WELSH SOILS

DISCUSSION GROUP

Report No. 8

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'UPLAND SOILS'

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Soil Science Dept

Univ. of Aberdeen

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UPLAND SOILS

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PART I

THE PARENTAGE OF UPLAND SOILS

D. A. JENKINS
U.C.N.W., Bangor

Upland soils in Wales are derived from a wide range of parent materials, and many of their distinctive properties, such as actual or potential nutrient status, mechanical composition and colour, can often be related directly to their particular parentage. This dominance of the effects of the lithology and mechanical composition of parent materials is due to the relative immaturity of these soils, pedogenesis having been initiated only some 10-20,000 years ago on the amelioration of the climate following the last glacial period. In considering upland soils, it is therefore useful to deal with the factor of parentage first, and this will be treated as far as possible in general rather than specific terms.

SOLID GEOLOGY

General relationships between upland regions, such as Wales, and their solid geology are not necessarily simple or easy to establish since they involve the events of some 500 million years of the earth's history. The actual existence of an upland region as geomorphological feature must be be explained geologically in terms of crustal movement, change of sea level and rates of erosion. Present day upland Wales probably owes its origins to a combination, over the last 5-10 million years, of (a) intermittent local crustal uplift,

(b) a general fall in sea level, and

(c) a relative resistence of the solid rocks involved to the processes of erosion.

The detailed reconstruction of events is still rather tenuous and controversial (T. N. George, 1961) and need not be pursued further here.

The detailed solid geology of Wales is well described in the two Regional Memoirs (B. Smith and T. N. George, 1961; J. Pringle and T. N. George, 1948) and only a brief summary is given below (Fig.1). The rocks are of Palaeozoic age and consist mainly of non-calcareous varieties of shales and grits; these originated as marine sediments deposited in a broad NE-SW trough. They range in age from: Cambrian strata, exposed mainly in the Harlech Dome, and flanked

by younger.

Ordovician strata, exposed in Snowdonia and the Cader Idris area where they are characterised by the presence of numerous igneous intrusions, extrusions and tuffs, both acidic and basic in composition. These in turn are overlain by

Silurian strata, exposed in the Denbigh moors and Middle Wales, and also to the east in the Welsh borderland where they become calcareous and include beds of limestone.

These rocks are now exposed as the roots of a deeply eroded mountain chain formed during the Caledonian orogeny which reached its culmination towards the end of the Silurian period. They were compressed, hardened and folded by pressure (mainly NW-SE, often transforming shales to slates), subjected to low grade regional metamorphism, and intruded by acidic and basic magma. The effects can be traced through the events of subsequent geological time to the present day where they can be recognised in the nature and structure of the rocks. Younger rocks which followed are:

Devonian sandstones, mudstones and marls formed under more arid continental conditions, and characteristically red in colour ("Old Red Sandstone"). These are exposed typically in the Brecon Beacons and are overlain by

Carboniferous shales, and massive limestones and sandstones, the most extensive exposures of which form the rim of the South Wales Coalfield, with Coal Measures occupying the centre.

These Upper Palaeozoic rocks suffered relatively little alteration and deformation during the Hercynian Orogeny that occurred toward the end of the Carboniferous Period, and during subsequent earth movements.

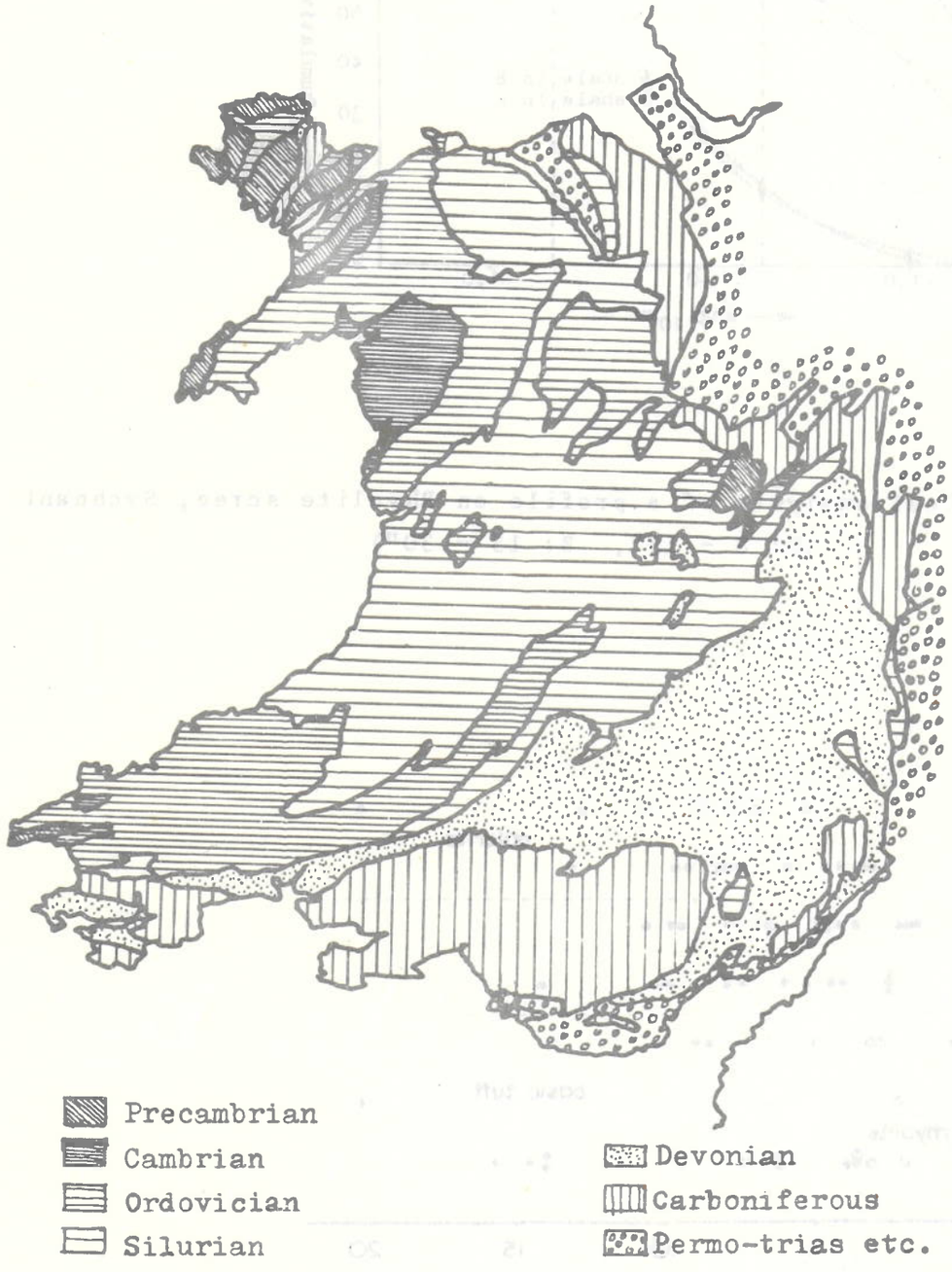
Thus there is a wide range of sedimentary and igneous rock types forming the parent materials of soils in Upland Wales.

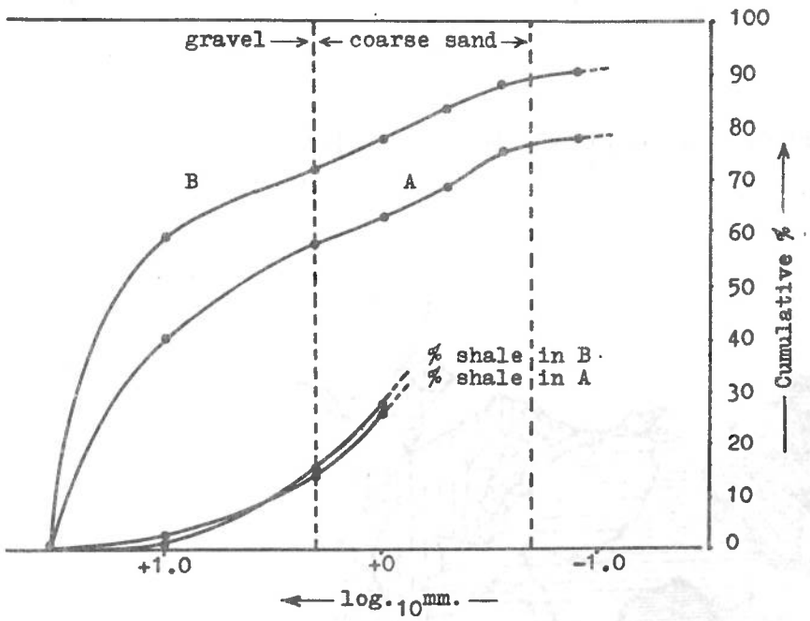
SUPERFICIAL DEPOSITS

The majority of upland soils in Wales are not sedentary, but are formed on deposits derived from the solid rocks by a variety of erosive processes. There are exceptions, as in the case of soils forming on rocks that weather particularly rapidly due to mechanical weakness or chemical instability, for example the soils derived from basic vitric tuffs in Snowdonia (Ball, 1963). Generally, however, the main problem that soil parentage poses is concerned not so much with the details of the solid geology, but with the mineralogical and mechanical composition of the superficial deposits. It is therefore

Fig.1

Simplified Geological Map of Wales





ig.2

Mechanical analysis of a profile on Rhyolite scree, Sychnant.
(A: 8 - 15", B: 15 - 30")

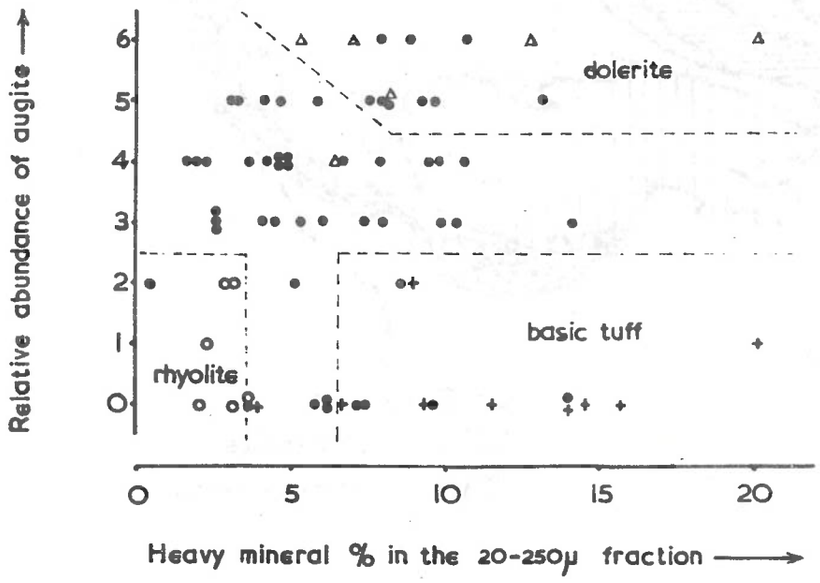


Fig.3.

A possible scheme for the Classification of soil parentage in Snowdonia based on Heavy Mineralogy.

(Reference soils: o - rhyolite, Δ - dolerite, + Basic Tuff)

necessary to consider the nature and origin of these deposits in some detail, particularly since they frequently bear no genetic relationship with the solid rock immediately underlaying them.

During the Pleistocene period (2m. y. - 10,000 yrs. B.P.) upland Wales in general suffered successive and extended periods of intensive glacial and periglacial erosion. This occurred on a world-wide climatic deterioration, but the regions of higher altitude, being cooler, became the initial sites for the accumulation of snow. In the case of Wales, the snow ultimately developed into minor ice caps with the ice releasing its potential energy by flowing downwards and outwards onto the surrounding lowlands as valley glaciers. This movement of ice involved considerable erosion of the land surface and transport of material and resulted in a radical change in upland topography. In adjacent areas rock debris was formed and redistributed by periclacial processes.

Pre-existing soils were stripped off during such periods or, more rarely, buried under glacial or periglacial debris. It is the latter deposits that then formed the starting point for a new cycle of pedogenesis. One generalisation that can be made about such deposits is that they originated by essentially physical processes of weathering, the low temperatures precluding significant chemical weathering: chemically unstable rocks and minerals therefore persisted in the deposits, but in a comminuted state. On the subsequent rise in temperature and onset of pedogenesis, chemical weathering and the release of nutrients into the soil system would therefore be relatively rapid.

Glacial Deposits

Glacial deposits can take the form of the typically unsorted boulder clay or till, consisting of a relatively uniform, indiscriminate mixture of different sized rock fragments derived from the various rock types exposed in the path of the glaciers: sandy, clay-rich or boulder-rich tills can be formed depending on the mechanical properties of the source rocks. Glacial deposits may also take the form of fluvioglacial silts, sands and gravels, resorted by the pro- and sub-glacial meltwater: these have the patchy, localised distribution typical of lake deposits eskers, kames etc. An important aspect of such glacial deposits as soil parent materials is therefore their very variable and often unpredictable mechanical composition.

Glacial erosion and redeposition involves the intermixing or rock debris and its translocation laterally along valley sides, and even

in some instances, across present-day divides and ridges. Often this does not effectively complicate soil parentage. For example, where the petrology is fairly uniform over a large area of uplands, as in the case of the Silurian shales and grits of the Denbigh moors, the precise source of rock material of any particular deposit is of little significance. Also, where the geology is complex but the ice moved parallel to the structural "grain" of the area (i.e. parallel to the rock outcrops) there is little intermixing of rock types; this is the case in (lowland) Anglesey.

However, where glaciers moved perpendicular to the "grain" of an area of complex geology, and thereby across rock outcrops, soil parentage is more complicated. This is the case in Snowdonia where the solid geology is complicated by the combination of the rapid variation between the different sedimentary and igneous rock types in the Ordovician strata, and the contorted structure produced mainly by the Caledonian orogeny, dips ranging from horizontal to near vertical. Consequently where valleys cut across the NE-SW "grain", as in the case of the Llanberis and Nant Ffrancon, there is a rapid alteration of rock type exposed which the moving ice transgressed.

Periglacial deposits

The composition of superficial deposits in upland Wales is further complicated by periglacial processes of erosion which operated in areas margining those actually glaciated. Periglacial phases of varying duration therefore formed interludes between glacial and inter- and postglacial periods in the glaciated zones producing further modification of glacial deposits.

During periglacial phases, intense physical weathering pervailed, mainly due to frost action. This resulted, for example, in the many fossil screes that can now be recognised under steep slopes in upland Wales (e.g. Ball, 1966), and in the solifluction deposits on the lower valley sides. The nature and distribution of these deposits is dealt with by Watson (1967) who has established their importance in Mid Wales. They obviously have an important influence on the mechanical composition of the soils derived from them, and on their physical properties - for example, the indurated subsoil zones ascribed to permafrost, described by Stewart (1961). Their effect on parentage, however, is not so confusing since the source of material is more predictable, movement having been down slope. The same applies

to the more modest postglacial and present day processes of hill-wash, -slip and -creep, although again their effects should not be underestimated, particularly on mechanical composition.

Other periglacial processes redistribute rock material in a different manner. Fine grained material, picked up from outwash plains unprotected by vegetation, is transported by the winds moving out from ice caps and can be redeposited as extensive, deep deposits of loess in lowland regions: its effect in upland Wales can also be detected as will be discussed below.

THE PARENTAGE OF SNOWDONIAN SOILS

It is evident that in an upland region of complex geology such as Snowdonia, soil parentage cannot be assessed by reference to "solid geology" maps, even where these are available on a sufficiently detailed scale. It is possible to find, for example, in an area mapped as dolerite a soil derived from rhyolite drift resting on the dolerite surface which still shows glacial striae: the dolerite has apparently contributed little material to the soil, having acted only as a physical support. Nor would "Drift" maps necessarily be adequate if these were available, since they do not indicate the composition of the drift: also, they only register substantial thicknesses of drift whereas 6 inches or less is sufficient to influence markedly the properties of a soil.

Parentage must therefore be assessed by reference to the inorganic fraction of the soil itself. But this also may be misleading since a differential distribution between size fractions of material from different rock types is involved, and this is determined by the mechanical properties of the source rocks and their component minerals. For example, detailed examination of Snowdonian soils suggests that massive fine grained igneous rocks (e.g. rhyolites) contribute mainly to the stone and gravel fractions: massive coarser grained igneous rocks (e.g. dolerites) also contribute stones and gravel sized material, but in addition yield cleavage fragments of individual constituent mineral grains to the sand fraction: by contrast, the contribution from mechanically weak rocks (e.g. shales) increases with decreasing particle size, with maximum contribution to the silt and clay fractions. This is illustrated by the analysis of a profile developed on rhyolite scree in the valley called Sychnant (Fig. 2) which shows an increasing proportion of shale in the finer fractions and a contribution of dolerite to the fine sand fraction, estimated approximately from the "heavy mineralogy" as described below.

Field examination of stones within a profile can therefore give a misleading impression of parentage, where a variety of rock types contributed. It is the resistant, inert varieties (e.g. rhyolite) which persist as stones, whilst softer materials of greater potential significance in a soil's chemical properties (e.g. shale) do not. Ideally the composition of the whole inorganic fraction should be assessed, particularly the clay fraction, but unfortunately the techniques and background information have not yet advanced sufficiently to indicate whether clay mineralogy could be of diagnostic use as far as parentage is concerned. At present the best compromise is to examine the mineralogy of the fine sand fraction (e.g. 60-200): normally the most suitable procedure is to isolate the small percentage of "heavy minerals" (i.e. S.G. 2.95) in which rarer, more diagnostic mineral species are concentrated. Contributions from particular rock types can then often be recognised and assessed semiquantitatively by the presence and abundance of distinctive indicator mineral species or assemblages (e.g. Smithson, 1953, 1961).

During a survey of the trace element status of soils from Nature Conservancy research plots in Snowdonia, this method was used to establish soil parentage (Jenkins, 1964). It was found that contributions from different sources were characterised as follows:

Rhyolitic rocks - zircon, anatase; heavy minerals 4%

Doleritic rocks - augite, actinolite, clinozoisite
heavy minerals 5-20%

Basic Tuffs - varied; titanite, rutile or manganilmenite,
heavy minerals 6-20%

Shale - euhedral tourmaline, "Powys" chlorite
(Smithson, 1953).

A satisfactory semiquantitative scheme for establishing parentage in terms of the rhyolite, dolerite and basic tuffs was devised by using heavy mineral % and augite abundance as parameters (Fig.3).

An interesting point which arose from this study was the rare occurence of a number of distinctive mineral species which have not been recorded in the solid geology of Snowdonia itself. These include, typically, the metamorphic minerals kyanite, staurolite, andalusite and glaucophane. The first three mineral species are characteristic of the "Red Northern Drift" that fringes North and West Snowdonia, and they presumably originated in Triassic deposits on the floor of the Irish Sea (Smithson, 1953); glaucophane occurs in schists of the Mona complex in Anglesey. The most reasonable explanation for the presence of grains of such minerals in soils at altitudes of up to 2,000' in the

centre of Snowdonia is erosion and selective transportation by wind under periglacial conditions. A similar cause of mineralogical contamination of some Glamorgan soils has been suggested by Crampton (1961). There is therefore a small, but significant, extraneous contribution to the parent materials of certain Snowdonian soils.

CONCLUSION

Under certain circumstances, the parentage of upland soils may be simple and easy to establish, but normally parentage should not be taken for granted. The distribution of parent materials in upland Wales has been complicated by glacial transport and by periglacial processes such as solifluction and aeolian transport: material is still being redistributed by the erosive processes operating on steep slopes. Parentage is therefore a factor which should normally be established, preferably by mineralogical examination of the finer fractions of the soil: its importance in relation to mechanical composition should also be borne in mind.

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DISCUSSION

D. A. Jenkins agreed with D. F. Ball (Nature Conservancy, Bangor) that the presence of traces of contaminants in the heavy mineral fraction of soils implied a considerably larger contamination of the lighter fractions.

THE GEOMORPHOLOGICAL FACTOR IN UPLAND SOIL FORMATION

EDWARD WATSON

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This paper is based mainly on field work in Mid-Wales but its conclusions are broadly true of most of the Welsh uplands, except possibly part of the northwest. In Mid-Wales there is increasing evidence that the last major geomorphic processes were associated with a periglacial phase of considerable intensity or duration. The soils of upland Wales have developed largely on periglacial deposits.

The processes responsible for these deposits were, in the main, slope processes, involving the movement of debris downslope. So the deposits are essentially valley deposits. In plan one is dealing with valley patterns. These are broadly two; the open shallow valleys of the upland plateaux which occupy the great central tract of Wales as well as much of the northeast, and secondly the deeply incised valleys with steep sides, characteristic of the upland plateaux margins, but often penetrating deeply into the plateaux.

These valley deposits may be subdivided into

1. solifluction deposits, characteristic of the open valleys of the uplands;
2. screes, associated with the steep slopes of the deeper valleys;
3. stream-laid gravels of the valley floors, found in both types of valley.

