown (10 YR 6/3) loam ; very stony ; very firm, brittle ; extremely difficult to dig ; pH 5.4.

The profile has many curious features of which the most unexpected is the grey colour of the horizon below the upper iron pan. The lower iron pan appears to have formed at the upper surface of a fragipan-like horizon and is not an uncommon feature of Cornish soils. The grey, sub-surface horizon is extremely compact, structureless material and closely resembles the bleached *Eag* horizon developed below a thick *H* layer of amorphous organic matter under sessile oak and bilberry in the Nature Conservancy's Yarner Wood near Bovey Tracey in Devon (Clayden 1962).

2. Soils on Culm Shales and Sandstones.

The soils on Culm Measure rocks consisting of shales with subsidiary bands of fine-grained sandstone have been mapped in several parts of Devon but there is, as yet, little information on the soils developed on similar rocks in Cornwall. Soil survey on the Culm shales of Devon revealed a catena or hydrologic sequence in which the soils are closely related to site conditions (Clayden 1964). Well drained, shallow, brown earths mapped as the Dunsford series are associated with steep or moderate slopes while gleyed brown earths or surface-water gley soils (Halstow and Tedburn Series) are found on flat or gently sloping sites. The soils are often more strongly gleyed on footslopes where the soil receives more water than on a ridge top. Vancouver (1808) recognized a similar division of the soils on Culm shales in Devon and on his soil map distinguished broad areas of "Free or Dunstone Land" from poorly drained "Moorlands".

Soils of the Dunsford series have similar characteristics to the representative brown earth profile described on Devonian and Pre-Devonian slate. Below the surface humus layers under woodland the soil shows only weakly developed horizons with yellow-brown or strong brown colours throughout and the texture of clay loam or silty clay loam (30-35 per cent. clay) remains constant down the profile. A pH value of about 4.5 throughout the profile is typical of soils of old coppiced oak woodlands near Exeter. The soil is normally about 18 in. deep but shallow soils are common

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and, where cultivated, consist of little more than a plough layer over the shale substratum, and are referred to as "shillot soils" by many farmers. The chief drawback to the agricultural utilization of land occupied by these soils is excessive slope.

Imperfectly drained soils belonging to the sub-group of gleyed brown earths commonly occupy gently sloping, convex ridge tops where losses of water by run-off are appreciably less than on the valley-side slopes. On farmland, the surface horizon consists of about 9 in. of dark grey-brown, silty clay loam overlying a prismatic-structured (B) (g) horizon of yellow-brown, silty clay with slightly greyer ped faces and orange-brown mottling within aggregates. At about 20 in. this merges to a mixture of shale debris and strongly mottled, light grey, silty clay before reaching bedded shale or shale head.

Surface-water gley soils are developed extensively on both gentle slopes and the flat, high-level erosion surfaces of Mid-Devon and East Cornwall, where pastures are often infested with rushes, and where *Molinia* moorlands are extensive. Soils of this group occupy much of the Forestry Commission's plantations around Halwill where many of the soils were correlated with the Tedburn series mapped in the Teign Valley survey, (Clayden 1964). A representative profile of the Tedburn series under pasture is given below.

- | | | |
|-------------------------------|-----------|--|
| A | 0-7 in. | Dark greyish brown (2.5 Y 4/2) silty clay loam with prominent reddish brown staining on root channels and ped faces ; slightly stony ; moderate, very fine sub-angular blocky structure ; friable ; narrow boundary. |
| (B) _g ₁ | 7-15 in. | Light brownish grey (2.5 Y 6/2) silty clay with prominent orange-brown mottling within peds ; slightly stony ; strong, coarse prismatic structure ; firm ; slow permeability ; merging boundary. |
| (B) _g ₂ | 15-24 in. | Light grey (N 7/0) silty clay with prominent orange-brown mottling within peds ; otherwise as horizon above. |
| (B)g/Cg | 24-36 in. | Light grey (N 7/0) silty clay with prominent orange-brown mottling ; stony with bands and fragments of grey shale ; weakly developed structure ; firm ; slow permeability ; merging boundary. |
| C | 36 in.+ | Grey shale dominant. |

Accumulations of manganese and iron oxides are frequently found in the profile as black cindery concretions or black staining on shale fragments ; the concretions are especially common in the upper part of the clayey subsoil where they may form a cemented band well-known to Devon farmers as "black ram".

Under both wet *Molinia* moor and under coniferous plantations at Halwill Forest the pH value is about 5.0 and varies little down the profile. Exchangeable calcium decreases with depth while the content of exchangeable magnesium shows the reverse trend and is the dominant cation in the layer immediately above the

shales. This is a commonly recorded feature of poorly drained soils. The data of the National Agricultural Advisory Service on surface soil samples show that the phosphate status is very low and may be appreciably lower than that of the freely drained Dunsford series although most soils on Culm shales have low or very low phosphate levels and respond well to regular dressings of phosphatic fertilizers.

The soils dry out in periods of summer drought, when the characteristic pattern of vertical fissures develops in the subsoil. In the subsequent wet period, water moving downwards through the cracks, is held up by the less permeable substratum and quickly builds up towards the surface causing waterlogging of the more finely structured surface horizon. Under these conditions ferric iron compounds are reduced to the more mobile ferrous state. The effects of the gleying process initiated by waterlogging are expressed by the drab colour and rusty stains in the A horizon, and the grey colours of fissure faces in the (B)g horizons which represent iron-deficient zones, iron having been either lost or re-precipitated to form the brightly coloured mottles within peds. In areas of semi-natural *Molinia* grassland a highly humose surface layer may overlie a thin sub-surface horizon that is almost completely grey in colour. The uppermost horizon normally found in a Tedburn soil is probably an old plough layer developed from the mixing of the surface humus and sub-surface bleached horizon.

Agriculturally the soils are some of the most difficult to manage in Devon and Cornwall as the slowly permeable nature of the dense, clayey subsoil and the shale substratum causes prolonged periods of surface waterlogging. The grazing season is short in a wet year, the ground being very easily damaged by poaching, while successful arable cultivation depends very much on favourable conditions in the spring. Thorough land drainage is necessary for the better utilization of the soils.

Most of the plantations of the Forestry Commission around Halwill are on soils of the Tedburn series and many show patches of stunted growth while difficulties have also arisen due to wind-blow. Little difference could be found between the areas of good and poor growth in either profile morphology or chemical characteristics of the soils but trials have shown that the trees emerge from check after application of phosphate fertilizers.

In the district around Bude, sandstones form a much more important part of the Culm succession than in the area studied in Devon. The soils often differ from those described above as they generally contain more fine sand while shallow, loamy soils occur on sandstone or sandstone head. Nevertheless, there is a similar pattern of well drained soils on steep slopes and generally poorly drained soils on gentler slopes. Surface-water gley soils occupy extensive areas as they do in the adjoining part of Devon which is shown on Vancouver's soil map as "Moorland". The variety of soils to be found on Culm rocks and locally derived head deposits is well seen in the cliff sections south of Bude.

Peaty gleyed podzol soils are rarely found on shaly Culm parent materials but sandstone and shale head overlying solid rock in which shale is subordinate to sand-patches of high ground on summits mainly between 750 and 850 ft. They occur under wet heath vegetation on Laneast Down and in Forestry Commission plantations at

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Wilsey Down. Quarry sections at Laneast Down show a considerable thickness of stone. The quarry shows a range of soil profiles but thin iron pan soils are prominent. they are associated with peaty surface-water gley soils and occupy uncultivated between Launceston and Davidstowe, near the southern margin of the Culm outcrop. In one profile the iron pan, at about 8 in. below the surface, is developed above a horizon of strong brown, silty clay loam having a narrow lower boundary at extremely compact, shaly silt loam with a strong platy structure.