Solifluction deposits

"Solifluction is a comparatively slow downslope creep of soil masses", (Dahl, 1956, 273); the surface has a more or less continuous cover of vegetation. In spite of the name it does not consist of great mud flows; these occur from time to time in the present-day tundra but they are relatively uncommon. It has long been established that solifluction occurs in debris that freezes ice-stratified, and that silt-sized material is the most susceptible, (Taber, 1929 and 1930, and Beskow, 1935). During freezing, thin layers of ice and soil are formed parallel to the surface, and silt permits a ready migration of water from the lower still unfrozen subsoil to the growing ice layers, tending to concentrate the water near the surface. These ice layers after thawing, form wet planes of dis -

continuity in the soil, which encourage a downhill movement under gravity, although the vegetation tends to act against this. Thawing in summer takes place from the surface downwards so that the downhill movement is greatest there and dies out at a depth of 20 - 70 cm.; (Smith, 1960; Dutkiewicz, 1961; Rudberg, 1964). The movement is more rapid on steeper slopes, (Rudberg 1962 and 1964; Budel 1963), so that if the slope decreases towards the stream, aggradation occurs, producing smooth concave terraces of debris. These "solifluction sheets are composed of an unsorted till-like mass of stones and fines of all sizes", (Washburn, 1947, 89), as several observers have stated. The included stones are angular to sub-angular and may be striated, so that Heim (1885, 449) referred to solifluction debris as "pseudo-glacial deposits in regions of frozen ground".

Sheets of stony clay are common in the upland valleys of central Wales and have long been interpreted as boulder clay. Two features have thrown doubt on this interpretation. One is their smooth concave terrace form and their frequent occurrence on one side of a valley only. The second is the close relationship between the development of of the terrace and the nature of the hill slope at its rear. This relationship has three aspects, in order of importance, rock type, height of the rear slope and orientation of this slope.

Some rocks break down under frost weathering to joint blocks and produce little in the way of fines, such as the Lower Ordovician Volcanics surrounding the Harlech Dome, or the Cambrian Grits of the Rhinogs in the heart of the Dome. On such rocks solifluction is of little importance; rocky boulder-strewn slopes are common. The mud-stones on the other hand break down by freeze-thaw to produce abundant silt and build up impressive solifluction terraces.

On a single rock type, a slope of great vertical extent produces more debris than a lower one. In a single valley, the height of the terrace bluffs can be seen to rise as the height of the valley side increases. Valleys rising on a plateau surface on the other hand tend to shallow out towards their source and the solifluction deposits die out upstream although altitude is increasing.

Given the same lithology and height of valley side, a slope facing northwest, north, northeast and east has at its foot a thicker solifluction terrace than one with the opposite orientation. The central axis of the relatively unfavourable arc, between southeast and west, points south-southwest towards the sun in the early afternoon.

This close relationship between the development of a solifluction terrace and the hill-slope at the rear not only explains the frequent asymmetrical development of these terraces in a valley, but means that

the great part of these deposits must be of slope origin, and not merely glacial deposits whose surface has been smoothed by solifluction. Confirmation of this is provided by the internal structure of the terraces; the weak stratification of the "till" where seen, is parallel to the existing surface slope; interbedded gravels which occur dip consistently with the surface slope and thicken downslope; the long axes of the embedded stones show a statistical preference for a direction sub-parallel to the surface slope, which as Lundqvist (1949) showed, is the case in solifluction deposits.

These terraces of compact, impervious stony clay, usually covered with peat, have been recorded in the upland areas west and east of the Central Wales watershed, as far northeast as the Berwyn Mountains and as far south as the Brecon Beacons, (cf. Lewis, 1966).

Screes

Where steep slopes are dominant, the typical slope deposits are screes. Here again there is a close link with rock type. The volcanic rocks or the Cambrian grits of North Wales, which break down to large joint blocks, produce block screes forming a fairly steep and constant slope. The closely jointed or cleaved rocks produce smaller debris with a lower angle of rest. On cleaved mudstones, the thin platy debris may form smooth concave slopes which merge into valley terraces or the valley floor.

The screes consist of a series of coarser open-work beds alternating with finer compact muddy beds and have many points of resemblance to the grèzes litées of France, though the latter are very much thicker, (Watson, 1965b). Y. Guillien who has made an intensive study of these grezes litees, concludes that their development was associated with snow banks on the valley sides; (1964). During the period of melting, these provide a steady supply of moisture for continued reduction of debris by freeze-thaw, producing the fine muddy beds. The coarser open-work beds he believes to be the result of occasional washing by snow meltwater. The beds have come into position by mud flow and sheet flow (water); (Guillien, 1954 and 1957). In some of the exposures in Mid-Wales the fragments involved are to some degree edge-rounded.

The stratified screes lie at lower angles of rest than gravity screes, and may be in part responsible for the concave profile of many of the valley sides. In the Tal-y-llyn valley, screes resting on river gravels, have a surface slope as low as 1°. Thus they frequently underlie cultivated land at the hill foot, ("colluvium", with a surface

slope of 1-5°).

The three-fold series of valley-side screes form thick deposits; in a recent paper on northern Wales, D. F. Ball quotes as typical in exposures, a thickness of 4-9 metres, or 12-30 feet, (1966, 159). The thickest exposures known to the author are in the Tal-y-llyn valley. The pit at the head, Bwlch Llyn Bach, (site 1, Watson 1965b, 22), had a backwall of 60 feet without reaching rock at its base. Another pit on the Tal-y-llyn Railway near Dolgoch, 4½ miles south-west of Tal-y-llyn Lake showed 40 feet. Scree slopes face all aspects, (Ball, 1966, 154-5), but the exposures so far recorded, which include the stratified scree (bed 2, above), face between southeast, southwest and west, (Watson, 1965b, 23-24). The preferred slope orientation is the opposite to that most favourable to solifluction. With all aspects, however, the uppermost bed on which the Post-glacial soil has developed is a relatively coarse unsorted free-draining scree.

Screes, including stratified screes, occur in the upland valleys on the steeper slopes (e.g. Bwlchystyllen pit, site 6, Watson 1965b, Photo IIb, and Ponterwyd, site 10, ibid., Photos 1a and 1b). They are more widespread in the deeper valleys.

Valley Floor Deposits

Under permafrost conditions, the very active slope processes tend to obliterate the smaller tributary valleys, especially where these have a low gradient. The surviving streams have a very irregular regime compared with those of the temperate zone. In winter, the groundwater is frozen, precipitation is in the form of snow and streams are generally deeply frozen. With the general thaw, the rate of discharge increases very rapidly and remains high for 2-6 weeks, subsequently falling off to a low level. During this period of flooding a very high proportion of the annual load is carried. Aggradation on a braided flood plain is characteristic. In the Mid-Wales area the valleys of the larger rivers show a series of unpaired alluvial terraces not only in their lower valleys but also in the more gently graded stretches of their upper courses. Dissected alluvial cones at the confluence of steeply-graded tributaries are common, again not only in the areas of deep dissection but also in the more open valleys of the uplands, such as the Rheidol above Ponterwyd. The maximum aggradation by the rivers occurred before the end of the periglacial phase as screes and solifluction deposits overlie the rear edges of the highest river terraces, as can be seen in the Tal-y-llyn, the lower Rheidol and lower Ystwyth valleys.

Other Periglacial Deposits

These three deposits, together with the rock outcrops of the higher ridges and the boulder-strewn plateaux, make up a very high proportion of the surface of the Welsh uplands and form the parent material of its mineral soils. Other periglacial features occur which do not occupy a large area but support the thesis of an overriding periglacial environment. Such are the pro-talus moraines built up by debris sliding down steeply inclined snow banks and accumulating at their foot. Examples are the curved moraine-like ridges of blocks found along the northern face of the Cader Idris escarpment, or opposite Llyn Bach scree pit at the head of the Tal-y-Llyn valley, or below Cwm Tinwen in the upper Ystwyth valley (Watson, 1966). The widespread involutions and wedge structures (Watson, 1965a), not only suggest widespread permafrost, but the existence of wedges in screes, (in one case clearly dating to the period of the upper scree; Watson, 1965b, Phot Ia), and in the terrace gravels, (the wedge in the Dysynni terrace being partly filled with fragments of the overlying scree; Watson 1965a, Plate 16b), shows that it persisted almost to the onset of the Post-Glacial period. The discovery of casts of Sub-Arctic pingos on a gravel fan in a "dry" valley near Llangurig, (Pissart, 1963a) and of large solifluction lobes on gentle upland slopes between the Severn and the Banwy, (Pissart, 1963b) fits in with the evidence of solifluction terraces in valleys such as that of the upper Wye.

Glacial deposits are relatively rare in these uplands, though they may in places be buried by soilfuction deposits. They are a feature of the fringes, on the coastal strip and along the eastern border. Where they do occur in the uplands they are small, heavily soliflucted and subdued.

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DISCUSSION

V. I. Stewart (U.C.W., Aberystwyth) asked what the relative importance of aspect and the original pre-periglacial valley morphology were?

E. Watson replied that there seem to be three main factors involved in deciding the scale of solifluction terrace development, in order of importance lithology, vertical extent or length of slope, aspect. If the pre-periglacial valley sides had either a different lithology or height, then these factors would probably override aspect.

D. Jenkins (U.C.N.W., Bangor) enquired whether geological structure was not also important?

E. Watson replied that it might produce an asymmetrical valley cross section (e.g. at the excavation for Nant-y-Moch Dam across the Rheidol valley). It might be important where the valley sides are approximately the same height and of the same lithology, as at the dam, and where aspect was "neutral" as in a NNE-SSW trending valley.

C. Crampton (Soil Survey Cardiff) commented that the structure of the O.R.S.

country is simpler than that in mid-Wales; there the terraces tend to be on W. and S. facing slopes, that is, the opposite to that in mid-Wales.

J. M. Hodgson (Soil Survey, Wolverhampton) asked whether the streams in the valleys were cut into bed rock or alluvial gravels?

E. Watson replied that the streams are frequently cut in rock. In a number of cases the terrace consists of superficial deposits in its upper part; the lower part of the bluffs and the stream channel are in rock. In the larger valleys there may be a floor of alluvial gravels and the river may flow between alluvial terraces, with the bluffs of solifluction deposits rising above. There is as yet no clear evidence that these stream channels in rock are due to a lateral shift of the stream as the solifluction deposits build up on one side.

W. Adams (U.C.W., Aberystwyth) requested Mr. Watson's views on three points:

1. the relative rates of solifluction movement compared with temperate hill creep,
2. the gradients necessary to cause solifluction,
3. the importance of the lack of vegetation roots in solifluction.

E. Watson replied that the evidence is as yet inadequate to give a precise answer to 1.

2. Modern solifluction has been reported on slopes as low as 1^{o}. The surface slopes of the solifluction terraces in the upper Rheidol are rarely less than 3^{o} but presumably the material was moving at this angle when the onset of the Post-Glacial halted it.

3. The lower density of plant cover under solifluction conditions is important, but plants are by no means absent under conditions of present-day solifluction. In most areas there appears to be a considerable amount of vegetation present which slows soil movement to a creep, rather than a flow.

D. F. Ball (Nature Conservancy, Bangor) asked whether the solifluction deposit was formed by a reworking of previous drift, or by direct weathering of solid rock?

E. Watson replied that the solifluction deposits may conceal in-situ glacial deposits in the lowest parts of the valley cross-section. Till deposited during an earlier glacial phase would also be incorporated in the lower layers and there is evidence that some such soliflucted till occurs. But the mass of the material in the terraces was in his opinion, derived from periglacial weathering of the rock slopes forming the valley sides above the solifluction terrace. Only this can

explain the consistent correlation between the thickness of the superficial deposits and the nature of the slope at whose foot it lies. In many valleys one can see the solifluction deposits thinning away as the vertical extent of the valley slope decreases and this may operate in a downstream direction as well as upstream. This argument from the distribution pattern is borne out by the stratigraphy of the terraces. These consist of interbedded waterlaid gravels and "stony clays". Where seen, the dip of the bedding is with the surface slope.

D. F. Ball (Nature Conservancy, Bangor) asked whether solifluction deposits were limited to original gently sloping surfaces as terraces in the Brecon Beacons appear to be associated with steep as well as with gentle slopes.

E. Watson replied that the evidence of the Aberystwyth area suggests that where the valley slope was steep from the valley shoulder to the floor, the debris of frost weathering moved rapidly and accumulated as screes. Solifluction probably occurred on more gentle slopes, with slower downhill movement during which a considerable proportion of the debris was broken down to silt and small gravel. Slopes of up to 30^{o} rising abruptly above a solifluction terrace with slopes of $5-6^{o}$ are seen but the evidence of the few tributaries dissecting the solifluction terraces in the upper Rheidol basin suggests that the solifluction deposits at the upper limit of the terrace are thin and that they rest on a rock substratum which slopes at an angle a little greater than the surface slope of the terrace. On the steeper slopes above the terrace, any superficial deposits are of the scree type. It was during the transport across the more gentle lower slope that this was further broken down to a stony clay.

UPLAND CLIMATES AND SOIL FORMATION

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Climate is but one of the factors of soil genesis. The climatic elements which play an active part in soil formation are temperature and moisture. This discussion will be concerned primarily with an examination of the aspects of these climatic elements which have distinctive features in the uplands, and thereby provide a different climatic environment for the development of the soil compared with the lowlands. Otherwise climatic conditions, which influence the characteristics of both upland and lowland soils, will be determined by the regional climate.

Moisture

The amount of water moving over the surface of the soil, or percolating through it to the ground water, the height of the water-table and frequency and duration of dry spells, when capillary action may produce an upward movement of ground water, are features of particular interest. We are concerned, therefore, both with the total precipitation and with the rate and intensity of the fall. Furthermore the temperature of the water has a bearing on chemical reactions in the soil.

Precipitation

We must consider the characteristics of precipitation in the Welsh uplands. Rainfall amounts increase with height in an irregular fashion which defies any successful attempt to define a general mathematical relationship. The average rainfall for Wales as a whole is 53 inches per annum, whilst for areas over 500 feet O.D. the average has been calculated as 61.1 inches (Howe, 1960). Not inconsiderable areas receive over 80 inches per annum, with a number of the Snowdonian stations frequently recording over 160 inches in a year, with a record fall of 246.68 inches in 1912 at Snowdon, No.4 gauge (2,500 feet). In wet years many upland gauges collect over 100 inches, for instance 59 in Wales, especially in Caernarvonshire and Merionethshire, in October, 1960. At a given height, uplands in the east are much drier than those in the

west or south-west, and indeed may have rainfalls below the wetter lowlands on the western coastal fringes (Fig. 1).

The wetness of the uplands can be expressed in another way according to the amounts received over specified periods. Wet months, notably October and November, can yield totals of 20 to 30 inches at many upland stations, with an extreme example provided by the 56.54 inches collected at Llyn Llydaw No. 9 gauge (1480 feet) in October 1909. Wet spells, extending over two adjacent months, can produce a large volume of water which has to be dealt with by run-off or percolation, for instance 61.70 inches which fell at Snowdon, Crib Goch (2340 feet) in October and November 1929 (Oliver 1958). Heavy daily falls result from steady precipitation over several hours rather than intense convectional rainstorms (such as many occur in south or south-east England) over short periods of time. Only one of the 13 recorded falls in Britain of over 8 inches in a rainfall day is from Wales, that at Lluest Wen, Rhondda (1280 feet) on 11 November, 1929 (Met. Office 1934, 1958, 1960 a and b). There are numerous instances of quite extensive areas receiving over 2.5 inches. (cf. Met. Office, undated). December 3rd 1960, provides a good example (Fig.2) of such a regional fall over upland south-east Wales in Glamorgan, Monmouth, Radnor and Brecknock (Met. Office 1960 c). Considerable run-off will result from a fall of 4 inches or so over a catchment, especially when the soil is near or in a waterlogged state. Intense falls in short periods do, of course, occur (see Met.Off. 1957, 1958, 1963 a) as the following samples will show:-

19/8/1958	Clydach	1.56	inches	at	a	rate	of	4.68	inches	per hour
18/7/1955	Gnoll Reservoir, Neath	3.32	"	"	"	"	"	1.66	"	"
6/6/1955	Pontypridd, Coedpenmaen Road	2.92	"	"	"	"	"	4.38	"	"
22/9/1949	Presteigne, Radnor	2.75	"	"	"	"	"	2.06	"	"
4/7/1915	Abergavenny, The Chain	2.20	"	"	"	"	"	4.40	"	"
26/6/1895	Churchstoke, Montgomeryshire, Nellington Hall	4.80	"	"	"	"	"	2,40	"	"
22/7/1880	Cowbridge, Ash Hall	2.90	"	"	"	"	"	5.80	"	"

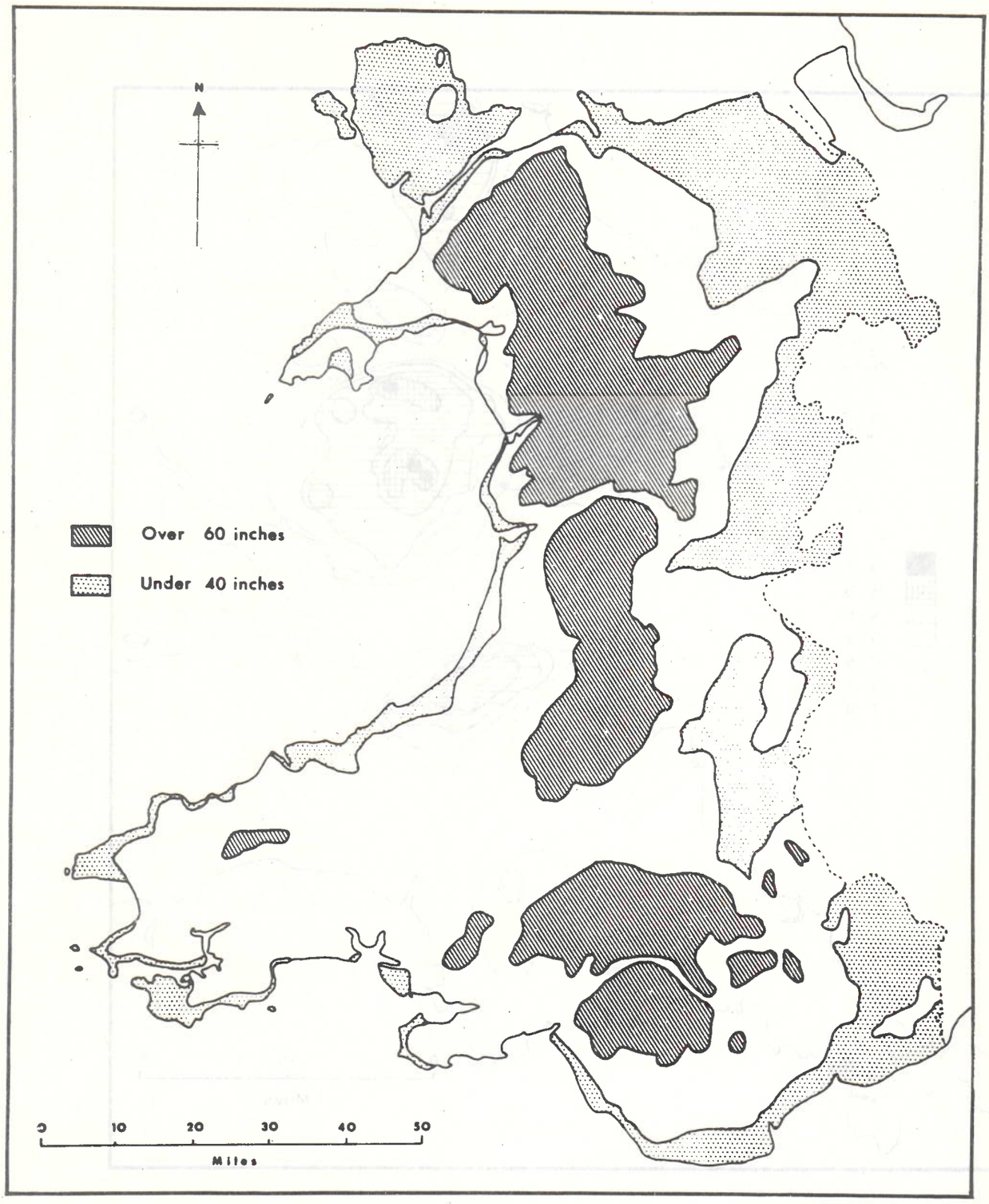

Fig.1

Rainfall in Wales. Areas over 60 inches and under 40 inches Mean annual rainfall (1881 - 1915).