3. Soils on the Granites.

Of the granite masses of South-west England, Dartmoor probably has the greatest range of soils and a broad fourfold division may be recognised (Clayden and Manley 1964). Blanket bog, with associated peaty grey soils, occupies the gently sloping summits of the northern and southern plateaux while valley bog and peaty ground-water gley soils are found in the bottoms of the valleys and basins. The uncultivated moorlands of *Molinia* grassland or wet heath surrounding the plateaux have soils of the peaty gleyed podzol group while brown earths occupy the lower north east part where the proportion of enclosed farmland is high.

Blanket bog is virtually absent from the granite uplands of Cornwall because of their lower elevation and consequently lower rainfall. Valley bogs are common in the well defined depressions on Bodmin and St. Austell Moors, shown on the geological map as being floored with alluvium, where the ground-water table is high. Otherwise, peaty gleyed podzol soils cover much of Bodmin Moor while brown earths become the most important soils on the lower and more westerly granites.

The most widespread soils of the north-east part of the Dartmoor granite around Moretonhampstead and on the east of the St. Austell granite around Luxulyan are brown earths while they probably cover much of the Carnmenellis and Land's End granite but very little of Bodmin Moor. The Moretonhampstead series described on Dartmoor has a thick surface horizon of dark brown to almost black, often humose, gritty loam merging to a 3 to 9 in.-thick layer of dark brown colour which is transitional to the strong brown (B) horizon below. The latter consists of gritty loam and has a fine crumb structure and a pronounced, very friable consistency. It merges to the C horizon of dull yellow-brown, gravelly loam which may be indurated below about 20 in. The clay content accounts for about 20 per cent. of the fine earth (< 2 mm.) in the surface soil and decreases with depth to as little as 10 per cent. in the substratum. The soils are naturally very acid and, under acidic grassland with bracken, have pH values of about 4.5 throughout the profile and an extremely low content of exchangeable calcium.

Soils of similar morphology are described in detail from sites near Luxulyan, Constantine and Sennen and, in each, digging was made difficult by an indurated layer at depths ranging from 22 to 30 in. The soil texture is consistently gritty loam throughout but the colour of the (B) horizon ranges from strong brown to yellow-brown.

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The loamy texture and free drainage of these soils enable cultivations to be made throughout much of the year and the surface soil breaks down readily to a friable, crumbly tilth. The ease of cultivation makes the soils especially suited to potatoes of which there is a considerable acreage in the more sheltered parts of West Penwith.

On Dartmoor, peaty gleyed podzol soils (Hexworthy series) occupy much of the wet moorland at lower elevations than the blanket bog of the high plateaux and very similar soils cover most of Bodmin Moor. They appear to occupy only limited areas of high ground on the more western granite masses although an accurate assessment of their total extent is yet to be made. The soils are normally found under a semi-natural vegetation of *Molinia* grassland or wet heath in which cross-leaved heath (*Erica tetralix*), ling (*Calluna vulgaris*) and bilberry (*Vaccinium myrtillus*) are the characteristic heath species.

The following generalised profile description of peaty gleyed podzol soils described on Bodmin Moor and Hensbarrow Downs is equally representative of profiles of the Hexworthy series on Dartmoor.

L and F		Absent or very thin.
H	5-0 in.	Black amorphous peat with abundant bleached sand grains ; strong fine angular blocky structure ; greasy ; narrow boundary.
A	0-6 in.	Black, gritty humose loam ; slightly stony ; weak, fine crumb structure ; friable ; narrow boundary.
Eag	6-8 in.	Dark grey-brown (10 YR 4/2) gritty loam with some ochreous mottles and black humus staining ; pronounced root mat above the iron pan ; sharp, irregular boundary.
Bfe	At 8 in.	Thin, irregular iron pan.
(B)	8-14 in.	Strong brown (7.5 YR 5/6) gritty loam with patches of dark reddish brown particularly immediately below the pan ; stony ; moderate, fine crumb structure ; very friable ; merging boundary.
(B)/C	14-22 in. +	Yellowish brown (10 YR 5/4) gritty loams ; stony ; weak, fine crumb structure ; friable.