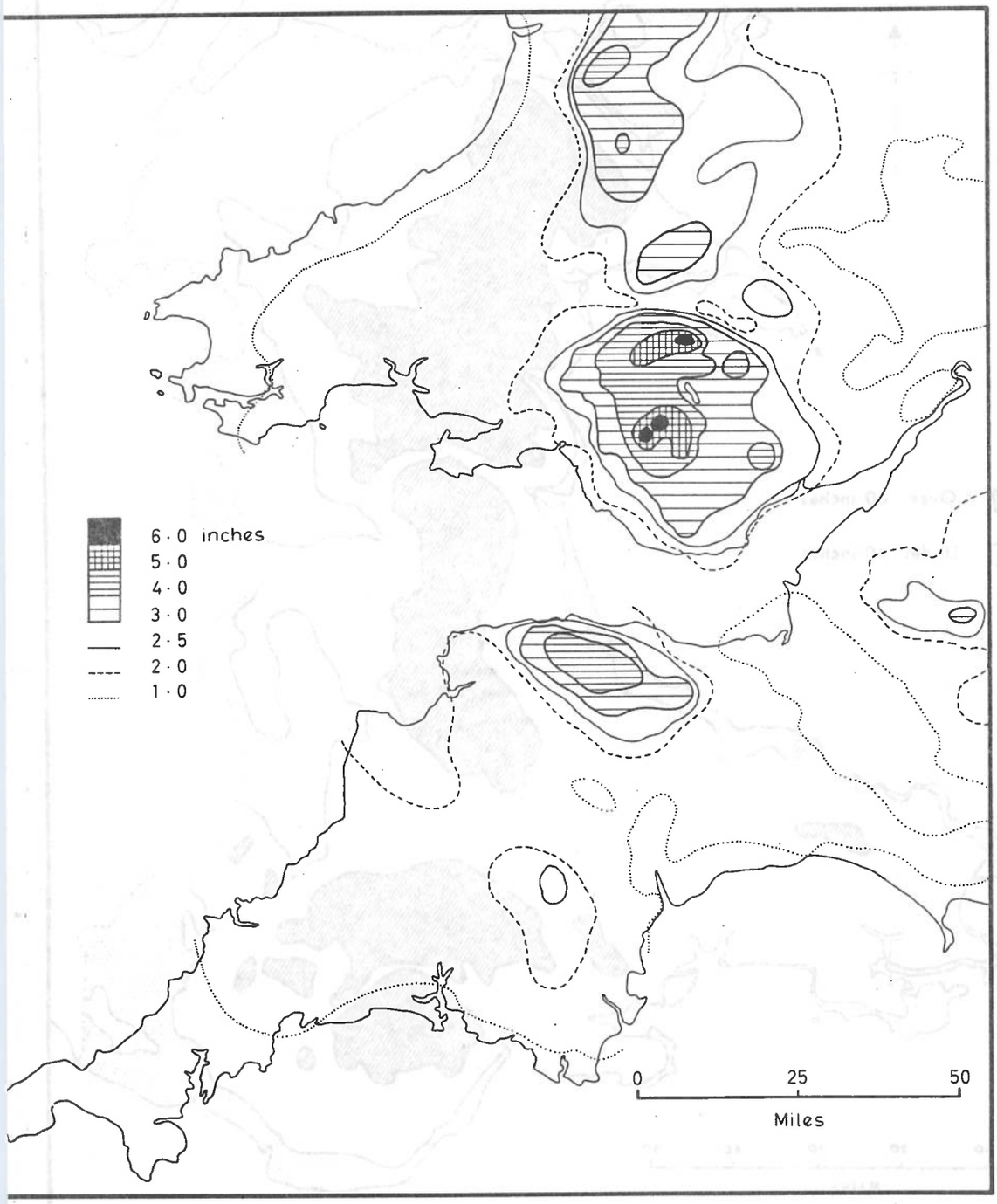

Fig.2

Rainfall in inches over South-West England, Central and South Wales, December 3rd, 1960.

This list, which is by no means comprehensive and is not of primarily upland stations, does not compare, however, in length with a far larger number of intense falls in short periods which characterise lowland parts of south or eastern England. Such falls, of course, greatly exceed the possible infiltration rates even in the most permeable soils.

The uplands experience higher rainfall totals, a greater average number of rain-days (.01 inches or over) and longer hourly duration of rainfall. Rain-days, and to a lesser degree hourly duration of rainfall, increase with height at a slower rate generally than rainfall, so that rainfall intensity increases also. Data from autographic gauges are somewhat limited but, as table 1 indicates, the increase in intensity based on amount per rain-day is less marked when the ration of rainfall to hours-of-fall is considered. The location of stations whether in east Wales or on the wetter western side, both lowland and upland, must be borne in mind when evaluating these data. Snowdon, Cwm Dyli (325 feet) illustrates well the effect of a site of low elevation but within a highland area and can be considered as representative of a much higher altitude.

Table 1.

Rainfall intensities in specified periods for selected Welsh stations

Station	Height above sea level (feet)	Rainfall intensity in inches a) per hour	b) per day	Duration of record
Swansea (Victoria Park)	32	.069	.259	1951-60
Cray Reservoir	1043	.071	.375	1951-60
Felindre (Upper Lliw)	599	.070	.312	1954-56, 1959-60
Cardiff (Penylan)	202	.058	.230	1951-60
Rhoose	20	.051	.200	1956-60
Wrexham	275	.054	.154	1951-55
Tredegar (Bedwellty Park)	992	.062	.350	1958-60
Snowdon (Cwm Dyli)	325	.097	.542	1951-60
Lake Vyrnwy	995	.076	.279	1951-57

The intensity of leaching, the removal of soluble bases, podsolization, gleying and peat accumulation will all be influenced by the conditions illustrated above and the surplus of water supply over evapotranspiration

losses.

Snow-fall and snow-cover.

Snow-fall frequency increases with the lowering of temperature as height increases. Wales is well below any permanent snow-line, and both the frequency of snow-fall and persistence of snow-cover reflect the oceanic modification of winter cold and the success with which relatively mild air-masses from the west can move in during the winter to melt the snow. Snow-cover will influence some of the soil forming processes. A snow-cover will act as a protective layer, which may limit frost penetration as well as lengthen the possibility of nivation processes beneath the snow, though persistent snow-beds are small in area and very few in number. Snow-cover is a more relevant statistic than snow-fall for the study of soil development except for the influence which snow melt-water may have on soil temperature.

Reliable data about snow-fall and snow-cover in upland Wales are difficult to obtain. Cantref (Brecknock, 1080 feet) over a 23-year period had an annual average of 20 days with snow-fall and 16.1 days (at 9 G.M.T.) with snow-cover, whilst Bwlchgwyn (Denbigh, 1267 feet), for a 9 year-period, had 46.5 days of snow-fall and 35.9 days of snow-cover. Bearing in mind the limited information available, representative estimates of days with snow-cover at the morning observation hour are Plynlimon 55, Cader Idris 63, Brecon Beacons 60 with, perhaps, the highest part of the Berwyns and Black Mountains (Brecknock and Carmarthen) rising up to 100 mornings on average (Howe 1957).

Evapotranspiration

Water losses due to evaporation and transpiration in the Welsh Uplands take a relatively small proportion of the precipitation i.e. rainfall effectiveness is high. For Welsh catchments, dependent on their overall precipitation totals and the underlying geology, run-off probably amounts to between 60 and 80 per cent of the water falling on them. Based upon calculations using the Penman formulae (Penman 1951) evapotranspiration losses for much of the Welsh upland will be within 17 to 19 inches per annum (possibly less on the wettest and higher western uplands). This loss will occur almost entirely in the warmer months between April and September.

A number of factors contribute to the relatively low loss. These include lower air temperature, long periods of high relative humidity

frequent occasions when the cloud base is below the height of the higher uplands (perhaps down to 1500 feet or even lower). The soil surface is normally damp. One might expect the increased wind velocities characteristic of the uplands to raise evaporation rates, but only rarely does the relative humidity fall to low values, when anticyclonic subsidence extends its drying influence down to the upland ground level. More often the air is humid and the potential moisture loss is low. For instance, at a Brecknockshire station at 2,000 feet a.s.l. 64.1 per cent of the total duration of 1959, and 74.8 per cent of 1960, had a relative humidity over 90 per cent. The number of hours below 50 per cent relative humidity was respectively a mere 229 (1959) and 63 (1960) (Oliver 1964). Table 2 and Fig. 3 emphasise the persistently damp atmosphere of the upland environment.

Table 2.

Percentage duration of relative humidity over 90 per cent at 2,000 feet a.s.l. in Brecknockshire

	Jan.	Feb.	March	April	May	June	July	Aug.	Sept.	Oct.	Nov.	Dec.
1959	86	67	77	64	49	54	57	53	29	57	82	94
1960	88	88	75	60	44	45	73	73	75	89	91	95

Dry spells are of short duration and are infrequent in the uplands, so that the soil moisture status is predominantly high (Howe 1957). Drying out of the soil to any depth, under present climatic conditions, is a rare occurrence. A water-logged state is a more common feature, especially where slope or soil type impedes the drainage.

Temperature

Temperatures influence the nature and rate of chemical reactions in the soil, as well as the life and activity of bacteria and other micro-organisms. (E. Griffiths, 1961). Soil temperatures, in this respect, are more directly important than the air temperatures.

The physical character of the soils is important. Heat diffusion is dependent upon the conductivity and specific heat of the soil. These properties are influenced by the constituents of the soil in particular the proportion of organic material and the ratio of water to air in the pore spaces. Moist soils have a more conservative thermal regime, and upland soils, as shown above, are characteristically waterlogged or the water table is high. Snow cover, or a frozen soil surface, will make soil temperature changes in the soil extremely small, but will

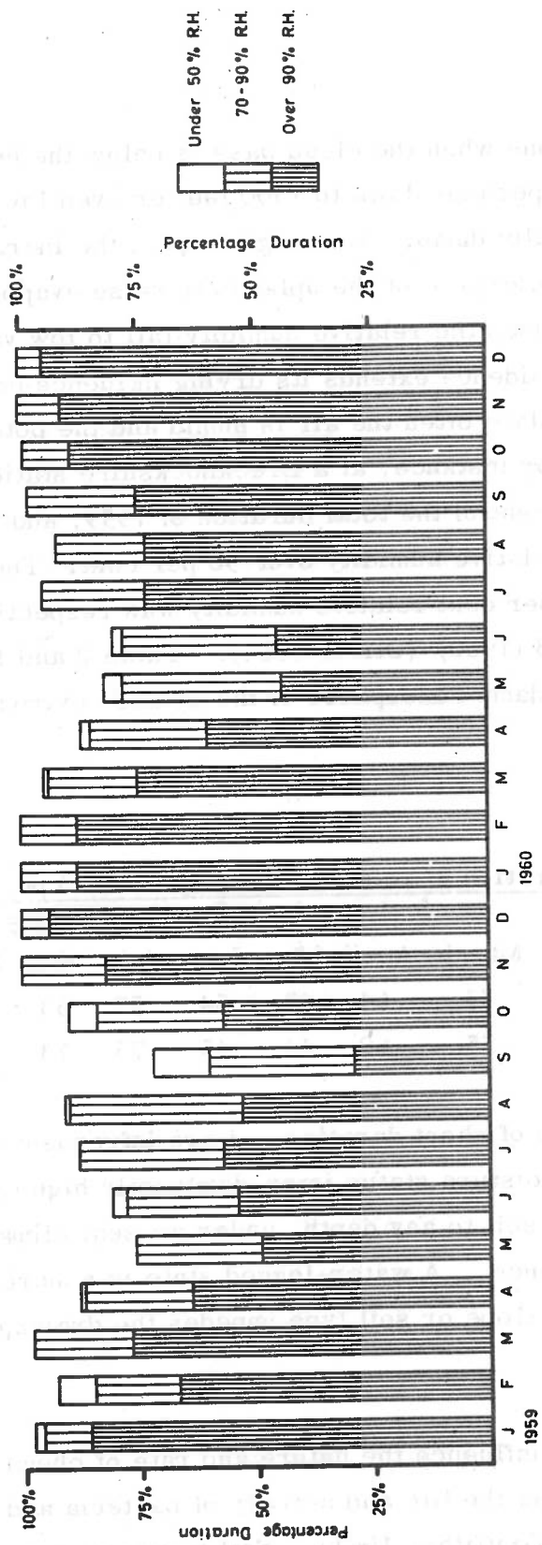

Fig. 3

Duration of relative humidity of selected percentage values at a height of 2000 feet above sea level in South Brecknockshire.

also help to maintain the average soil temperature in levels below the frozen layer.

The characteristics of upland climates play a major part in influencing the thermal regime in other ways, in addition to the maintenance of a high moisture status. Sunshine duration in the uplands is reduced by 300 to 350 hours per annum compared with the lowlands, so that the energy available for surface heating is considerably less. At night higher cloud frequency reduces radiation losses. Evaporative cooling from a damp surface, or heat conduction in winter from relatively warm air-masses, are other contributory processes. On the relatively few occasions when the weather is dry and cloudless, the uplands benefit to a greater extent than the lowlands, and surface temperatures in summer can rise to relatively high values.

Table 3 indicates the nature of soil temperatures at a depth of two inches in a wet peat bog at 2000 feet above sea level in Brecknockshire. Such values may be used as broadly representative of the extensive peat covered upland surfaces, but would be modified, and more extreme in range, in mineral soils (Oliver 1962). Over a two-year period of investigation the absolute extremes were 29.9°C and -0.5°C. In the winters 1959/60 and 1960/61 respectively the temperature was 0°C or below on 19 and 15 days. Although the surface of the soil will be frozen for longer than in the lowlands, deep penetration of frost (except when a long spell of severe cold persists over the whole area, uplands and lowlands together) is less marked than might be anticipated. The high water content of the soil, and the fact that very low minima are not a dominant feature of the uplands, limit the depth of frozen ground. High soil temperatures have a very short duration over the year or during any one day. Taking 21°C (70°F) as a reference threshold, as table 3 shows, very little of the year experiences a soil warmth at 2 inches depth above this value (1959 4.2 per cent; 1960 1.6 per cent). Just over half the year (continuously between June and August) had daily minima above 6°C.

The conservative thermal regime at a shallow depth is reflected in the low value and limited penetration of the diurnal temperature wave to lower levels in the soil. At the two-inch depth the diurnal range exceeded 10°C on 42 days in the dry sunny summer of 1959 and on only 9 in the succeeding wet, cloudy 1960. The maximum diurnal range recorded was 18.3°C (see table 4). In contrast, the winter diurnal range of 1 to 2°C on sunny days became hardly detectable on wet, cloudy days or when the surface was frozen.

Table 3. Soil Temperatures at 2 inches depth in a peat bog south Brecknockshire at 2,000 feet a.s.l. °C

		JAN.	FEB.	MARCH.	APRIL	MAY	JUNE	JULY	AUG.	SEPT.	OCT.	NOV.	DEC.
1959	Mean Max.	1.1	2.1	4.7	7.1	12.7	18.5	19.4	18.9	19.0	12.1	5.5	3.7
	Mean Min.	0.5	0.9	2.8	4.7	8.2	9.8	11.3	12.0	8.8	7.2	3.4	1.9
	Mean	0.8	1.5	3.8	5.9	10.5	14.2	15.4	15.5	13.9	9.7	4.5	2.8
	Mean diurnal range	0.6	1.2	1.9	2.4	4.5	8.7	8.1	6.9	10.2	4.9	2.1	1.8
	Hours over 6°C	0	5	16	334	658	720	744	744	697	626	217	0
	Hours over 21°C	0	0	0	0	0	43	45	16	19	0	0	0
1960	Mean Max.	2.2	1.8	4.7	(9.4)	13.7	18.4	14.5	14.4	11.5	8.1	-	-
	Mean Min.	1.3	1.3	3.2	(4.1)	7.8	11.3	10.8	11.2	9.7	7.5	-	-
	Mean	1.8	1.6	4.0	(6.8)	10.8	14.9	12.7	12.8	10.6	7.8	-	-
	Mean diurnal range	0.9	0.5	1.5	(5.3)	5.9	7.1	3.7	3.2	1.8	0.6	-	-
	Hours over 6°C	12	0	14	(384)	714	720	744	744	720	725	-	-
	Hours over 21°C	0	0	0	0	0	46	0	0	0	0	0	-

Values in brackets based on incomplete or adjusted data.

Table 4.

Extreme annual range of soil temperature 1960/61 in a peat bog at 2000 feet a.s.l.

°C

2 inches depth	29.3 (1959/60)		1 foot depth	11.4
4 inches depth	14.0		2 feet depth	6.6
8 inches depth	13.0		3 feet depth	4.5
			4 feet depth	3.3

Mean annual soils temperatures below one foot depth were 7.5°C and above those of the screen air-temperature but still low from the viewpoint of the rate and intensity of chemical reaction in the upland soil compared with the lowlands. The annual regime at different depths shows that from mid-October to mid-March the surface was colder than below the surface, but in the summer the relationship was reversed. (see Oliver 1962).

Air temperatures are significant largely to the extent that they affect heat loss or gain from the soil or influence the vegetation which in turn modifies the effects of soil climate and the soil forming processes.

The lapse of air temperatures with height varies according to the time of day, season and air-mass and weather conditions. In Wales we may work on the basis of 1°C fall for a rise in height of between 450 and 490 feet. Table 5 illustrates the sort of temperature conditions which might be anticipated in different parts of Wales at an assumed height of 2,000 feet above sea level. The general level of the temperature curve is lowered whilst the amplitude of the range is also reduced with height (Taylor 1965). There is, of course, a higher frequency of frost on the uplands than on the marginal lowlands. Air-frost data in the screen are very limited, but short period records from for Allwen (1100 feet), Bwlchwyn (1267 feet) and Tredegar (1028 feet) give average annual frequencies of 115, 80 and 81 days respectively. There must be increased freeze-thaw breakdown of exposed rock in these circumstances on the uplands.

As remarked upon above, extreme low minima of air temperature are not a notable feature of upland plateaux, but this comment is certainly not true of depressions or valleys in the uplands where temperature inversions occur. Under conditions of night-time radiation cooling, the cooled surface air over the gentle upper sur-

faces or slopes will drain to lower land and may produce severe frost.

Table 5
Air temperature equivalents at 2000 feet a.s.l. referred to specified lowland stations and assuming 1°C lapse per 490 feet rise. 1931-60 monthly means in °C .

Station	Height (feet)	Highest Mean	Lowest Mean	Highest mean maximum	Lowest mean minimum
Aber	60	11.7	1.4	15.0	-1.2
Haverfordwest	131	11.6	1.0	15.3	-1.8
Hawarden Bridge	17	12.5	0.3	16.8	-2.7
Newport	265	13.1	0.6	17.5	-2.1

The air at higher levels will be mixed with warmer "free air", so that it will be less cold than might be expected. Very low temperatures do, of course, occur at high levels in Wales, but these are usually associated with very cold polar or arctic air-masses which will also bring severe cold to the lowlands. Extreme summer minima are more notable on uplands than extreme winter minima. The range of mean daily temperatures is reduced in the uplands more through the lowering of the maxima, though, under favourable summer conditions, the higher land can record values above those which would be anticipated from a correction for height of lowland values.

Vegetation

The plant cover influences soil formation through its effect on the moisture and heat balance, as well as on the chemical and bacterial processes in the soil. Upland climates will directly affect the vegetation, so that, in the higher areas, this has been described as almost tundra in character. One of the obvious but important vegetation contrasts is that between grass and woodland. As well as the climatic elements already referred to, aspect and slope and most of all exposure to damaging and dessicating winds (particularly when these are cold) must be considered. Uplands have both a greater number of gales and a higher average wind velocity than the lowlands, though distance from the coast is also a significant criterion.

Further aspects of the plant/climate/soil relationship cannot be pursued in this discussion.

Climatic change

In Wales the time available for many soils to develop to their present condition has been a mere 20,000 to 25,000 years since the end of the Pleistocene; even less if the starting point for more rapid development is placed after Pollen Zone III (under 10,000 years). In the spectrum of Late- and Post-Glacial climatic changes, on the simple tripartite division of rising temperature, Climatic Optimum (Atlantic phase) and subsequent cooler conditions, there have been superimposed short-period fluctutations of temperature, and also some significant periods of higher precipitation and/or lowered evaporation. The soils we examine to-day represent a dynamic response to changing environmental conditions over the post-Pleistocene period. Only so far as the present relationship between upland and lowland climates was true in the past can what has been stated above apply to earlier periods of soil development.

In the Late Glacial period the sea temperatures and ice conditions in the seas around the British Isles differed from to-day. Air-masses, particularly from the west, would have been modified, including their lapse of temperature with height, as compared with those affecting the uplands now. Until the Pre-Boreal phase, about 9600 years ago, the snow-line was lower than to-day, and it has been estimated that in the wetter north-western uplands it would have been down to 2500 feet (Manley 1951), with snow beds persisting in deep depressions or sheltered parts of the South Wales uplands. When the climate is cool, cloudy and wet the uplands suffer relatively more than the lowlands; conversely with dry, sunnier anticyclonic conditions in summer the difference between the uplands and lowlands is minimised (Manley 1952). Soil formation would reflect the contrasting climate in the uplands in the humid Atlantic or Sub-Atlantic periods with the drier phases of the Sub-Boreal or mediaeval times. (Oliver 1966; Taylor 1965). Different climates in the past have been associated with modifications of the wind directions and of the trajectories of air-masses and depressions.

The relationship between soils in their present-day state and upland climates can only be understood fully if the range of climates experienced during the complete period of soil evolution can be reconstructed. This is a big challenge. Data on the precise character of upland climate are deficient for Wales to-day; for the past, con-

ditions are even more conjectural.

Conclusion

Regional soil characteristics and contrasts reflect a variety of soil forming factors. Upland climates give different soils some degree of underlying unity by which they may be distinguished from lowland soils. In specific soils, and particular locations, it may be difficult to detect the climatic influences because of other more dominant factors.

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DISCUSSION

In reply to a comment by L. J. Hooper (N.A.A.S., Trawscoed) concerning the relationship between temperature and transpiration, Professor Oliver said that transpiration is dependent on the meteorological parameters of energy supply (basically solar radiation), air movement and atmospheric partial vapour pressure. At best, air temperature can serve only as a rough index to the energy available from transpiration or evaporation. The plant, as the transpiring mechanism, and the soil temperature (especially at low temperatures) will influence water movement and water intake.

UPLAND SOILS IN NORTH WALES, WITH SPECIAL REFERENCE TO SOILS DERIVED FROM IGNEOUS ROCKS

D. F. BALL

The Nature Conservancy,

Bangor.

General Features of Upland Soil Distribution in Wales

A generalised map (Fig.1) of the distribution of Major Soil Groups in Wales, presented in a paper at the Soil Congress in Bucharest in 1964, (Ball, in press) was based on published soil survey maps and on reconnaissance for a soil map of Britain, by D. Mackney and D. F. Ball in North and South Wales respectively. Three soil zones are defined on this map:

(a) a mountain or moorland zone, dominated by peaty podzol - peaty gley - peat soil associations (heather moor and mat-grass moor are typical vegetation types);

(b) a lowland zone, dominated by a Brown Earth - Brown Earth with gleying - Gley soil association (agricultural land, oak woodlands are typical vegetation types) and

(c) a marginal zone, the characteristic soil expression of which is a freely drained Brown Podzolic Soil (fescue-bent grassland, bracken and gorse are typical vegetation types), classification of which has been discussed in a recent review (Ball, 1966(1)).

Both the marginal and mountain zones can be considered to have "upland" soils if we are not asked to be too precise as to how "upland" is defined. I do not intend to amplify this definition here, which can be made on climatic or altitudinal criteria but which I am making in terms of a general distribution of podzolic soils. The only climatic variable for which data were available and which I was able to correlate with the broad distribution of these soil zones, was mean annual rainfall. In general terms, mountain zone soils occurred at 60" mean annual rainfall and the marginal zone soils were best expressed between 50 and 60 inches mean annual rainfall. Thus the western seaboard of Wales with higher rainfall has mountain soils as defined above down to as low as 600 ft. and marginal soils down to sea-level, compared to drier eastern Wales where the marginal zone soils do not commence until about 1,200 ft. and the mountain zone soils until about 1,800 ft. In this case "upland" as

defined by soils differs from upland as defined by altitude.

The report on Water Resources in Wales (H.M.S.O. 1961) gives 22% of the country as having greater than 60in. mean annual rainfall, and 7% between 50 and 60 in. The soil map also shows 22% of the total land area of Wales as being in the mountain-zone but with 7% only in the marginal zone, defined as dominated by Brown Podzolic Soils. Figure 2 also reproduced from Ball (in press) shows the correlation of Major Soil Group, altitude, solid geology and mean annual rainfall for three cross-sections in North, Mid and South Wales which illustrate the points summarised here.

Although the broad rainfall - soil zone correlation is a fact, there are considerable exceptions even on the non-calcareous sediments which were the standard parent material assumed when the map was drawn up (locally high or low base status parent materials must be ignored at such scales). One such exception is the North Denbigh Moors (Mynydd Hiraethog) where rainfall does not reach much above 50 - 55 inches mean annual rainfall, but the moorland soil association is present. The explanation must lie perhaps in land-use history or possible in climatic factors other than rainfall alone. There is undoubtedly a significant rainfall-temperature interaction with profile development as seen in the contrast between Brown Podzolic Soil occurrences in Wales and Southern Scotland (Ball and Ragg 1960). In the latter area Brown Podzolic Soils occur at sites of much lower rainfall but of otherwise similar conditions (slope, altitude, soil texture) to those in Wales. Mr. Rudeforth's paper elsewhere in this W.S.D.G. report also indicates probable effects of temperature differences on soil distribution.

I have fortunately been asked to concentrate on igneous rocks as parent materials in North Wales and leave Palaeozoic sediments to Mr. Rudeforth, so that I need not extend further the general aspects covered in this introduction.

SNOWDONIA

Post-glacial igneous rock weathering and sedentary soil formation

Although igneous rocks are widespread in Snowdonia and some other areas of North Wales, soils derived purely or dominantly from such rocks are of relatively minor extent.

Those who attended the W.S.D.G. field meeting on Snowdon in May 1966 will have seen that the rhyolite lavas have remained virtually unweathered since ice-retreat. They carry thin, highly acid soils of

Soils of Wales: A Reconaissance Map of Major Soil Groups.

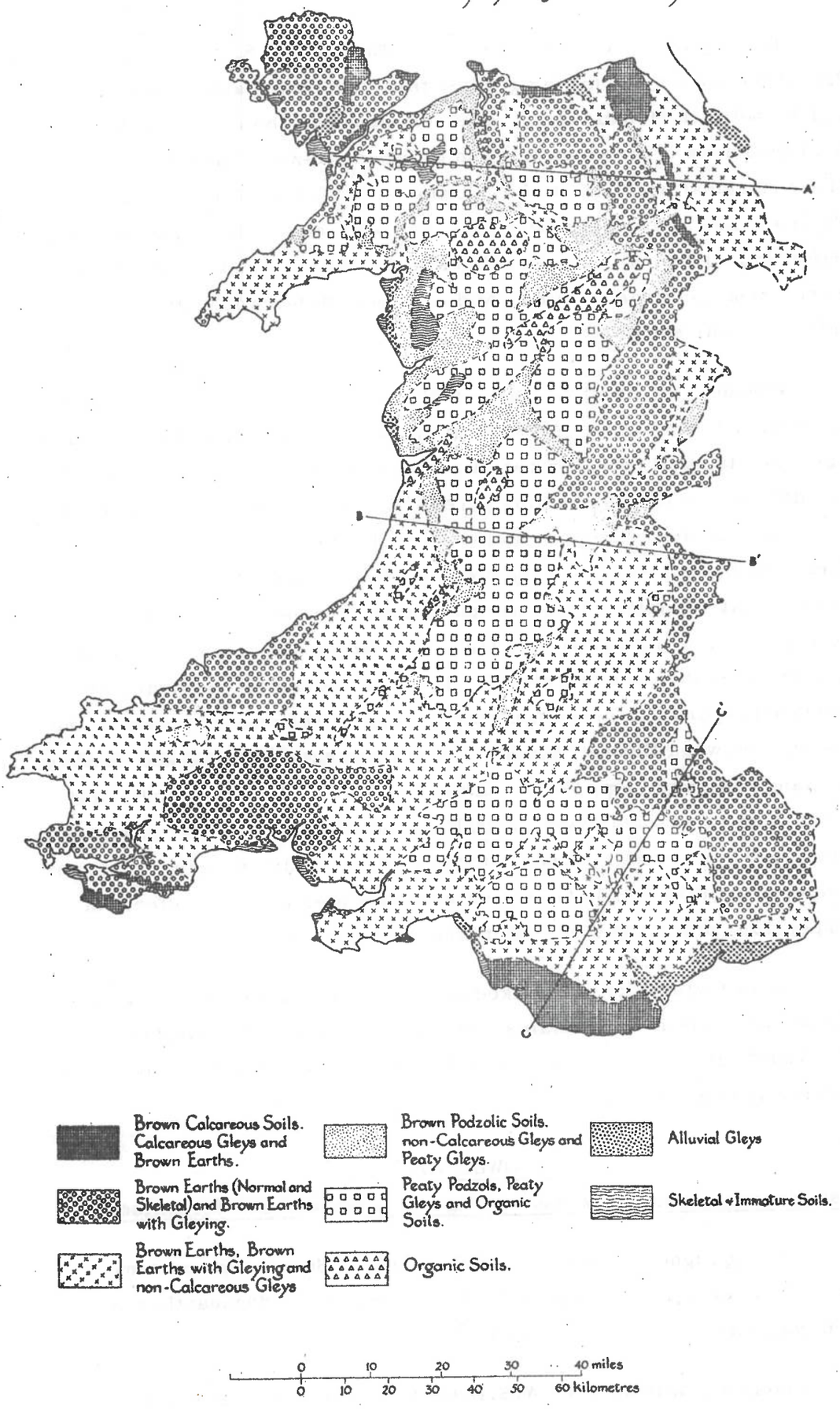

Fig. 1 (D.F. Ball)

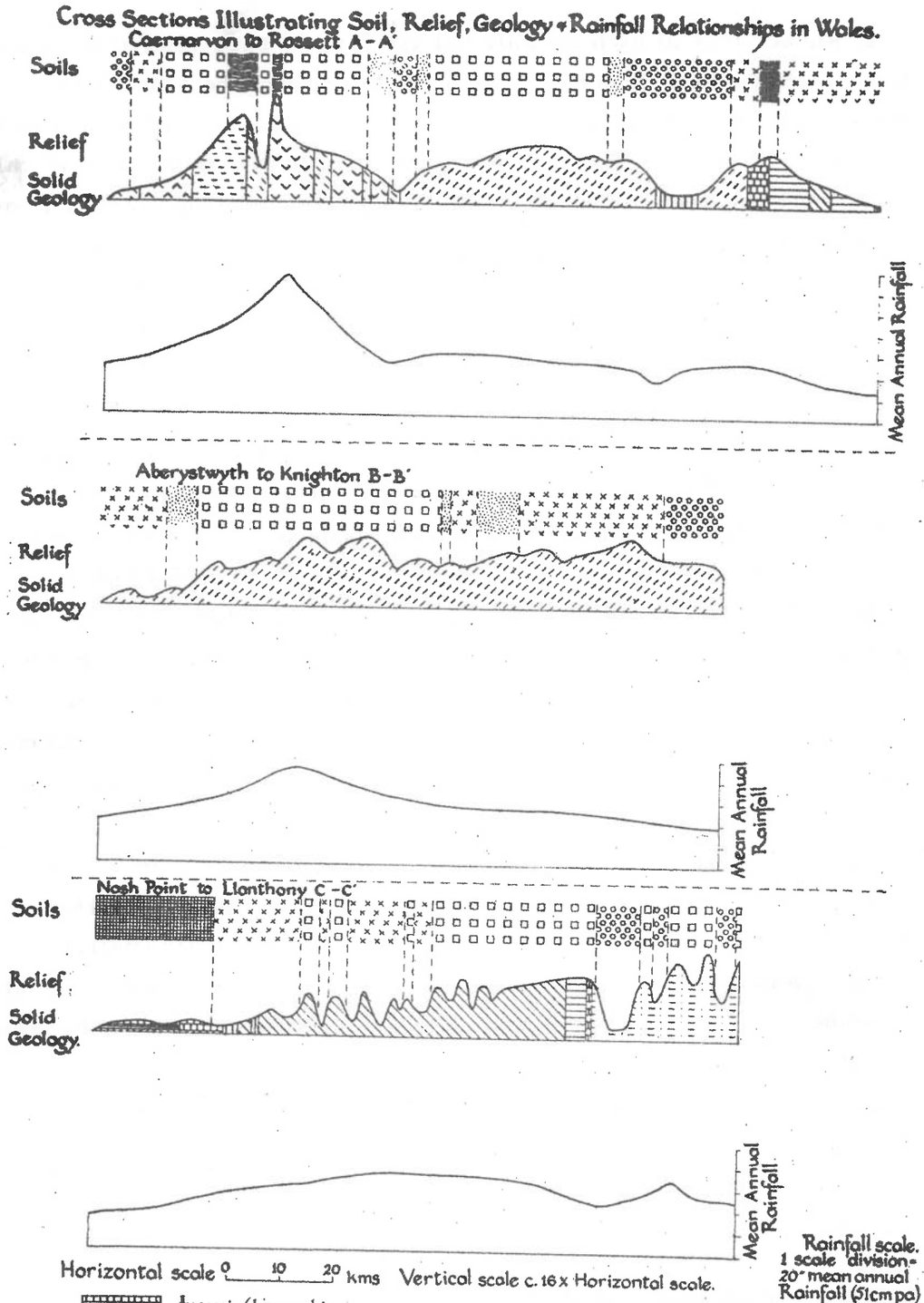
Cross Sections Illustrating Soil, Relief, Geology & Rainfall Relationships in Wales.
Caernarvon to Rossett A-A'
Soils
Relief
Solid Geology
Mean Annual Rainfall
Aberystwyth to Knighton B-B'
Soils
Relief
Solid Geology
Mean Annual Rainfall
Nash Point to Llanthony C-C'
Soils
Relief
Solid Geology
Mean Annual Rainfall
Horizontal scale 0 10 20 kms Vertical scale c. 16 x Horizontal scale.
Rainfall scale.
1 scale division = 20" mean annual Rainfall (51cm pa)
Jurassic (Lower Lias Limestone and Shale)
Triassic (Bunter Sandstone in North, Keuper Marl & Breccia in South.
Coal Measures & Pennant Sandstone
Millstone Grit
Carboniferous Limestone
Carboniferous
Devonian (Old Red Sandstone, Sandstone and Marl)
Silurian, Mainly Shale.
Ordovician Sediments, Mainly Shale
Ordovician Volcanics, Mainly Rhyolite
Cambrian Sediments, Mainly Grit and Slate
Pre-Cambrian Volcanics, Mainly Rhyolite.
Brown Calcareous Soils, Calcareous Gleys and Brown Earths
Brown Earths (Normal & Skeletal) & Brown Earths with Gleying.
Brown Earths, Brown Earths with Gleying & Non-Calcareous Gleys.
Brown Podzolic Soils, Non-Calcareous Gleys and Peaty Gleys.
Peaty Podsols, Peaty Gleys and Organic Soils
Skeletal and Immature Soils

Fig. 2 (D. F. Ball)

Peat Ranker type at high rainfall and are largely bare rock at low rainfall. Soils derived from post-glacial weathering of the silica-rich rhyolitic rocks widespread in Snowdonia are confined to areas of rhyolitic ash. Their cleaved, fissile character allows greater mechanical weathering and they give rise locally to shallow immature soils of Brown or Moder Ranker types. Similarly the less siliceous, relatively Fe, Mg and Ca-rich basic igneous rock, dolerite, because of its massive, non-fissile character, has also weathered very little post-glacially. On Snowdon frost-shattered joint-bounded dolerite retains clearly its columnar jointing and the only sedentary soils on dolerites are very shallow Moder Rankers. Thus differences in rock chemistry alone are not sufficient to cause differential post-glacial weathering and soil development from igneous soil parent materials in North Wales. Neither chemical nor mineralogical differences can alone, in a cool humid climate over the 8 - 10,000 post-glacial years, explain the different rates of breakdown of rock to a loose mineral substrate on which pedogenesis can act.

The control on the rate of weathering is lithology and rock fabric, that is the relative arrangement of the constituent minerals in a rock. If rocks are well-cleaved allowing disaggregation by a combination of physical and chemical processes, they can break down to give a mineral soil. This can be seen in some rhyolitic ashes, but is most marked on the slightly calcareous, iron and magnesium rich chloritic (Ball, 1966(2)) volcanic ashes called pumice-tuffs. At Llyn Llydaw, Snowdon, striated rhyolite pavements can be seen alongside deep immature Brown Earths on rapidly weathering pumice-tuffs. The eroded tuff-derived soil forms a lake-floor sediment overlying unaltered glacier-moulded rhyolite pavement. Ash-derived soils (mainly Cwm Glas and Crafnant series) are the only important post-glacially derived soils formed from igneous rocks in Snowdonia.

Igneous contribution to drift-derived soils

Other soils in which igneous influence is marked are derived from glacially comminuted rock, or possibly from pre-glacially weathered igneous rock incorporated in glacial drifts. Material derived from basic igneous rock is subordinate but widespread in drift-derived soils in North Snowdonia as has been shown in mineralogical studies (e.g. widespread occurrence of augite) by D.A. Jenkins. The significance in terms of soil fertility is small except where there is a large colluvial admixture of dolerite or pumice-tuff.

There is a considerable contribution of rhyolitic rocks to the general Snowdonian drifts and we can perhaps extend a definition of rhyolite-derived soils to include such drifts in which rhyolites and other acidic

igneous rocks are dominant. Ideal end-members of a sequence of soils from those derived from igneous rocks (very stony and light-textured) to those derived from sediments (less stony, silty textured) are recognised as Soil Series (e.g. Bodafon and Hiraethog Peaty Podzols) in the early annual reports and in the subsequent Survey Memoirs but in terms of practical soil survey and probably also in terms of land-use, it is not always possible to draw divisions of parent material within this sequence in an area where a complicated drift distribution overlies an area of complex solid geology. Because of this, in the Bangor sheet survey, the mapping units were taken as complexes involving the entire range of mixed parent material.

Possible influence of residual weathered material

It has been noted that where Late-Glacial ice was present, e.g. on Snowdon itself, there has been only very slight weathering of basic intrusive igneous rocks, such as dolerite. In other areas of Snowdonia, away from Late-Glacial cwm-glaciers, small extents of Brown Earths containing a high proportion of material of dolerite origin, overlie dolerite rocks. It is possible that such sites represent areas where a greater length of time has been available for rock weathering than the c.10,000 post Late-Glacial years, although this suggestion is purely speculative at present. This age-difference may account also for some soils on granitic igneous rock, for example in Lleyn, and there is scope for a comparative study of weathering and soil formation on igneous rocks in relation to the postulated glacial history of the region.

Influence of Relief on soil type

It is generally accepted that greater rainfall implies greater leaching and more extensive podzolisation. The general soil distribution in Wales conforms to this but at the highest rainfall areas other factors come into play. Snowdon, a centre of Late-Glacial ice, has few well-developed podzols, which are mostly all confined to the moraine slopes and even there, the Peaty Podzols are less "ideal" in type than on the lower rainfall but more gentle and stable slopes of the moorland areas of mainly sedimentary rock. The instability of the deep pumice-tuff slopes is a major factor in maintaining a Brown Earth character in these soils. On gentler slopes and stable sites not subject to continuous creep, intermittent slip and flushing of water from calcareous outcrops above, even the pumice-tuff soils develop a podzolic character. Thus the simple rainfall - leaching - podzolisation picture is disrupted by relief differences.

Cader Idris

Of the less extensive Welsh areas of igneous rocks outside north Snowdonia, one of the most interesting is Cader Idris. There, current work on the summit and Llyn Cau regions of the National Nature Reserve, has included profile sampling for the Nature Conservancy by Richard Bower of the University College of North Wales. No simple well-defined sedentary soil-rock association has been recognised, but some profiles indicate at least through their stone-content a dominant influence of one or other igneous rock type, with weakly podzolised Brown Earth on basic lavas, more typical Brown Podzolic soil at lower altitudes but on drift with high granophyre contribution, and Peat Ranker at higher altitudes sedentary on granophyre.

Bwlch-y-Cywion granite

In spite of what I have pointed out to be a relatively limited and local importance of igneous rocks compared to sediments as soil parent materials in North Wales, there are some features of igneous rock weathering of considerable academic interest to pedologists and mineralogists. One such indication that all is not yet known about this subject is the occurrence above the Nant Ffrancon of an area in the Bwlch-y-Cywion granite which has, I believe, the only British soil (admittedly of very limited area and plant cover) with gibbsite ($Al_2O_3 \cdot 3H_2O$) as the sole crystalline clay mineral (Ball, 1964). Is this a result of hydrothermal alteration or sub-aerial weathering? - either way the answer would provoke many further difficult questions. It may also suggest that glacial drifts can contain much fine material which has passed through more than one weathering cycle.

Summary

1) A general soil/relief/rainfall correlation in terms of lowland (Brown Earth), marginal (Brown Podzolic Soil) and mountain (Peaty Podzol) zones applies throughout Wales.
2) There are some extensive exceptions to a simple rainfall relationship such as the North Denbigh Moors where mountain-zone soil associations occur at a rainfall typical rather of the marginal zone elsewhere in Wales.
3) Igneous rocks have contributed extensively to glacial drifts in Snowdonia. Because in general the most widespread acidic types weather less easily than the dominant shale sediments this contribution is probably subordinate in practical terms of differences in soil fertility over most of the area.

4) Locally the influence of igneous rocks is more marked. This results from

   a) Post-glacial weathering of the pumice-tuffs

   b) Drift-filled cwms where the solid geology is exclusively or dominantly igneous, as Cwm Dyli, Snowdon

   c) The possible local survival of pre Late-Glacial weathering products of dolerite and other igneous rocks away from centres of the Late-Glacial cwm glaciers.

Acknowledgements

I am grateful to the Maps section of the Nature Conservancy who prepared Figures 1 and 2.

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DISCUSSION

D. A. Jenkins (U.C.N.W., Bangor) asked whether there was any evidence in Wales of the deep weathering predating the last glaciation which had been described from Scotland.

D. F. Ball replied that there was not, with the possible exception of the site at Llymllwyd, superficial deposits in Wales being mainly periglacial in origin.

UPLAND SOILS FROM LOWER PALAEOZOIC SEDIMENTARY ROCKS IN MID-WALES

C. C. RUDEFORTH *
(Soil Survey of England and Wales)

INTRODUCTION

The uniformity of Ordovician and Silurian rock types throughout much of Mid-Wales, dominated by rapid alternations of mudstones, shales and sandstones occurring over a wide altitudinal range, has provided a good background for studying the effects of factors other than lithology on soil formation. In describing the Upland Soils, local catenary variations are distinguished from soil variations dictated by climatic factors. A possible relationship between summer temperatures and the distribution of podzolized soils is considered.

SOIL MACROMORPHOLOGY SUMMARIZED IN A CONTINUUM DIAGRAM

The diagram (Fig.1) represents continuous variations in the morphology of slope soils across the landscape. The most common relative positions of soils are shown, so that the diagram provides a reference framework indicating how the soils (illustrated during the meeting by colour transparancies) usually fit into the patterns of continuous variations.

Local 'catena' variations are represented along the vertical axis (Y). Their occurrence is often associated with parent-material divisions, whose distribution, like those of the soils, is itself commonly related to topography. Three parent material categories related to hydrologic properties are recognized: Solid Rock , Permeable Scree, and Slowly Permeable or Impermeable Drift materials. All three categories occur throughout almost the full altitudinal range of Central Wales.

It is useful to distinguish changes along the Y-axis from those along the X-axis so as to eliminate some of the variations which are not associated with climatic differences between lowland and upland. Thus, down the Y-axis, ungleyed A/C soils on solid rock pass to A/B/C soils over rock, scree or more consolidated drift, thence through increasingly gleyed soils to peaty gley soils and peats. Superimposed on this arrangement in the uplands are the effects of climatic differences conveniently expressed by lower temperatures and higher rainfall.