Most of the thin iron pan soils of the granite uplands show a similar sequence of horizons to that described above. The surface layer of black amorphous peat ranges in thickness from 3 to 12 in. while the Eag horizon above the pan is seldom thicker than 6 in. and is sometimes masked altogether by humus staining. The iron pan normally occurs at depths of 10 to 15 in. from the surface and traces an erratic but continuous line across a profile face, occasionally pitching 6 in. or more below its mean position. It is about $\frac{1}{8}$ in. thick, the upper half being black and the lower part is reddish brown. The orange-brown horizon below the pan is sometimes absent in which case the pan overlies yellow-brown loam.

Like the Moretonhampstead series under semi-natural conditions, the soil is very acid and strongly base unsaturated. The presence of the iron pan provides an effec-

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tive barrier to water movement so that surface waterlogging is experienced for much of the year. The pan also precludes root penetration so that as rooting medium, the Hexworthy soils are generally much inferior to the deep, well aerated Moretonhampstead soils.

Blanket bog, comprising soils with a surface layer of peat thicker than 16 in. that has formed as a result of excessive precipitation, is mainly confined to the summit plain of Dartmoor where the annual rainfall exceeds 80 in. It is found locally on gently sloping hill tops at about 1,000 ft. on Bodmin Moor as, for instance, on Brockabarrow Common where it has suffered from much cutting. It is unusual to find an iron pan below the thick peat and the mineral soil consists of an uppermost horizon of dark grey, humose loam above a thick horizon of olive-grey or grey, loam or clay loam which merges to the yellow-brown parent material. The whole of the mineral soil is traversed by brown, dead roots which form a conspicuous feature of the profile.

Soils with a thinner layer of peat but lacking the characteristic thin iron pan of the peaty gleyed podzol soils are classified as peaty gley soils but again are only widespread on Dartmoor. Some lack the distinct olive-grey subsoil horizon associated with the blanket bog and have instead a horizon of yellow-brown or brown loam with abundant, fine reddish brown mottles. Soils of this kind are found between 1,000 and 1,100 ft. on the summit of Buttern Hill on Bodmin with peaty gleyed podzol soils on its flanks.

Valley bog and peaty ground-water gley soils form an important group which occurs extensively on Bodmin and St. Austell Moors but has yet received little study. The soils are associated with the basins and valley floors covered with head, and sometimes alluvium, into which water moves from the surrounding high ground. Most of the soils are strongly influenced by the presence of ground-water close to the surface and consist of peaty surface layers of variable thickness overlying grey mineral soil that experiences waterlogging for much of the year.

It has been shown (Reid *et al.* 1910) that the valley basins on Bodmin Moor are associated with zones of kaolinized granite. The peat stratigraphy in the moorland marshes at a number of sites is described by Connolly *et al.* (1950), and up to 10 ft. of peat is recorded.

4. Soils on the Serpentine.

Combe and Frost (1956a, b) have provided a fascinating account of the soils over the serpentine of the Lizard peninsula investigated during their studies of the heath communities. In the absence of soil maps for any part of Cornwall, the work serves to illustrate the complex soil pattern to be found in a small area even where it is underlain by one geological formation. They describe four main groups of soils which are outlined below.