Morphology of Upland Soils

The most important single morphological feature of upland soils is

* Presented by Dr.V. 1. Stewart

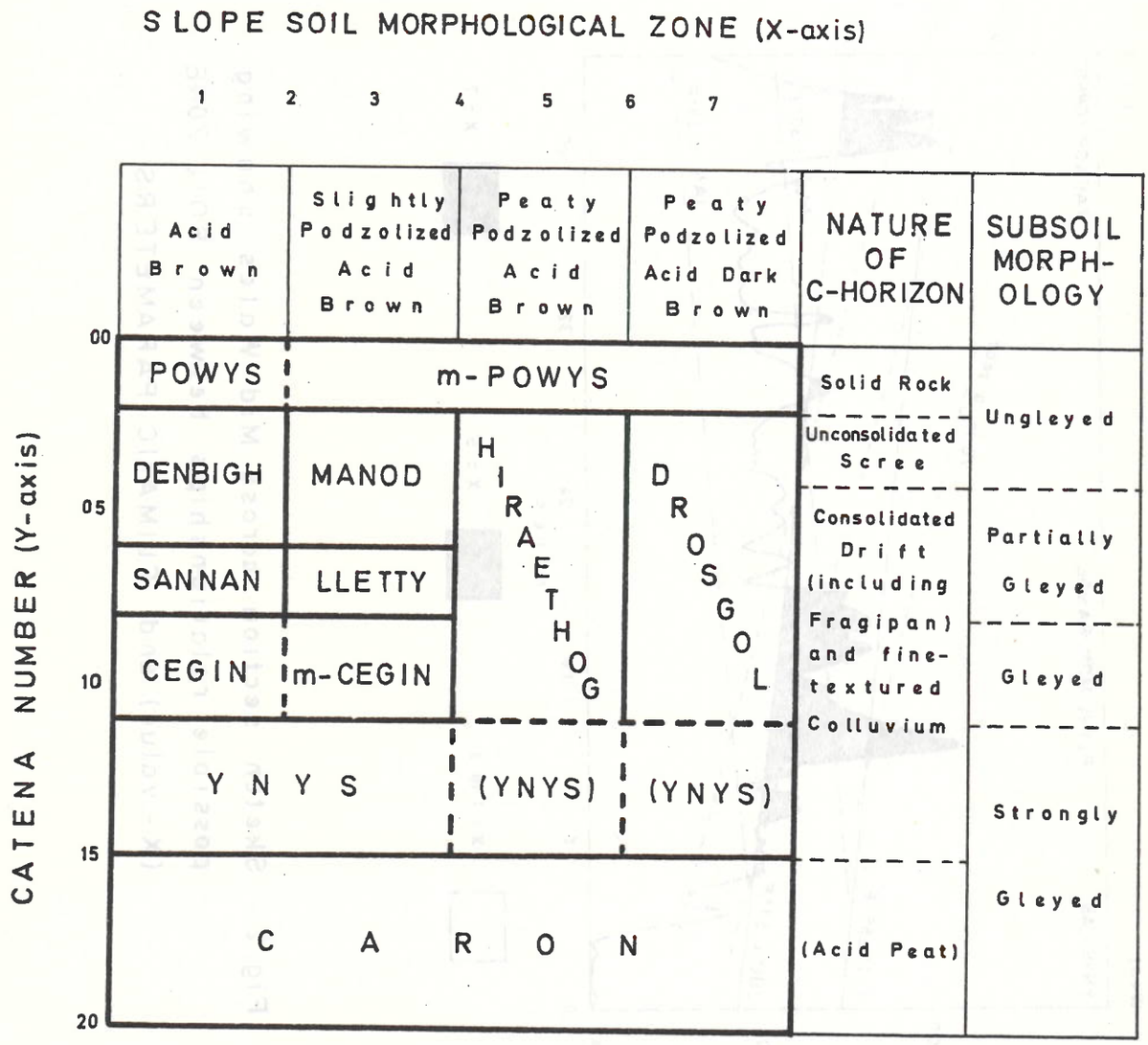

Fig. 1. Part of a Continuum Diagram for Soils derived from Lower Paleozoic sedimentary rocks in Mid-Wales. (after Rudeforth, 1966).

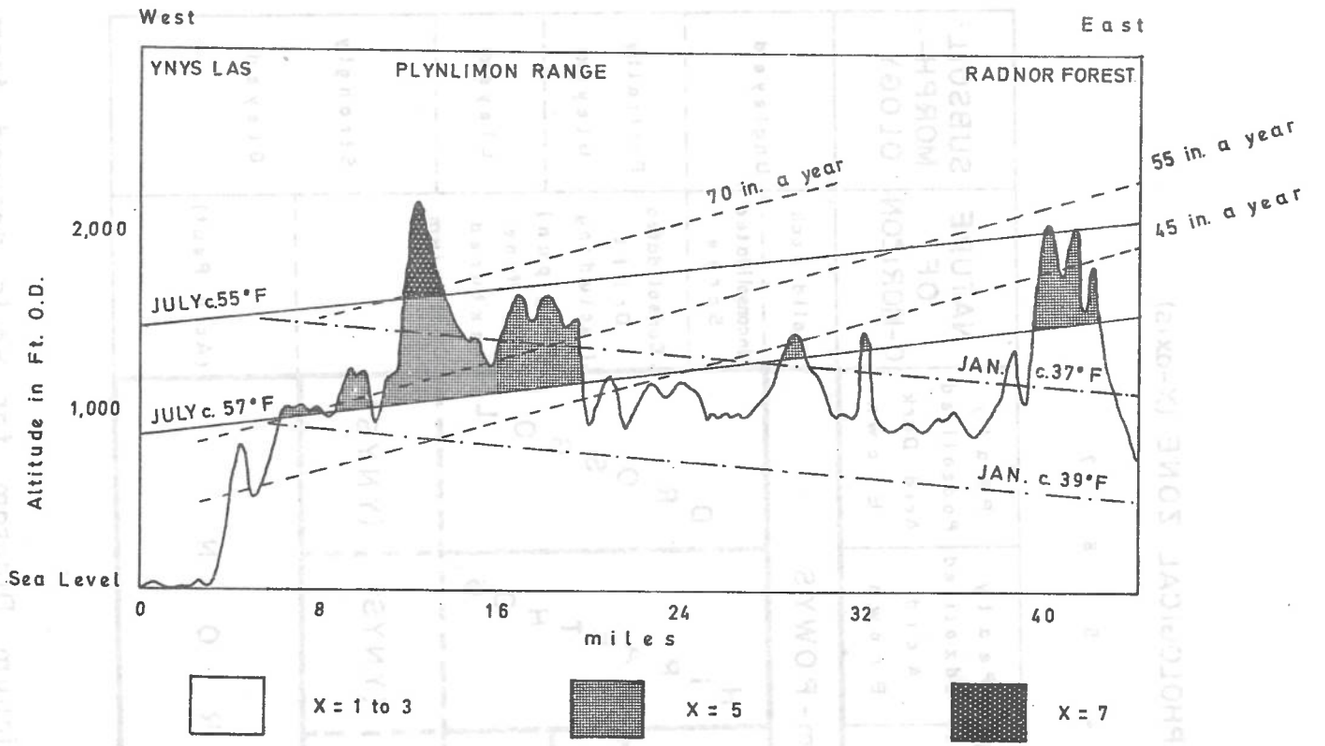

Fig. 2. Sketch section across Mid-Wales showing possible relationships between SOIL ZONE (X - value) and CLIMATIC PARAMETERS.

the accumulation of unincorporated surface organic matter (O-horizon) on soils with ungleyed, permeable substrata. Other features, such as a podzolized, grey A_2-horizon near the surface, depleted of iron and aluminium, appear in Mid-Wales to be largely correlated with the occurrence of a surface O-horizon.

The range of soils most extensive in the uplands is therefore represented by zones 3 to 7 in which surface O-horizons occur at all catena positions. Most soils of zone 5 possess the additional feature of a continuous, grey A_2-horizon (often over a thin iron pan), while those of zone 7 are distinguished by the very dark (reddish) brown colouring of the fine earth of the ungleyed B-horizons, compared with strong brown and yellowish-brown ungleyed subsoil colours characteristic of lower zones. As the shape of the units in the diagram implies, zonal distinctions are least obvious in soil morphology towards each end of the catena.

SOIL MICROMORPHOLOGY

While the organic surface horizons characterising upland soils on permeable, ungleyed substrata are distinctively different from those of lowland soils, the gradual transitions which occur across the zones in character of the lower horizons is not always obvious, but can be illustrated using thin sections.

Micromorphology of A_2- Horizons and Associated Thin Iron Pans

Discontinuous pockets of a grey A_2-horizon at the transition from Manod to Hiraethog soils (interzone 4, Fig.1) , though showing depletion of iron, commonly retain a micro-crumb structure similar to that found in the nearby zone of ferric hydroxide concentration forming an incipient convoluted thin iron pan.

The thicker continuous A_2-horizons of zones 5 and 7 often have a less porous fabric. These horizons commonly overlie a thick iron pan showing finely dispersed ferric hydroxide filling voids between mineral grains.

Both forms of iron pan have fabrics related to those of spodic horizons (U.S.D.A., Soil Survey Staff, 1960), although subsequently such formations have been separated as placic horizons (B.W. Avery, private communication).

It is concluded that iron may be translocated initially beneath a thin superficial layer of unincorporated organic matter (e.g. at X = 4, Y = 03, Fig.1) under fairly well aerated conditions. Iron

mobility resulting from the formation of iron-organic complexes which Bloomfield (1953) and others have associated with podzolization, may explain the observed patterns of iron distribution at this stage.

As time passes, the crumb structures of the podzolized A_2-horizon, now largely depleted of iron, except at the inner cores of the larger shale fragments, lose their coherence, and coalesce. Seasonal drying may produce fine prismatic structures such as those described by Crampton (1963), but under wet mountain conditions, especially where peat has accumulated on the surface, the horizon may remain substantially structureless. At the same time, the more continuous iron-pan developed below retards percolation and aggravates surface waterlogging.

Micromorphology of B-Horizons

The microstructures of diffuse aerobic B-horizons of many upland soils, like those of the thin iron-pans, are related to the microstructures of spodic horizons (Soil Survey Staff, 1960). The diffuse B-horizons in zones 1 to 4 and some in zone 5, however, frequently correspond more closely to cambic horizons, especially where they are yellowish brown rather than strong or reddish brown in colour. Strong brown horizons, like those reported by Mackney and Burnham (1964) near Lake Vyrnwy, may possess microfabric features similar to those of spodic horizons for profiles belonging to morphological zone 3. In the diffuse spodic horizons, brown pellet-like aggregates 0.02 - 0.06 mm. diam. are common. In the cambic horizons, on the other hand, the fabric is paler brown and more continuous, often showing weak preferred orientation patterns in the matrix. Fine matrix grains with preferred orientation parallel to edges of shale fragments and cracks are interpreted as stress cutans (Brewer, 1960), indicative of swelling and possibly other matrix movement pressures (Lafeber, 1962).

The distribution of humus and clay provides another example of difference between aerobic B-horizons of upland and some lowland soils. Where base saturation is moderate, humus and clay may have been deposited along fissures. The division in this case seems to lie within zone 1 (Fig. 1) (Rudeforth, 1966, p. 80, pl. 21).

OTHER SOIL PROPERTIES

Rudeforth (1966) gives profile descriptions and analytical data for upland soils, and further information will be published in the Soil Survey Memoir for the Aberystwyth and Llanilar districts. Only a brief summary of soil properties is therefore given here.

Texture

Mineral soil textures usually range from loam to silty clay. Silt loams and silty clay loams are most common. The grey A_2- horizons are generally finer textured than other horizons of upland and mountain soils, probably because shale fragments have disintegrated following removal of iron and aluminium oxides.

Mineralogy

Sand Minerals. Coarse sand fractions are generally dominated by shale fragments, while the fine sand is mainly micaceous. Quartz, orthoclase and opaque iron oxides are most common among the remaining fine sand minerals.

Clay Minerals. Illite and Chlorite are common and appear to be inherited from the rock, while mixed-layer (10/14Å) minerals, and vermiculite, which occur most frequently near the soil surface may be of pedological origin. Kaolinite, quartz and felspars persist in small quantities, but montmorillonite only occurs locally.

Chemistry

Iron and Aluminium. The proportions of sesquioxides in clay fractions, and of free iron oxides, support the contention that stage of podzolization of mid-catena soils is related to soil zone.

Organic Matter. High C/N ratios indicate lack of decomposition of peats in both mountains and lowlands. Slower rates of decomposition in mineral soil horizons (Organic Carbon 2 - 3%) of mountain areas are inferred from C/N ratios of 17 - 20 in the higher zones, compared with 8 - 10 in zone 1.

Base Saturation may be as low as 4 to 7% in B-horizons of the higher zones (X = 4 to 7, Fig.1), and often lies between 15 and 50% in the freer draining B-horizons of zone 1. Mineral soils in receiving sites tend to have slightly higher ranges of values.

pH Values. (1 : 2.5 in water) in soils of zones 3 to 7 (mainly in the uplands) are generally less than 5 and can be as low as 3.8. In the lowlands, on the other hand, pH averages about 5.4 $\pm$ 0.5, though lower values may be found on the acid basin peats.

INFLUENCES AFFECTING THE RELATIONSHIP BETWEEN SOIL MORPHOLOGICAL ZONE AND ALTITUDE

Several factors prevent complete correlation between soil morphological zone and altitude. These are considered below.

Lithology

Many impoverished sandy materials accumulate organic surface horizons more readily than do finer textured and base-rich materials. Thus, signs of weak podzolization are found on coastal sands at a few feet above sea level, while in Snowdonia base-rich igneous rocks fail to develop podzolized soils at altitudes characterised by podzolization in more acid materials (Ball, 1963). The Silurian siltstones of East Central Wales appear to be susceptible to a similar level of podzolisation as the other Lower Paleozoic sediments. It is possible that any effect of their lower clay contents may be offset by the occurrence of occasional slightly calcareous strata.

Steep Slopes

Instability on steep slopes and lowered potential leaching at right-angles to the surface combine to limit profile differentiation.

Aspect

Relatively high temperatures on sufficiently moist south-facing slopes encourage the activity of soil organisms which comminute and incorporate plant debris into the mineral soil, thus reducing the likelihood of podzolization. High temperatures and exposure may also cause increased evapotranspiration, so reducing the amount of water available for percolation, and possibly even reducing the activity of soil organisms by limiting their moisture supply. In such circumstances, good growth of the deeper rooting plants, being less limited by surface drought conditions, may allow additional organic matter to accumulate on the surface. Highest mean organic matter levels have been observed on southerly slopes at Gogerddan, near Aberystwyth (zone 1) (Rudeforth 1966, pp. 111-112), and Avery (private communication) notes that mor humus, commonly associated with podzolization, in South East England and Belgium is usually best developed on the drier south- and west-facing slopes.

Man has profoundly affected the course of soil development through altering vegetation, by clutivation, adding fertilizers and draining the land. Although man's rural activities themselves are often limited by the rigours of the upland climate, they generally tend towards lowering both X and Y values (Fig.1), by removing or incorporating surface organic horizons and improving drainage, while at the same time raising the base status of the soils.

Regional Climatic Differences

Regional climatic differences at constant altitude clearly affect soil morphology and have been described by Ball (1959) and Ball and Ragg

(Soil Survey Note 17, approx. 1960). Of particular interest is the altitude at which the peaty podzolized soils of the Hiraethog series occur on hill slopes. Ball and Ragg stressed rainfall and winter temperatures as influencing the distribution of these soils, but Rudeforth (1966) has suggested that summer temperatures may be more closely related to their occurrence.

A sketch section (Fig.2) from East to West across Central Wales illustrates the inferred relationship between altitude and the three climatic parameters. Shaded areas indicate the upper soil zone divisions observed in the field. The close fit of the 57°F July isotherm with the lower limit of general podzolization (X = 5) is apparent. Winter isotherms are lower in the more continental east than near the west coast and run contrary to the altitudinal trend of the soil divisions. The gradient of the rainfall isolines, on the other hand, is steeper than the soil division gradient, so that podzolized soils rarely occur under a rainfall of less than 55 in. a year in the west, and yet are common under rainfalls about 45in. a year in the east.

To test the hypothesis relating summer temperatures with the lower limit of podzolized soils on similar materials, the altitude at which the 57° July isotherm crossed the Denbighshire moors was estimated and found to be about 1,000 ft. O.D. The lower limits of the Hiraethog series as mapped by Ball and Harrop (1960) from west to east were then noted, and found to correspond well with the levels predicted from the summer temperature data.

Summer temperatures may similarly affect the occurrence of the dark brown subsoils of zone 7. It is interesting to note that the 55°F isotherm which appears to mark the lower limit of zone 7 is very close to the July temperature (12.6°C) at Bethel, Alaska, quoted by Rieger (1966) in his paper describing dark well-drained soils of tundra regions.

It is concluded that summer temperatures may control the activity of soil organisms which cause the decay of plant debris, and that the podzolization distinguishing upland soils in Mid-Wales is dependent on the accumulation of such plant remains on the soil surface.

Acknowledgements

The author is indebted to C. L. Bascomb and Miss A. M. Du Feu for supplying chemical and clay mineral data, and grateful thanks are offered to B. W. Avery and D. Mackney for their helpful criticism of the original script.

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DISCUSSION

R. I. Davies (U.C.N.W., Bangor) made the following comments.

The scheme presented fits with the fate of organic matter in the soil profile and it parallels that of surface organic matter. The first is important in pedogenesis, the second, in my opinion, is coincidental with pedogenesis in the inorganic soil but does not play a very active or direct part in it.

We should recognise two distinct and separate processes which though they cannot act in a soil together may nevertheless act in different parts of the profile at the same time, or in the same part of the profile at different seasons, or at longer periods of time.

The first should properly be called the pdsol process; it is present to some degree in all soils where rainfall exceeds evaporation and where soil texture and structure give ready permeability. Water soluble organic matter washed by rain from growing leaves readily forms complexes with exchangeable cations, e.g. Ca^{+2}, Mg^{+2} and with Fe and Al of weatherable minerals. By reason of their low electric charge, these complexes can move down the profile relatively unhindered by the exchange complex. The organic

matter of the complex is ultimately mineralised by soil organisms and the Fe and Al are precipitated as hydrous oxides. In the limit this process results in the podsol.

The second process is that of gleying for which a prerequisite is alternation of wet and dry phases during which anaerobic and aerobic processes succeed one another. Here the movement of Fe is a consequence of the reduction of Fe^{+3} --- Fe^{+2} during the anaerobic phase; the mobile Fe^{+2} is ultimately precipitated as hydrous ferric oxide either where the drainage water has moved laterally or on local existing sites of ferric oxide.

Both processes can produce bleached zones yet they must never be confused one with the other. The scheme before us shows a gradation of profiles consistent with gradation of changes in degree and intensity of the two processes.

D. F. Ball (Nature Conservancy, Bangor) suggested that the apparently precise correlation in the diagram of zonal soils with the July isotherm was coincidental.

Professor J. Oliver (U.C.W., Swansea) commented that air-temperature does not show any direct correlation with soil temperature.

THE EVOLUTION OF SOILS ON THE HILLS OF SOUTH WALES, AND FACTORS AFFECTING THEIR DISTRIBUTION, AND THEIR PAST PRESENT AND POTENTIAL USE

C. B. CRAMPTON

Soil Survey of England and Wales, Rothamsted Experimental Station, Harpenden.

Soil Evolution

Summarising the data presented in Fig. 1, it can be seen that an earlier (Mesolithic) and a later (Bronze Age) forest were eroded by human and climatic agencies to yield heathland (Neolithic and Medieval). Man as a factor of deforestation is suggested by evidence of burning (Crampton 1965b), and climate as a factor is suggested by the spread of hazel first over the higher peaks in South Wales (Crampton 1966a), implying the earlier retreat of forest from these higher peaks: it is unlikely that man would deforest the prominences first. Progressive leaching of the soils accompanied these vegetational changes, culminating in the development of podzols during Roman times, and blanket peat during post-Medieval times. There were two phases of clay translocation, Neolithic and post-Medieval, coincident with or following periods of peak storm activity in the region (Higgins, 1933), a second phase suggesting discontinuity in the accepted cycle of soil evolution as proposed by Pearsall (1960) and Dimbleby (1965), and the influence of man. During this late phase gleying occurred in many soils. Fig. 2 illustrates, diagrammatically, soils buried during Bronze Age and Medieval times and surrounded today by peaty gleyed podzolized soils, demonstrating aspects of the soil evolution described. In particular, Fig. 3 illustrates with the passage of time the increasingly finer textures of soils around these archaeological sites.

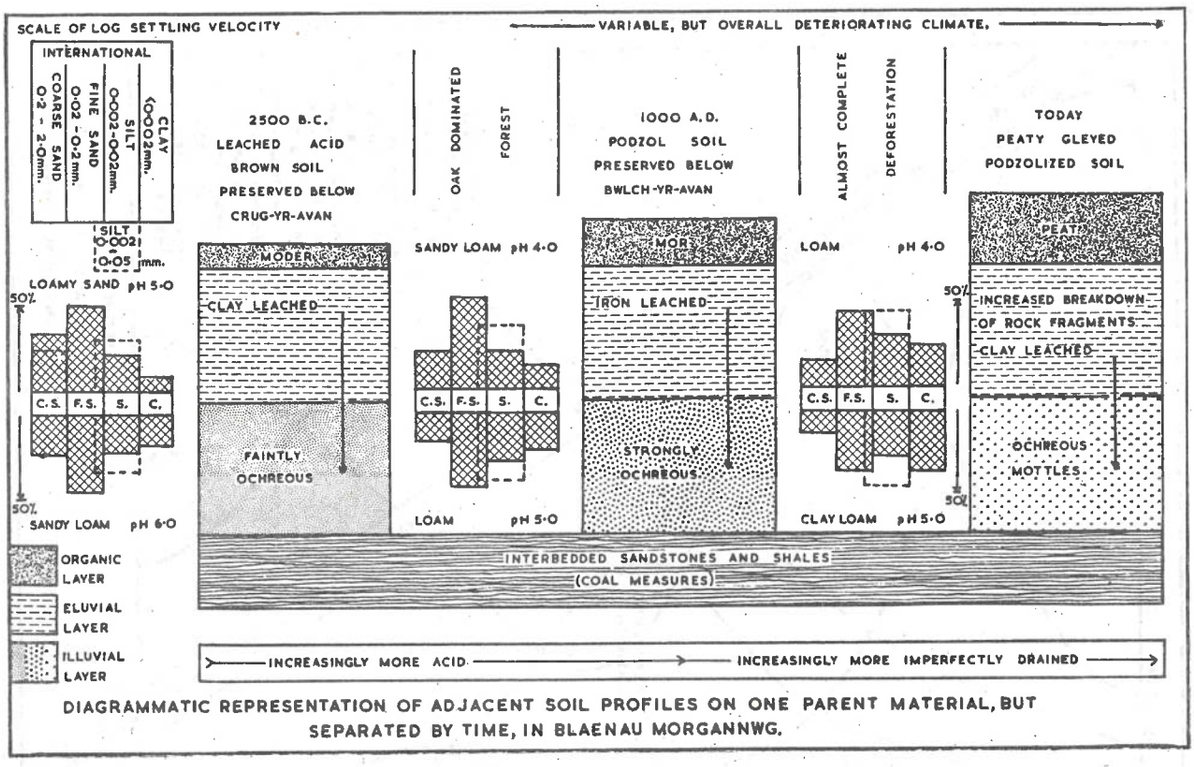
It will be shown later (Fig. 10) that planting trees in hill soils improves their fertility by removing more water from the soil than does grass, this being crucial in areas of moderately heavy rainfall. Conversely, it might be supposed that the removal of trees would allow more of the precipitation falling on the area to remain in the soils, as observed by Zakopal (1958). In conjunction with an increased rate of weathering and release of clay into the soils, this would encourage waterlogging and peat formation.

Physiography

The Black Mountains range arising from Old Red Sandstone rocks constitute the backbone of the hill-lands investigated in S. Wales, these

Fig. 1

Evolution of soils and flora in South Wales.



DIAGRAMMATIC REPRESENTATION OF ADJACENT SOIL PROFILES ON ONE PARENT MATERIAL, BUT SEPARATED BY TIME, IN BLAENAU MORGANNWG.

Fig. 2

Palaesols in the upper Avan Valley.

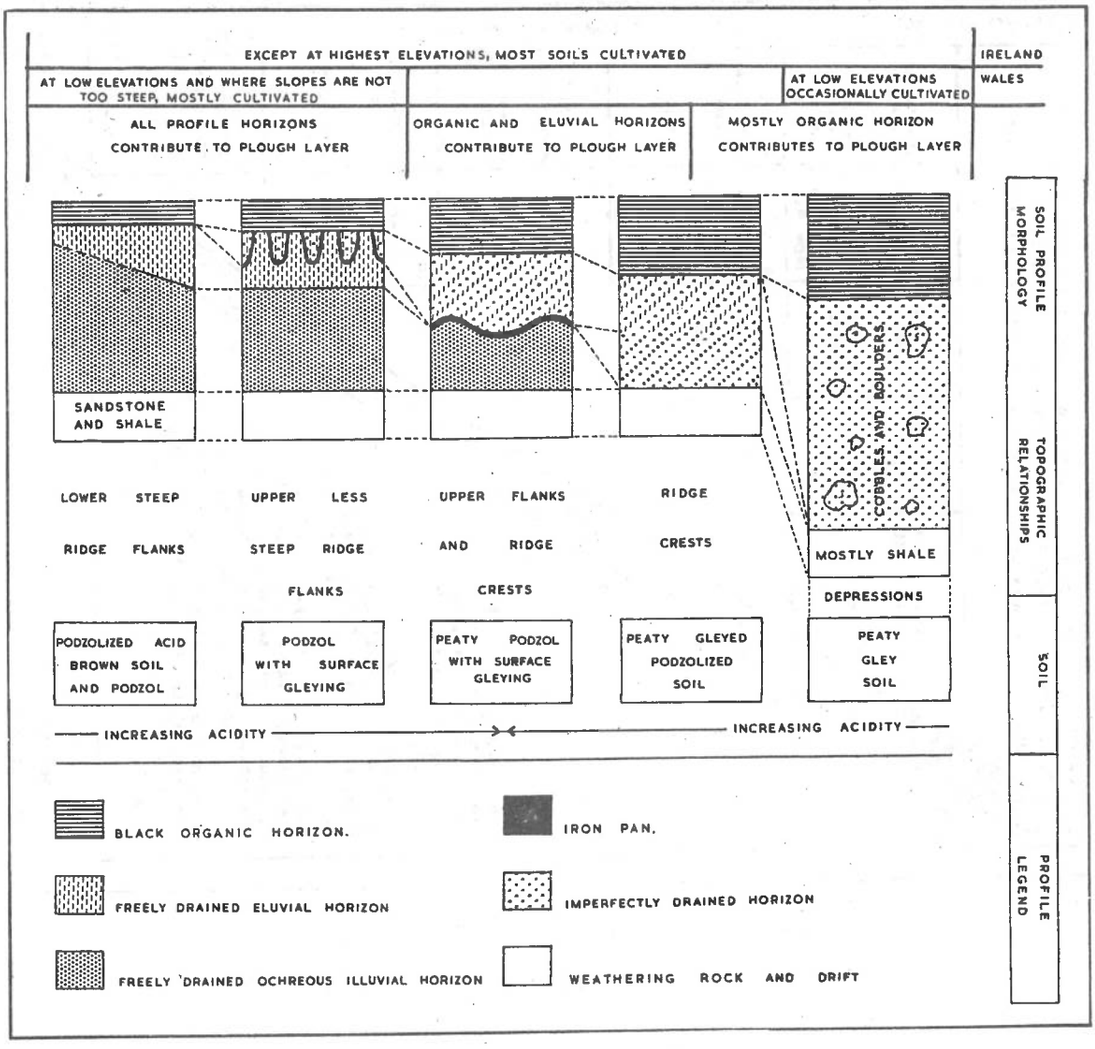


Fig. 3

Morphology of selected profiles.

hills culminating in the Brecon Beacons (2906 ft. O.D.). The outcrop of the Coal Measures to the South of this range gives rise to Blaenau Morgannwg, culminating in Craig-y-Llyn (1969 ft. O.D.), and the outcrop of Lower Palaeozoic rocks to the North of the Black Mountains range forms the escarpment of Mynydd Eppynt and the highland of Drygarn. (Fig. 4).

On the hillslopes occur podzolized acid brown soils ("podzolized soil bruns acides" - Mackney and Burnham, 1964) and podzols with surface gleying (Crampton, 1963). Plateaux and valley bottoms are occupied by peaty gleyed soils, described as "peaty gleyed podzolized soils" on ridge summits. Peaty podzols with surface gleying (peaty gleyed podzols - Muir, 1934; Crompton, 1956) occupy the summit margins. Both the normal topographic (Fig. 3) and altitudinal zoning of soils, and exceptions arising from differences in parent material, rainfall and aspect, are illustrated by reference to the Eppynt plateau and Irfon valley (Fig. 5).

Most of the plateaux are occupied by Molinetum, the upper slopes by Vaccinetum, and the lower steep slopes by Pteridetum. Brecknock has a higher proportion of commonland than any other county in Britain except the W. Riding of Yorkshire, the only extensive privately owned upland areas being Fforest Fawr and the military range on Mynydd Eppynt. The three dominant types of vegetation are widely, though unequally, distributed in this commonland.

The rainfall is greater than 90 inches per annum over the summits of Drygarn, Brecon Beacons and Craig-y-Llyn, falling to around 70 inches per annum over most upland plateaux. The Black Mountains (in the East of the range) and the East of Blaenau Morgannwg lie within the rain shadow of the higher western parts. Similarly, Mynydd Eppynt lies within the rain shadow of the Brecon Beacons (Fig.5).

A History of Deforestation

In Fig. 5, Mynydd Illtyd has been chosen as an example in Brecknock of deforestation by successive phases of hill farming and neglect. The Iron Age camp indicates an early phase of settlement on the hill. There is evidence of widespread burning by Iron Age folk to clear the trees for settlement (see Appendix to Report No.8). During Romano-British times, settlement will have concentrated in the fertile lowlands and, probably, Mynydd Illtyd was largely abandoned to woodland regeneration. However, a road was taken across the Common, part of which has been previously recorded, though where it crosses the

southerly part of Mynydd Illtyd (Fig.6), greatly enlarged air photographs (lodge at the Mountain Centre, Brecon Beacons National Park) reveal its previously unrecorded course. As the Romans left Britain, there is evidence in the form of Ogam Stones (Jones Davies, 1956) and place-names (Richards, 1960) that the Irish penetrated along the abandoned roads into Brecknock. "Llwch" in nearby "Cwm Llwch", "Cefn Cwm Llwch" and "Llyn Cwm Llwch" is Irish in origin. On the northern prominence of Mynydd Illtyd (Crampton, C. B. Ancient settlement patterns in Mid-Wales. Arch. Camb., (in press)), "Clachen-type" nucleated enclosures and a network of very small fields ("gardens" - less than one acre in area), are reminiscent of the ancient farming pattern in Ireland based on the "rundale" system (Evans, 1937), now largely relic, although any correlation must be tentative as so little is known of early Welsh farming patterns. An examination of field boundaries reveals how the original sub-surface layers in some were compacted by traffic, presumably for the purposes of cultivation and harvesting. Other fields were hedged with gorse for grazing animals and, locally, can still be discerned.

These fields cross all other features on the hill (and therefore are later), except for areas of ridge-and-furrow ploughing which represents a later episode of hill farming, probably around 1000 A.D. when there was a temporary warming of the climate (Lamb, 1965). With local exceptions, this phase of ridge-and-furrow ploughing cannot be discerned easily on the ground, though a later phase (possibly 19th Century) can. There has been insufficient time for the land to completely settle and there are pronounced corrugations across the ground surface.

The Irish re-introduced Christianity into Brecknock, and following the earlier pagan settlements, St. Illtyd established a church on Mynydd Illtyd, possibly during the 6th century. The Normans (Renn 1961) or Welsh (King, 1962) erected a motte on Mynydd Illtyd, there being no trace of a bailey. Under the Normans the Cistercians created vast sheep estates, which severely hindered forest regeneration (Rees 1959). There followed active afforestation to create game and timber reserves, but this phase also passed and the hills were again used as pastures. In the 16th century the Act of Union uniting Wales with England created large markets for dairy produce, and hafotai were erected on the hills as summer dwellings and dairies (Davies, 1937). The hills were becoming uninhabitable during the winter as the climate was deteriorating fast, culminating in the so-called "Little Ice Age".

Late 19th century Scottish families emigrated into Brecknock, and carved farms or allotments out of the rough grassland. Their farms

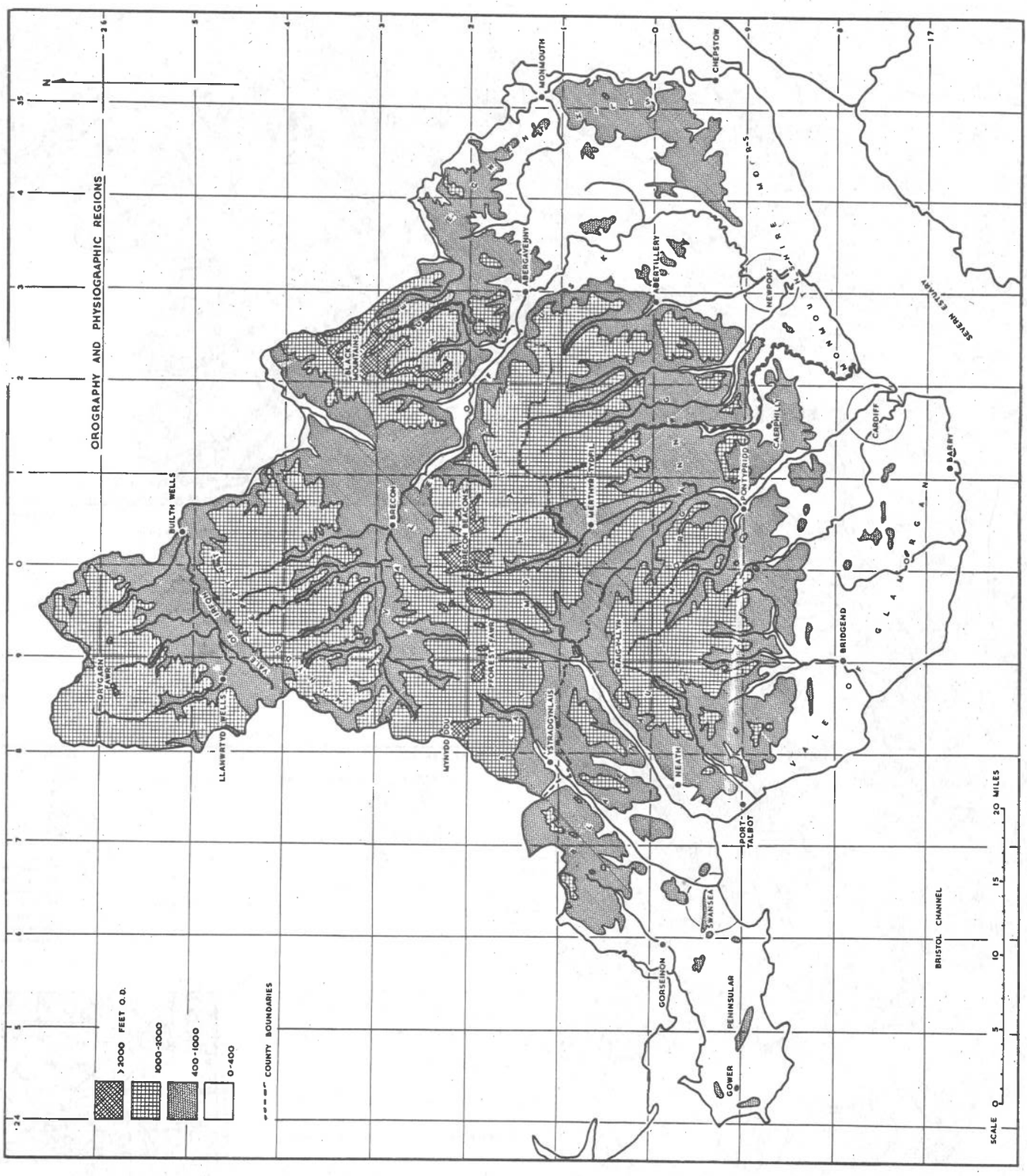


Fig.4.

Orography and physiographic regions.

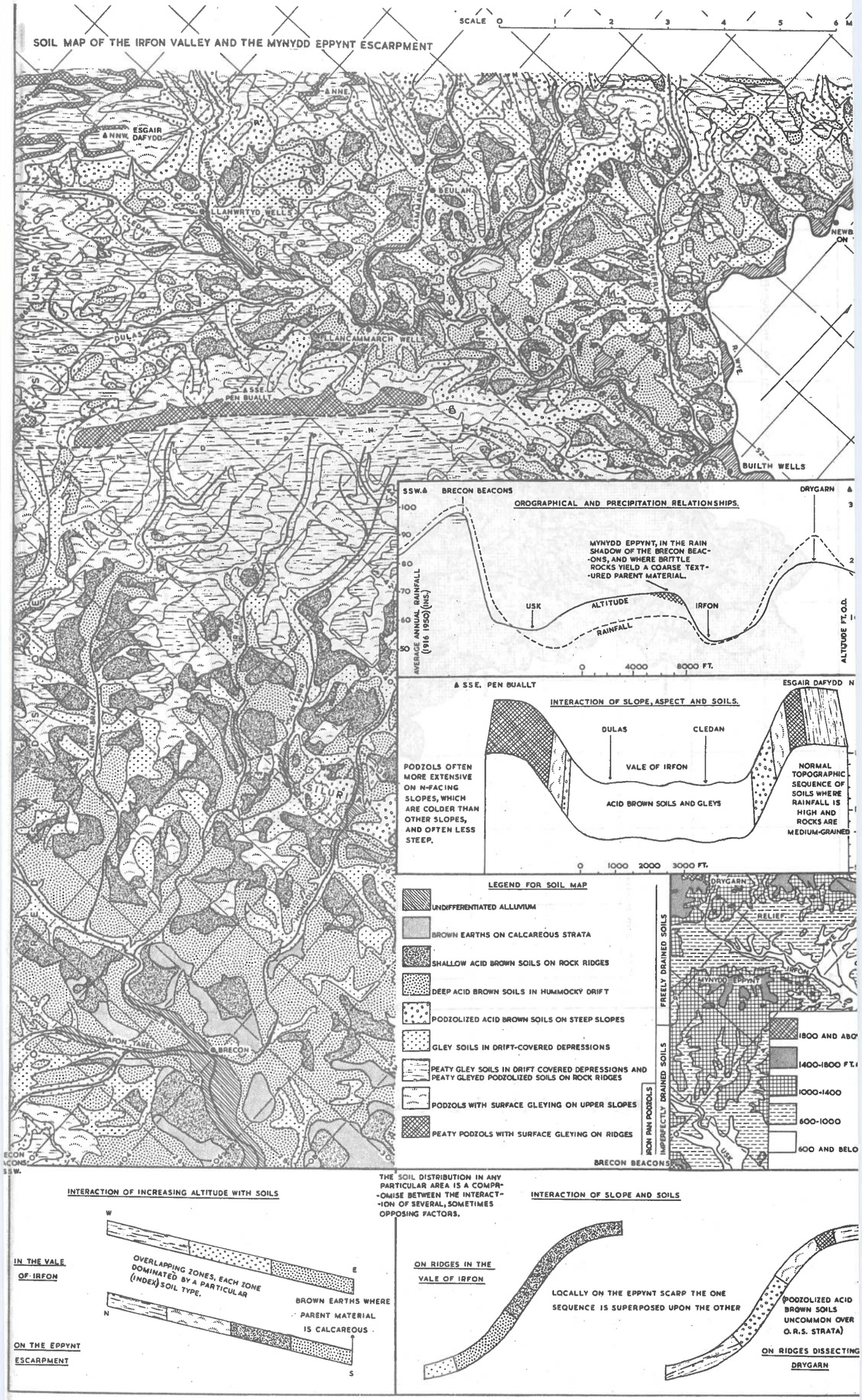


Fig.5
Soil Map of the Irfon Valley and Mynydd Eppynt Escarpment

can be recognized by the shelter belts of trees around the home fields, and by the very extensive drainage schemes which they initiated in the area.

Hill Reclamation for Intensive Farming

Podzolized acid brown soils and podzols with surface gleying normally form part of a catenary sequence on slopes, but on lower hills these soils may occupy the tops. The former soils are usually associated with bracken (and sometimes gorse), and the latter soils with bilberry (and sometimes heather, although in many swards today this has been grazed out). The old saying of mid-Wales "There is Gold under bracken, Silver under Gorse, and Copper under Heather", is a very true assessment of soil potential for reclamation. During the "Golden Years of British Farming", around 1870, records show that bracken land was sought after for enclosure and ploughing to grow wheat. Today, many hill farm arable soils show a sub-soil layering characteristic of the podzolized acid brown soil and podzol with surface gleying (Crampton, 1964). Ploughing breaks up the superficial organic mat and underlying gleyed horizon in these soils (Fig. 3), to yield useful arable land, today capable of producing 25 cwts/acre oats, 15 tons/acre swedes and 9 tons/acre potatoes. This productivity is difficult to obtain by ploughing peaty and gleyed soils which, if reclaimed (today, with a comparatively large capital outlay), are best utilized as pasture, though in Southern Ireland peaty gley soils and peaty gleyed podzolized soils were, at one time, widely reclaimed for agriculture (Fig. 3), such was the pressure on the land.

The approximate yield/acre on unreclaimed hill is 1 sheep. Fig.7 below gives examples of useful reclamation schemes in South Wales. War-time (1939-45) reclamation was hindered by restricted supplies of fertilizers. Both Griffith et al. (1951) and Ellison (1953) describe Agrostis and bracken land as the most amenable to improvement by ploughing. Less account has been taken of bilberry land which is unusually widespread in South Wales and also amenable to improvement by ploughing.