The soils derived from the serpentine itself are freely drained, reddish brown loams and are subdivided into two groups based mainly on depth and the degree of development of a (B) horizon. The first is found on ledges and in pockets on ser-

pentine outcrops and supports the *Festuca ovina*-*Calluna* heath type. The soil is rarely more than 6 in. deep and is described as a brown ranker, a variant of the ranker group of soils which embraces soils consisting of little more than an organo-mineral surface horizon resting directly on rocks other than limestone (Kuebiena 1953). Soils of the second group, associated with *Erica vagans*-*Ulex europaeus* heath, are 8 to 16 in. deep and are correlated with the eutrophic braunerde of Kubiena. All the soils are of high base status and Combe and Frost report that magnesium is the dominant exchangeable cation. Very similar soils are mapped as the Trusham series on diabase intrusions in the Lower Culm rocks of the Teign Valley near Exeter. (Clayden 1964.)

Two other main soil types are described as being developed partly in material weathered from the serpentine and partly in loess that overlies much of the plateau. Broad depressions and shallow valleys on the plateau with *Erica vagans*-*Schoenus nigricans* heath have poorly drained gley soils with an anmoor humus form (Kubiena 1953). The soil is normally 18 to 22 in. deep with a silty clay texture in all horizons although mechanical analysis of a representative profile shows more than 40 per cent. clay only in the horizon immediately above the serpentine. A profile described by the author under the same heath type on Goonhilly Downs was a surface-water gley soil developed in about 2 ft. of silt loam with 65 per cent. silt (0.05-0.002 mm.) overlying varicoloured clay merging into weathered serpentine at 30 in. The three horizons sampled above 24 in. have pH values of 5.6 but the value increases to 6.3 in the horizon of very sticky and plastic clay adjacent to the rock. It is interesting to record that the very low content of exchangeable cations increases sharply in the clay which is 90 per cent. base saturated, magnesium accounting for more than 90 per cent. of the total exchangeable cations.

The fourth group of soils is associated with nearly level areas on the plateau with a vegetation poor in species in which *Agrostis setacea*, *Calluna vulgaris*, *Erica cinerea*, *E. tetralix*, *Molinia caerulea* and *Ulex gallii* are usually co-dominant. The soils are developed in 3 ft. of loess overlying a thin clayey layer above the serpentine. In brief, the profile consists of a humose surface horizon above a discontinuous, nodular iron pan which overlies mottled subsoil horizons. The reaction is strongly acid in the surface but becomes neutral in the horizon above the serpentine. Soils showing these features are regarded as a type of podzol soil with gleyed subsoil horizons.

The work of Combe and Frost shows that major differences in soil characteristics are associated with previously unrecognized, thin spreads of superficial deposits overlying the serpentine. As soil survey progresses in parts of unglaciated Britain, more and more soils are being identified which are developed within thin layers of locally transported materials rather than on material weathered from the rock below.

V. DISCUSSION

The brown earth is the most widespread type of soil formation in Cornwall. The brown earths on slates show little tendency to podzolization despite the extremely

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low percentage base saturation found in woodland soils, and, in the absence of B horizons of illuviated clay, may be correlated with the sub-group of *sols bruns acides* (Duchaufour 1960). Some of the granite soils may be regarded as transitional to the podzol group and correspond approximately to *sols brun podzoliques* included by Duchaufour in the group of *sols podzolique*. The soils developed on basic and ultra-basic igneous rocks unaltered by thermal metamorphism are often of high base status and correspond closely to *sols bruns melanisés* of Duchaufour and entrophic braunerde of Kubiena (1953). Cornwall lacks parent materials of siliceous sands and gravels on which humus-iron podzol soils are found in other parts of southern Britain, and evidence of podzolization is mainly confined to the higher moorlands where soils of the peaty gleyed podzol type are extensively developed.

The brown earths so widely represented in Cornwall commonly have very bright orange-brown colours, crumb or very fine sub-angular blocky structures and very friable consistencies. These morphological features, together with very low base status, are also found in the strongly leached brown earths of the hills of Britain described by Crompton (1960). In the latter soils, formerly regarded as either "truncated podzols" or "creep brown earths", the silica/sesquioxide ratio of the clay fraction is low, especially in the surface horizon, and appreciably less than 2 which has been taken as typical of brown earths. He suggests that, under conditions of low temperature, high rainfall and free drainage in the subsoil, weathering is weak but leaching is intense so that there is a considerable loss of bases and silica with the result that the residual clay fraction is sesquioxidic and has a low ratio. The data for two soils regarded as brown earths in Table 1 suggest that the clay is sesquioxidic and may provide testimony to soil formation under conditions favouring weak weathering and strong leaching.