About 6½% of the combined areas of Glamorgan, Monmouth and Brecknock is now forested, virtually all by the Forestry Commission. In 1965 the total yield from these forests was 1,7000,000 Hoppus feet . Coed Morgannwg (combining Rheola, Rhondda, Margam and Michaelston Forests) is the largest in Wales, and the third largest forest in Britain. Central Blaenau Morgannwg is not commonland, and this has allowed

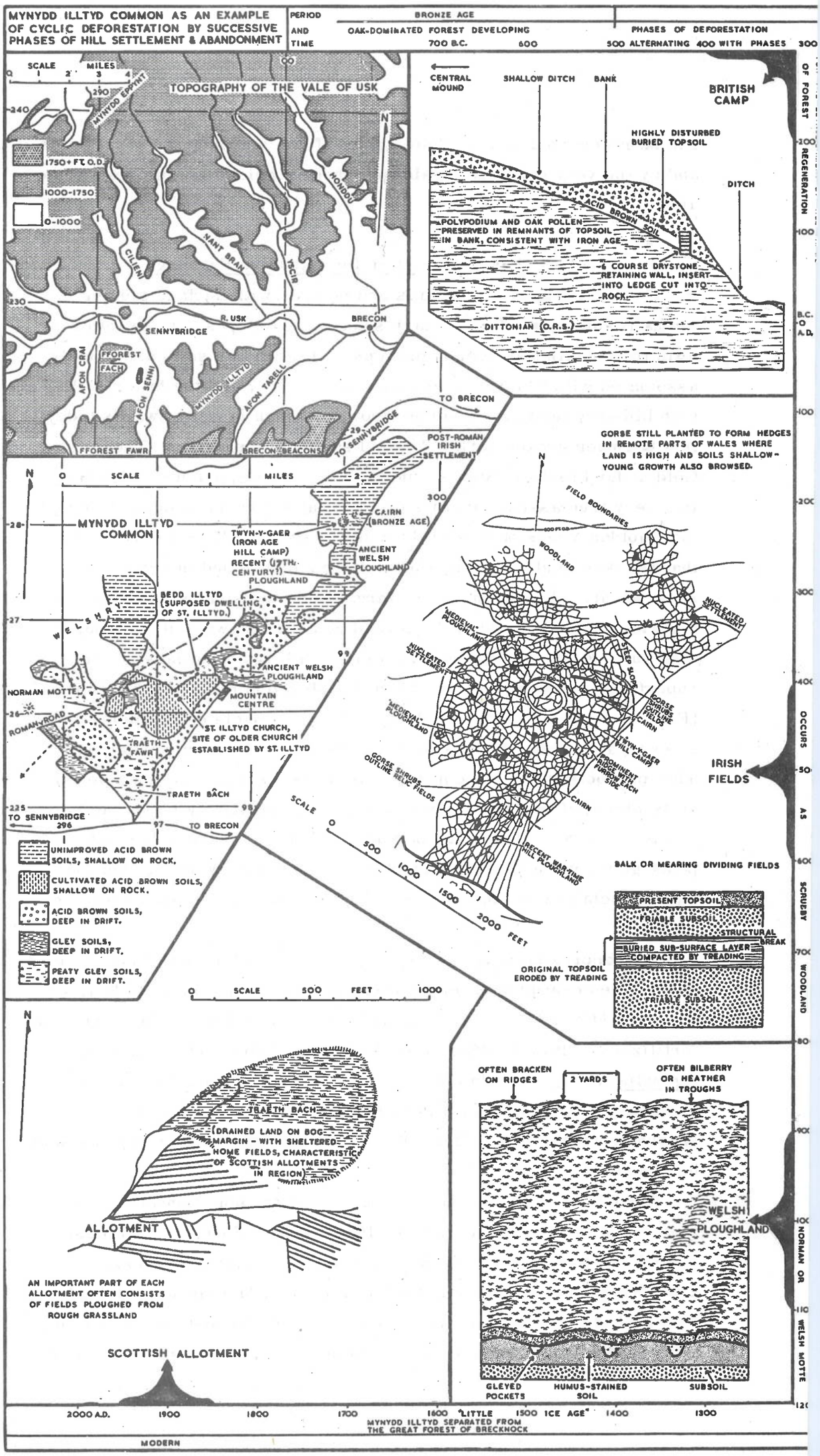


Fig.6.
History of Settlement and Deforestation on Mynydd-Illtyd.

Location, treatment and yield.			
	1939 - 1945	1957 - 1962	
Podzolized acid brown soils	650 O.D. on Mynydd Emroch. 3 tons burnt lime - 10 cwts basic slag - 5 cwts complete fertilizer per acre. 100 bales grass - 5 sheep - 5 lambs - 2 cattle per acre.	750 O.D. on Foel Fynyddau (N. aspect). 5 tons burnt lime - 1 ton basic slag per acre. Too exposed for lambs and cattle - but 10 sheep per acre.	Blaenau Morgannwg (Coal Measures)
Podzol with surface gleying	Seeded with mostly perennial ryegrass and white clover.		
	1200 O.D. on Hay Common. 3 tons ground limestone - 10 cwts basic slag per acre. 30 cwts barley - 3 sheep - 1 bullock per acre.	1200 O.D. on Mynydd Fforest Rape on which 13 lambs fattened - 8 tons potatoes per acre.	Black Mountains Range (Old Red Sandstone)
	700 O.D. on Garth. 3 tons ground limestone - 15 cwts basic slag per acre. Rape and oats grown - cattle and sheep grazed.	1200 O.D. on Mynydd Eppynt. (N. aspect). Surface treatment, cutting and grazing.	Mynydd Eppynt scarplands (Silurian)
	Cattle and sheep, periodically, appear to need a change from the rich lowland pastures. This, dunging and "camping out" at night noticeably improve hill pastures adjoining the reclaimed land.		

Fig. 7

FIG. 7

Reclamation Schemes in South Wales

a rapid expansion of the forest. Elsewhere, commonland rights have precluded such a rapid expansion and, for example, the growth of Talybont and Bannau Forests in the Brecon Beacons, or of Gamrhiw and Irfon Forests in Drygarn has virtually ceases.

Hardwoods would never grow into an economic crop on the hills, and so have been planted only where amenity considerations are important. Japanese larch has been planted in the better drained soils and Pteridium on steep lower slopes; Scots (and recently Corsican) pine has been planted in the imperfectly drained soils and Vaccinetum on upper slopes; and Sitka spruce in the poorly drained soils and Molinetum occupying ridge summits.

Slope soils are most extensive where hard geological strata give rise to prominent land masses with abundant steep slopes. In the Black Mountains Range, slope soils (that is podzolized acid brown soils, podzols with surface gleying and peaty podzols with surface gleying) are most extensive in the East of the range, whilst peaty gley soils are more extensive in the West of the range. Blaenau Morgannwg is rich in slope soils, except at its summit. The plateau of Mynydd Eppynt is occupied mostly by peaty gley soils, whilst the scarp gives rise to a parallel S.W. - N.E. belt of slope soils. Likewise, the central plateau of Drygarn is occupied by peaty and gleyed soils, whilst slope soils dominate the periphery of the hill-mass.

Slope soils are associated with the most nutritious pastures for sheep (Crampton, 1966b), chiefly because of the variety of species present, and the yield from sheep increases as the proportion of slope soils in the land increases (Crampton, 1964b). Conversely, in the South Wales hills the yield from timber increases as the proportion of peaty gleyed podzolized soils in the land increases (Fig. 9). Any unit of sheep walk or forest must be large to be economically viable, and so the use of all slopes as sheep walks and all plateaux as forests is not tenable. Instead, large areas rich in slope soils (although also including plateaux soils) would be most usefully utilized as sheep walks, and large areas rich in plateaux soils would be better utilised as forests. Previous afforestation must be accepted, but future planting might be considered in the light of these suggestions.

In Fig. 9, if per cent values are transformed into angles, the correlation between soils and yields from sheep on the Glamorgan commonlands is significant at 0.02 level.

In Rheola Forest, if Sitka spruce is grown on the slopes to increase the yield above that from comparatively poorly productive Japanese

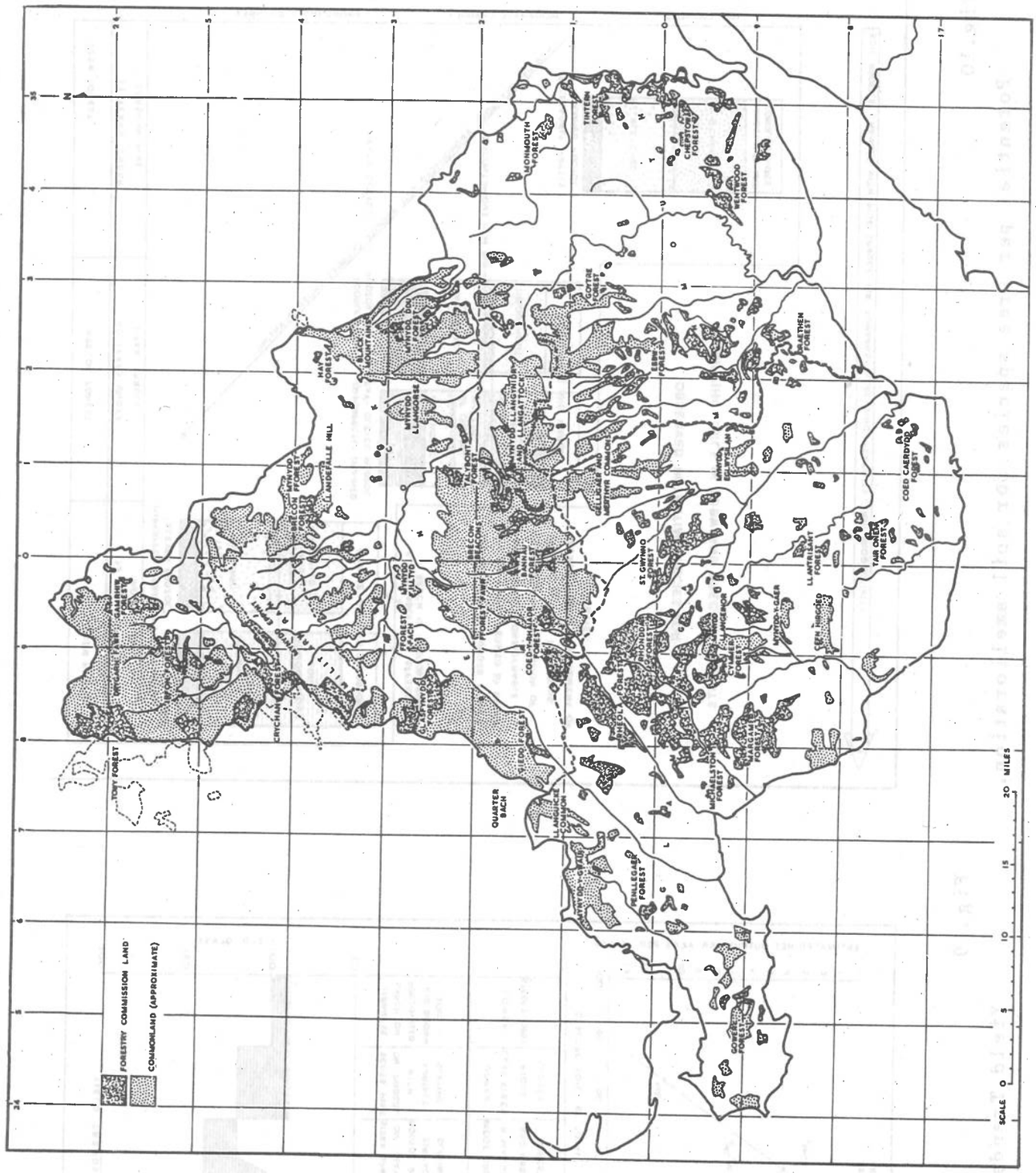


Fig. 8

Forest and Common land.

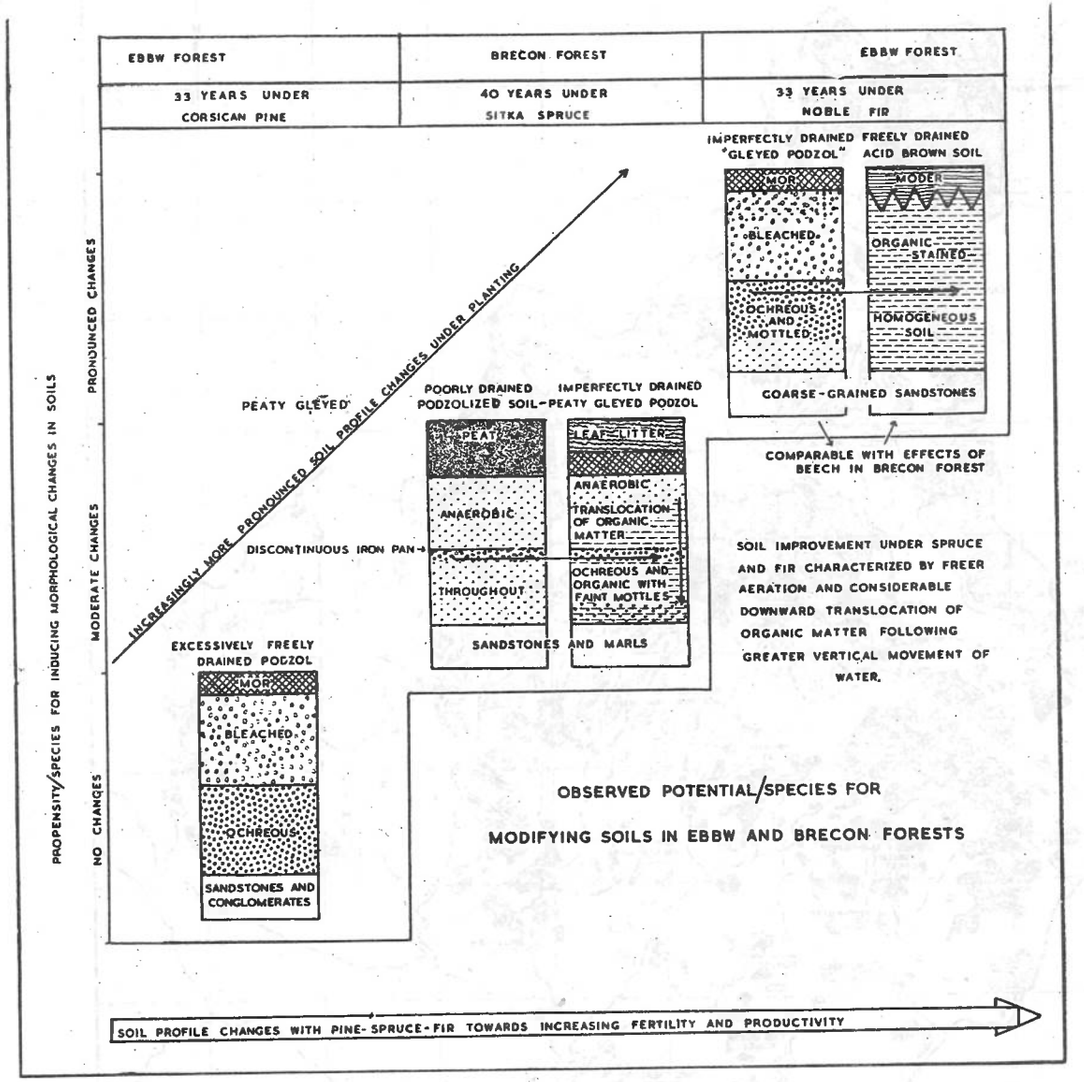


Fig.10

Potential per tree species for soil amelioration.

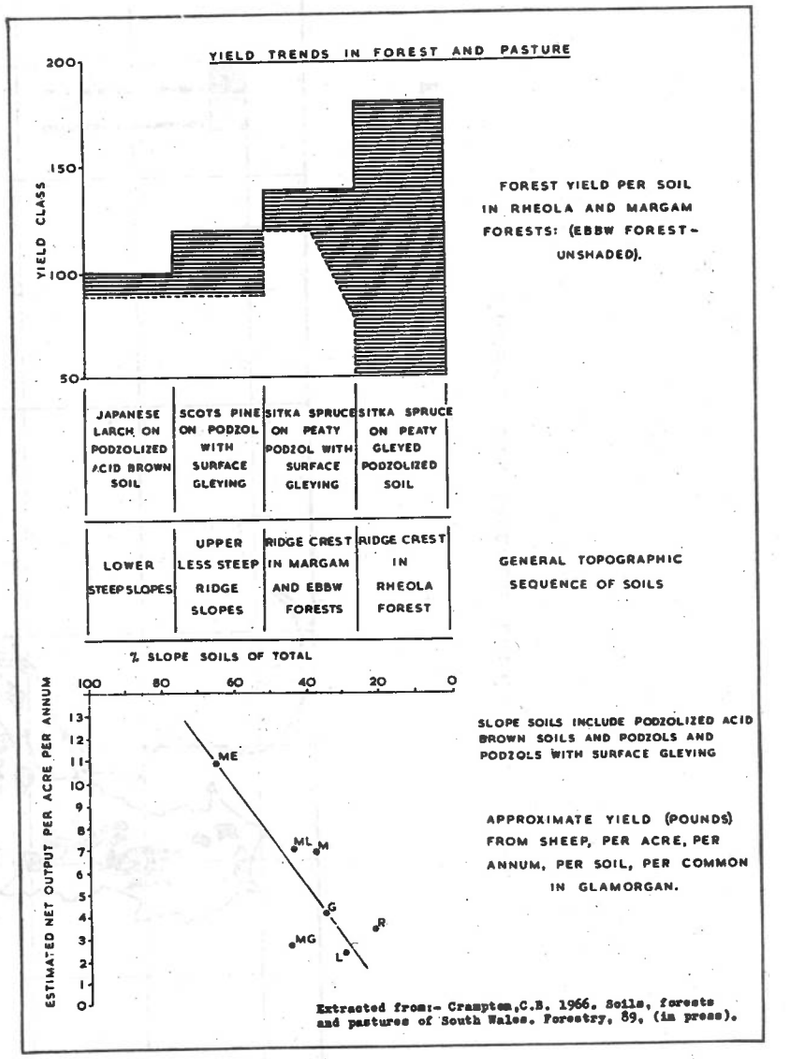


Fig. 9

Yield Trends in Forest and Pasture.

larch, seasonal (spring and summer) dryness often hinders its maximum potential growth. Although Salter and Williams (1965) found cultivated loamy soils have the maximum water-holding capacity, Hartge (1965) found undisturbed (podzolized and other) loamy soils settle most when the water-holding capacity is greatly reduced. Loamy soils are extensive on the hills in S. Wales, but the poorly structured, very compact, sub-surface layer usually present in the podzolized soils minimizes an otherwise high potential water-holding capacity. The effect is most noticeable in Ebbw Forest, which lies in the rain shadow of Blaenau Morgannwg, where all tree species are, more or less, affected, despite a rainfall which locally on the hills is 45 - 50 ins. per annum.

Insofar as the limited data allows interpretation, fir has the greatest potential for improving hill soils, the trend being towards acid brown soils or soils more suitable for the optimum growth of fir (Fig. 10). This modification of gleyed soils by fir in Ebbw Forest is comparable with that by beech in Brecon Forest. Though not so pronounced an effect, spruce is also capable of improving soils when they are of very low initial quality, that is peaty gleyed podzolized soils in Brecon Forest. In Ebbw Forest, pine has produced only small changes. This improvement is chiefly in the form of freer drainage and a greater penetration of the soil profile by organic matter (which ceases to be confined to the surface peat), with a significant amelioration of structure. This improvement can only have been achieved because of a greater amount of transpiration by trees compared with grass, the tree roots demanding more water from the subsoil, (Rutter and Fourt, 1965) which encourages a greater vertical movement of water in the soil profile, carrying organic matter downwards.

Penman (1949) thought rooting depth an important factor governing the water available for transpiration. Croft and Monninger (1953) considered that the greater rooting depth of trees compared with the ground flora allowed the trees to tap far greater moisture reserves and, therefore, to transpire for longer and remove more water from the soil. Zonn and Mina (1949) observed drying of the soil to a greater depth and more uniformly under trees compared with steppe vegetation. Consistent with this work, Voronkov and Sokolova (1951) measured more run-off from a cleared catchment than from forested land, and Steven (1964) reported measurements suggesting a one third less run-off from under Sitka spruce, compared with the surrounding grassland.

Hence, the extensive planting by the Forestry Commission of Sitka spruce in peaty and gleyed soils on the South Wales hills should moderately

improve the fertility by removing excessive quantities of water from the soils. Potentially, fir may be a greater improver of soils as it is a more exacting species than spruce, but it is difficult to establish fir in ridge summit peaty soils (Legard and Harris, 1964). After a generation (60 year cycle) or two of Sitka spruce, the soils might be more suitable for more exacting and more productive species.

Byrnes and Kardos (1963), Borovinskaya (1963), Solov'ev (1960) and others found that compared with grassland, afforestation improved the humus and nutrient content of soils, and their structure and premeability.

A greater vertical movement of water in the soil profile will not recreate the widespread podzols of Roman and Medieval times as during these times the soils were relatively coarse-textured (Fig.2) and a suitable medium for podzolization, whereas since these times sufficient clay has been released into the soils for medium textures to be widespread on the hills.

Acknowledgements

Eppynt plateau soil map from field data, by kind permission of K. E. Clare, Head of the Soil Survey of England and Wales.

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DISCUSSION

R. T. Smith (U.C.W., Aberystwyth) suggested that the general availability and siting of ancient monuments might lead to misleading results. Considering the present altitudinal zonation of soils, it seems important that archaeological sites be related to natural profiles at the same elevation before interpreting the order of developmental phases.

C. B. Crampton, in reply, stated that ll the archaeological sites examined were erected on or near ridge summits, and all are surrounded by peaty gleys on loamy/sands to clay loams at the present day.

D. A. Jenkins (U.C.N.W., Bangor) enquired how two phases of lessivage (as suggested in Fig.1) could be differentiated in the evidence from a single profile.

C. B. Crampton replied that two phases had been deduced by examining many archaeological sites: in any one profile there was evidence of clay movement in the form of clay skins on structure surfaces, but phases of clay movement cannot be differentiated. In reply to a further suggestion by R. T. Smith that gleying might be correlated with clay lessivation, C. B. Crampton said that no such correlation had been made although clay movement no doubt contributed to gleying.

L. J. Hooper (N.A.A.S., Cardiff) asked whether the conclusions from the sequence of events depicted in Fig. 1 were that man or climatic cycles were the cause.

C. B. Crampton replied that the Neolithic Heathland arose from deforestation for agriculture; corn pollen had been found in Neolithic sites at Llanelwedd in Radnorshire, and Ogmore in Glamorganshire. The Bronze Age folk were probably primarily pastoralists whilst the Iron people once again undertook extensive felling which resulted in wide-spread erosion and buried charcoal layers.

G. E. Jones (U.C.W., Aberystwyth) enquired how many Forestry Commission Compartments were considered in the statistical analysis of timber yields from sitka spruce and Scots pine; he also suggested that it was unfair to compare the yields from the two species since they would invariable be of different yield classes and would be planted on totally different sites and soil types.