Peaty gleyed podzol soils are thought to develop either from humus-iron podzols or from brown earths but it is likely that most of those on the uplands of the South West were formerly brown earths under deciduous woodland. It is suggested that the equilibrium was upset by woodland clearance followed by the spread of heathy and grassy vegetation the litter of which was instrumental in causing the mobilization of iron in the upper part of the profile. If the horizon found below the iron pan was the former diffuse Bfe horizon of a humus-iron or iron podzol it could be expected to have a particularly low silica/sesquioxide ratio but this is not the case in profiles sampled on Dartmoor and Hensbarrow Downs (Table 1). Moreover, when thin sections of undisturbed soil taken from subsoil horizons of the Moretonhampstead and Hexworthy series are examined under the petrological microscope they show very similar fabrics and only within the immediate vicinity of the iron pan does the peaty gleyed podzol soil show evidence of illuviated iron. The hypothesis suggested for Dartmoor, that the iron pan soils and the brown earths are derived from a common ancestor of brown earth type, may be equally true of other parts of the South West.

Although much of Cornwall receives an annual rainfall in excess of 40 in., gley soils have a very limited distribution. They are most extensively developed on the

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Culm shales in the north of the county where, on gentle slopes and flats, the soils have sub-surface horizons of dense, impermeable silty clay which are absent from the brown earth soils of adjoining steep slopes. It has been suggested (Clayden 1964) that the weathering of the shale substratum to give clayey soil horizons is strongly influenced by the quantity of water received at a site and by its rate of loss, so that clay formation may be considerably greater on subdued slopes than on steep slopes favouring rapid run-off. A similar relationship of soil development to slope is seldom found on the more highly metamorphosed slates of the Devonian and Pre-Devonian formations which seem to provide more pervious substrata.

ACKNOWLEDGEMENTS

Thanks are due to Dr. D. A. Osmond for valuable criticism and advice. For the analytical results the author is indebted to his colleague Mr. C. L. Bascomb.

APPENDIX

Horizon Nomenclature (after Avery, 1964)

Organic and organo-mineral surface horizons.

- L Undecomposed litter.
- F Decomposing litter.
- H Well decomposed humus layer, low in mineral matter.
- A Mixed, mineral-organic layer.

Sub-surface horizons.

- E* Eluvial horizon, depleted of clay or sesquioxides.
- Ea Bleached (ash-like) horizon in podzolized soils, depleted of sesquioxides and clay.
- Eb Brown (paler when dry) friable, weakly structured horizon, depleted of clay, characteristic of *sols lessivés*.
- (B) Altered horizon without appreciable depletion of, or illuvial enrichment in, colloidal material; distinguished from the overlying A horizon and from underlying C horizons of less altered material by colour and structure.
- B Altered horizon containing illuviated material.
- Bt Horizon containing illuviated clay, characteristic of *sols lessivés*.
- Bh In podzolized soils, horizon of maximum deposition of humus.
- Bfe In podzolized soils, horizon of maximum deposition of iron.
- C A horizon that is little altered, except by gleying, and is either like or unlike the material in which the overlying horizons have developed (where two or more distinct depositional layers occur in the lower part of the profile, they are designated C₁, C₂, etc.)
- (B)g) Mottled (gleyed) horizons subject to waterlogging; where gleying is only weakly expressed the suffix (g) is used.
- Cg)
- A/C) Horizons of transitional or intermediate character
- (B)/C)

When a particular horizon is subdivided the component layers are designated for example A₁, A₂, or (B)₁, (B)₂, etc.

* Such horizons have been commonly designated A₂.

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