C. B. Crampton said that the analysis of timber yields was not statist-

ical, and concerned information only from the few sites available. Comparison had been made between two species of different yield classes and occupying different sites and soils, but this was the object of the exercise. Confirmatory results had recently been obtained from the Forest of Dean.

E. H. M. Harris (Gwydr Forester Training School, Capel Curig) said that yield classes are in fact comparable between species, and went on to ask what the effect of afforestation by sitka spruce was.

C. B. Crampton replied that recent investigations showed that planting firs, in particular, and spruces on impoverished hill soils improved drainage and fertility. Because so much sitka spruce had been planted on hills in South Wales, any resultant improvement of soil fertility, even if small, was very important. In the Forest of Dean, the effect of spruce was greater than that of pedunculate oak.

PART II

The Upland Environment

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The aim of this paper is to place the upland soils of Wales within their environmental context. The term environment is here used in the broadest sense to include, both the physical or 'natural' factors affecting soil development and the human or biotic factors embodied in a legacy of cumulative land use. An integrated study of upland soils will be attempted within the evolving ecosystem of which they are a fundamental part. Although initially easily described such an integrated view is ultimately difficult because it demands adequate reconciliation of physical and human factors, and of economic and social priorities as well. Again, any theoretical assessments of our uplands must be cast agains their usage in practice - a usage which is equally at the mercy of factors quite external to the uplands as well as factors derived within the uplands themselves. Decision making within land use systems ranges from the considered opinion, prejudice or even the whim of the individual land user or land owner to the local or national decisions made normally via committee procedures and subject of course in particular circumstances to local authority or governmental ratification. It is becoming increasingly difficult to make academic assessments of land use problems when confronted with this formidable hierarchy of decision-making particularly should the latter tend to be negative, procastinating or obstructive rather than positive and remedial.

None the less it is possible to assess soil as a resource as well as to describe and map it as a component of the landscape. It is also possible to relate the soil to the ecosystem and land use of the site. Again, inherent soil and site potential can be measured against the actual performance of the land use system operating. Relative productivities can be determined and schemes drawn up for the optimisation of land use resources. The latter must include the complex factor of land management which is inevetably subject to economic and social factors in addition to purely technical and personal considerations.

Such a broad conspectus of the upland environment ranging from

the genesis of the soil resource to the ultimate decision as to its use can achieve focus only by precise, if selective, illustration and by critical case-studies.

II. THE CHARACTER AND LIMITS OF THE WELSH UPLAND ENVIRONMENT

The Welsh uplands consist of a series of dissected plateaux (Brown 1960) mostly above the 1000' contour - an initially crude, simple but convenient limit. Fragmentation is the key note. Familiar and famous sub-units emerge such as Snowdonia, Hiraethog the Cadair Idris range, and the Brecon Beacons. Equally famous upland vales separate these blocks - the Dee, Dovey, Severn and Wye to name but a few. A degree of geological consistency is imposed by the extensive exposure of Silurian and Ordovician rocks which impart a softness of contour except where hard rock bands such as contemporary volcanic rocks introduce ruggedness. The consequence in the relief is a repetition of plateau units with distinctive'tops', slopes of varying aspect, and 'bottoms' which are essentially parts of the valley heads and upland vales previously noted. Thus, in general terms, fragmentation of relief is accompanied by repetition and relative monotony of land form.

Superimposed on, and locally related to, this distinctive topography is an extremely maritime macro-climate. Both geographical position and a relatively sharp change of elevation on the west are primarily responsible. The climatic and associated ecological gradient between the coast at Aberystwyth and the summit of Plynlimon, for example, is probably one of the steepest per mile in Britain as is the well known contrast between lowland and upland Caernarvonshire. The ten major components of the largely unmeasured, upland maritime climate as opposed to its much better documented lowland counterpart are as follows:- vide Manley (1945), Oliver (1960), Taylor (1961).

(i) high rainfalls with higher intensities and longer durations
(ii) low evaporation rates and therefore high precipitation/evaporation ratios.
(iii) relatively heavy snow falls and more persistent snow cover.
(iv) high humidity and cloud amounts.
(v) low sunshine amounts.
(vi) reduced illumination.
(vii) low average temperatures and particularly low maximum

temperatures.

(viii) long winters, low minimum temperatures and high frost frequencies.

(ix) late and short growing season.

(x) increased exposure to strong winds and winds in combination with low temperatures, snow, rain or on occasions relatively dry air all of which at times may constitute hazardous or critical weather conditions.

Therefore, in climatic terms, the upland environment is one of severe limitations even with small increases in altitude. Equally remarkable too, however, is the earliness and warmth of south-facing sites as against the lateness of north-facing ones. The advantage operates inversely during prolonged dry spells.

Now this upland climate, like any other climate, is subject to change and fluctuation on varying time scales. Within the Post-Glacial period since circa 10,000 B.C., the well known series of climatic phases has been established by the work of Godwin (1956) et al. In upland Wales, however, it is very probably that these climatic phases were differently timed (possibly retarded) and involved different values of temperature and rainfall. This would imply different vegetation and soil history, as research by Smith (1967) at Aberystwyth is indicating. The results of this research, based mainly on the extraction of soil and sub-soil pollen, suggest that the mixed deciduous oakwood climax manifest in data for English bog sites and indeed for some lowland, and one or two upland, bog sites in Wales, did not develop on the higher plateau surface of upland Wales above say 1500' O.D. where the pine and birch woods of the Boreal period may have persisted till the deforestation which began about Neolithic times and subsequently. Burnett (1964) virtually implies a parallel development for the higher parts of the Scottish Highlands. On the slopes below the plateau edges, however, it is likely that oak was in fact much more prominent. These are essentially the ffridd lands of Wales and the zones of the Cymmer soil series (now included as the steep phase of the Denbigh series). These are the areas of late enclosure above 700' O.D. which took in land up to about 1000' - 1100' O.D. On the vegetation map of Wales produced by Stapledon and Davies in 1936, the same zones emerged as dominated by Agrostis with fescue spp., fringing the so-called Molinia-Nardus Moor of the uplands proper. On the maps of the current Vegetation Survey of Wales, as reported by

Taylor (1967), the true variety of the upland vegetation units is emerging as is a correlation between the major occurrences of bracken (Peridium aquilinum) and the ffriddoedd zone which constitutes a transitional unit sandwiched between true upland and true lowland. The pressure of land use has oscillated across these intermediate slopes reaching its maximum height over a century ago but now easing downslope as rural areas depopulate and as modern, mechanised grass farming places more emphasis on the role of improved lowland pastures.

The Welsh maritime uplands are thus strongly characterised both in morphology and climate and associated soil/vegetation development. Their limits are equally dramatically expressed in the ffriddlands, an oscillating marginal zone of land use change.

THE EVOLUTION OF THE UPLAND SOIL ENVIRONMENT

The modern soils and vegetation cover of the Welsh uplands are not only directly affected by modern cultivation and grazing but also reveal the effects of past changes in both the bioclimatic environment and in land use systems or cycles. Pre-historic as well as recent events can effect the modern soil profile and its use potential. Stewart (1960 and 1961) has shown, for example, that fossil perma-frost layers dating from the Late Glacial Period or earlier can create perched water tables which maintain the moisture status of the soil above during dry spells whilst adjacent land, where such layers are not present, burns out. This was particularly noticeable during the dry summer of 1959 on sites overlooking Aberystwyth. On the debit side, however, such impermeable layers, when undetected in the field reconnaissance conducted prior to afforestation, can restrict root development in conifers after some ten years or so of satisfactory growth. Dovey Forest affords exampled of this problem. Alternatively, frost-shattered shale debris, again dating back to cold phases of the late Glacial Period or earlier is easily percolated by water and moisture deficiencies in associated soils are in fact increased. Irrigation of afforested sites in Dovey - even those receiving 60 to 70 inches of rain p.a. - has been experimented with and would appear to be economically as well as ecologically worthwhile. Watson (1967) has demonstrated the impact of prolonged periglacial conditions on surface materials and soil differentiations in West Wales. The striking contrast between warm and cold slopes convinced Crampton

and Taylor (1967) that cycles of terrace development for example due to solifluction on warm slopes first and cold slopes later was the probable explanation of the surviving patterns of terrace features in South Wales. Shallow, compacted, but early, dry soils on overgrazed, south-facing slopes contrast today with deep, wet, late soils on undergrazed, north-facing slopes.

The periodic burning of vegetation, especially Ericaceous vegetation, since early times is evidenced in charcoal horizons in modern soil profiles. Duplication and even triplication of "organic tops" and their altemation with thin mineral horizons has been attributed to burning and also to the effects of hill wash. The profile described near Rhayader by Taylor (1965) at an elevation of 1450' O.D. revealed a variety of organic and inorganic horizons, suggesting the effects of earlier cultivation, burning and hill wash.

A relatively recent element to accumulate in the uplands is the so-called 'climatic' peat. Whilst the upland climate has certainly been a major agency in its development, the shallow phases of upland peat would now appear to be definable as a pedological formation, at least in part. The postulated continuous heath vegetation on High Plateau sites must also be implicated as an additional agency within an ecosystem which was bound to involve the progressive accumulation of organic material at the surface. Evidence on this subject and on the problem and effects of peat erosion is being assembled by the current survey of upland peats in Wales (vide Taylor and Tucker 1966).

Thus, modern soils and their productivities may be affected by fossil properties derived from antecedent environments.

CONTEMPORARY CASE-STUDIES

Turning to modern land use of upland soils it is remarkable how land of such relatively low value can involve at times such critical competition for selected, specialised sites often where problems of accessibility are involved.

Sheep farming traditionally occupies large areas. The standardised grazing it generates is deleterious to the moorland vegetation. Palatable species are being grazed out; unpalatable species are expanding. It has been estimated that the total area at present under bracken in Wales, if taken together as a unit, would cover the entire counties of Breconshire and Radnorshire, (Taylor 1967). This is about 15% of the Principality or almost

twice the area owned by the Forestry Commission, over two-thirds of which in fact is planted. Since bracken normally colonises superior soils and warmer, less exposed sites, quality, as well as quantity, hill land is being sterilised, since reclamation techniques are so uneconomic and often ineffectual.

For nearly forty years now the work of the Forestry Commission has progressed in upland Wales. Much ffridd land has been planted including the steep slopes unwanted for agriculture and often originally in scrub woodland, mainly oak.

Integration between forestry and agriculture via employment, shelter belts etc. is a well-worn theme. Suffice it here to state that both forms of land use will continue to compete for the larger land units. It is almost inevitable that surviving upland farms will become larger by amalgamation, thereby enabling survival, and it is possible that the Commission will look to lower elevations as well as higher elevations for new land.

On the smaller localised scale, the need to develop water resources pinpoints the small specialised valley site. The resevoir construction effectively eliminates previous land use but affords opportunity for afforestation in its catchment and usually provides new and superior access roads which benefit both agriculture and tourism. The economic and national priority which must be given to water resource development is irrefutable. At the same time arguments concerning the preservation of other forms of land use, including amenity, should be reconciled.

Two case-studies will be used to focus the alternatives.

First of all in the upper Severn a number of recent events have converged, initiating research investigations which could prepare the way for a proper control and planning of the catchment along Tennessee Valley Authority lines. Initial ploughing for afforestation had on occasions caused flash floods and silting of rivers but the recent increase in flood frequencies (especially since 1940) could well be due to an inherent short-term climatic trend. Flood control will be aided by the imminent completion of the Clwedog dam, but the existing towns and quality lowland pastures in addition to any proposed new town will all need permanent protection aginst the flood hazard. Although the proposal to establish a new town raises the vexed question of further anglicisation, it is likely that the new town

if properly planned in terms of industry could maintain a diluted but stable rural land use structure based on large scale sheep and cattle farming including of course dairying and some market gardening, afforestation, tourism and further water resource development. Land capability surveys would reveal a basis for classifying land in terms of its optimum usage. Land-based economies cannot afford to ignore the basic and inherent qualities of the environment, qualities often reflected in the soil itself. The upper Severn then could, if the proper decisions are taken in time, become an example of how land resources can best be appropriated on a long-term, satisfactory basis which must accommodate economic, social and ecological alternatives.

A similar set of dilemmas confronts the Nant Ffrancon Valley in the heart of the Snowdonia National Park. Flooding it would enhance national water supplies but would meet with stiff opposition on amenity grounds. It is significant that the first major motel in North Wales was recently opened in this valley. Mobile tourism should provide a major source of revenue in the future for attractive amenity areas such as this.

CONCLUSIONS

This survey of the Welsh upland environment and its exploitation affords the following three conclusions.

First, that land capability surveys incorporating soil surveys and vegetation surveys must be regarded as a first step in assembling evidence for planning purposes. Antecedent, as well as contemporary, environmental factors are relevant to these surveys.

Second, that economic, social and, ultimately, political factors, despite their current escalation, should be allowed to control short-term changes only provided long-term ecological arguments, where relevant, have been fully reconciled.

Thirdly, it is obvious that since the upland environment is now exposed to powerful external factors which will control its destiny, it is only reasonable that any regional values placed on this environment should be functionally adjusted to its interrelationships with other regions which have received and will continue to receive its people, its animals, its water, its timber in comparative return for the financial subsidies which are invested in it.

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WELSH SOILS DISCUSSION GROUP

The Growth of Plants in an Upland Environment

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It can generally be said that conditions for the growth of plants in the uplands become rapidly less favourable as the altitude increases. Consequently not only does the quantity in terms of dry matter of the standing crop, and abundance in terms of numbers of species decrease, but the type of plant cover changes at greater elevations. It is the aim of this paper to consider briefly some of the more important factors which determine the growth of plants in the uplands, to indicate their effects upon the physiological processes of the plant and to consider the manner in which some plants have become naturally adapted to conditions of severe stress, with particular reference to their mineral nutrition.

It is apparent that often there is no direct relationship between a particular environmental factor and plant growth. Many factors may be operating at any one time, and this complex situation is made more difficult to analyse because of the perennial nature of the growth of most upland plants; furthermore the growth of a plant in one season may be influenced by the success or otherwise of the previous season's growth, and the severity of the intervening overwintering period. One of the most interesting aspects of the growth of plants, which has received much attention in recent years following the classic papers of Turesson in 1922, in which he put forward the concept of the ecotype, is that of adaptation of plants to the particular environmental conditions in which they are growing. Many environmental factors have been found to produce ecotypic variation within a species. Such variation is the result of the action of the environment, selecting from the mixed genotypic material of the local population plants. (Billings 1957). Although the plant variant and its physiology is the result of selection acting on the entire population by all the environmental factors in operation at any one time, it is possible to select the major factors and to observe the responses of the plants involved.

As altitude increases and the climate becomes more severe there appears to be a direct relationship between the growth of plants and the altitude of the habitat. Temperature, sunlight, rainfall, soils, and supply of mineral nutrients are the principal factors operating in the environment.

Temperature and the growth of plants

The effect of temperature upon the growth of plants is of considerable

importance. It is useful to appreciate that the rate of decrease of temperature in Wales is on average 1°C to 450 - 490 feet rise in height (Oliver 1966), so that at 3,500 feet, one can expect a temperature drop of some 7 - 8°C. Such rates of decrease in temperature have been found at Aberystwyth (Smith 1958), and at Craig Cerrig Gleisiad, Breconshire (Oliver 1964); preliminary unpublished data from Snowdonia indicates similar conditions. The effect of decreased temperature on plants is that of a decrease in metabolic rate, i.e. the rate of photosynthesis, enzymic reactions and cell division.

The rates of reaction of plant chemical processes are considered in terms of the temperature coefficient; that is the ratio between the rate of reaction at x°C to its rate at x - 10°C, this being called Q10. For ordinary thermochemical reactions the Q10 is 2 - 3; but photochemical reactions involving the absorption of radiant energy are almost insensitive to temperature and have a Q10 value close to unity. It is therefore important to realize that plants growing at altitudes at which a decrease in temperature of some 10°C can occur, will experience at least a halving of their metabolic rate in terms of thermochemical reactions. It is not surprising, therefore, that unless plants are adapted to have a greater metabolic efficiency at lower temperatures, then this factor will be of great importance in reducing their annual production of dry matter.

To illustrate the effect of altitude on the dry matter production of grasslands, data is presented below of the net dry matter produced by three Agrostis-festuca sites in Snowdonia;

Moel Eilio	1200 feet	391g/M^2
Llyn Llydaw	1600 feet	199g/M^2
Crib y Ddysgl	3,000 feet	78g/M^2

These are accumulative values obtained by clipping at monthly intervals vegetation which had been protected from sheep grazing by small portable cages. The results relate to the 1966 growing season, and show the rapid decrease in herbage dry matter production as the severity of the environment increases. It must be remembered that this effect is not due to temperature alone but due to a number of factors which include effects of solar radiation, rainfall and availability of mineral nutrients. The results were obtained as part of the Nature Conservancy's research programme on mountain grasslands carried out in conjunction with Dr. C. Milner, and directed by Dr. R. Elfyn Hughes.

Another feature that has been investigated by some workers is the extent to which plants are adapted to growing under conditions of low

temperature. The activity of enzyme systems in several bacteria exhibit a low sensitivity to a decrease in temperature, some being able to grow at 0°C. These enzyme systems have a low activation energy thus minimizing the decelerating effect on reaction rate of low temperatures. But when higher plants are considered this modification is not thought to be an important mechanism in low temperature adaptation. Data by Rabinowitch (1956) and Forward (1960) give the temperature coefficients for photosynthesis and respiration rates of groups of some arctic, temperate and tropical plants. There is not evidence of differences in Q10 values between these widely differing groups of plants. There is clear indication, however, that the rate of respiration is more intense in plants native to cold climates than those in warm climates. Forward (1960) quoted data by several authors and gave the mean rate of carbon dioxide evolved in milligrams/dm^2/hr at 20°C as 0.5 for tropical, 1.45 for temperate, and 2.8 for arctic plants. The fact that cold habitat plants have a greater respiration rate than plants found growing in warmer climates may to some extent compensate for the effects of low temperatures on growth. Mooney and Billings (1961), working with northern 'arctic' and southern 'alpine' populations of Oxyria digyna in North America, found that the respiration rate of the northern populations was greater at all temperatures, and that the rate increased more rapidly with increasing temperature. Plants of the northern population also had higher photosynthetic rates at lower temperatures than did the plants of the southern 'alpine' populations. Similar results have been obtained for species of Lycopodium and Equisetum by Scholander and Kanwisher (1959).

Arctic-alpine plants because of their dwarf habit and characteristic life-form, are generally well adapted to take full advantage of the more favourable temperatures near the ground. They are also able to withstand sudden drops in temperature during the growing season. (Bliss 1962). Such plants can often be found flowering surrounded by snow and ice and can later continue growing apparently unaffected by the period of low temperature, a situation which would seriously damage lowland species. In the most extreme environmental conditions found on the summits of mountains, the vegetation often consists entirely of moss and lichen communities, which have very slow rates of growth and minimal requirements as regards temperature and the supply of mineral nutrients. Many plants are adapted to the low winter temperatures of the uplands, by undergoing a period of dormancy, the cessation of growth prior to dormancy occurring even when temperatures are still adequate for growth. The ability of a plant to adapt to unfavourable

conditions in this manner means that the minimum of adjustments are necessary in the normal processes of metabolism, the mechanism ensuring that these processes are carried out only during the most favourable period of the year (Heslop-Harrison, 1964).

Mooney and Billings (1961) concluded, however, that the primary factor limiting the distribution of Oxyria digyna appears to be high summer temperatures. It is said that carbohydrate reserves are depleted owing to poor photosynthetic economy at high temperatures, so that although many of the plants are well adapted to growing under low temperature conditions, high summer temperatures may be a more important factor than adaptation to low temperatures, particularly in areas where plants are growing at the limit of their range. Because plants growing in arctic and alpine environments have greater rates of respiration at any one temperature than more temperate plants, then the net result will be a lowering of the compensation point (the point at which photosynthesis just balances respiration), so that under conditions of high summer temperatures rapid depletion of carbohydrates might occur. Mopney and Billings however, found that Oxyria digyna plants from the southern 'alpine' populations displayed somewhat greater tolerance to abnormally high summer night temperatures than the northern 'arctic' plants. They concluded that the existence of Oxyria digyna throughout a wide range of arctic and alpine conditions is due largely to differences in metabolic potential among the component populations of the species.

It is often the length of the growing season, in terms of an adequate temperature and light regime, which ultimately limits the growth of plants. This limitation of growth is particularly pronounced in the uplands. During an examination of the growth of Nardus stricta in 1964, at Moel Eilio, Conway Valley, (Perkins, unpublished data) the mean air temperature was above 6°C from mid April to mid November. However, tillers of Nardus showed a significant dry matter increase only during a period of about 12-13 weeks from mid May to the end of August. This example illustrates the short period during which growth in terms of dry matter production takes place in the uplands. It is a feature of the climate of the uplands of western Britain that the accumulated temperature above 6°C during the summer months is considerably reduced as compared with the lowlands.

An interesting but extreme example of the short period of time available for growth can be found in plant habitats near late snowbeds; examples of this can be seen in Scotland. Although the plants have been protected by a covering of snow during the winter period of low

temperatures and high winds, the rather specialized flora, consisting mainly of mosses and a few vascular plants, must subsequently be able to complete their growth cycle within a few weeks once the snow has melted.

Solar radiation and the growth of plants

The intensity of solar radiation increases and its quality also changes with altitude. However, in considering the uplands in which the altitudinal range is small, changes in quality of solar radiation will be small. In areas of greater altitudinal range, changes in the short wave region of the spectrum are important, long wave radiation being much less affected by the absorbing qualities of the atmosphere (Tranquillini, 1964). In areas of limited altitudinal range the extent of cloud cover is likely to be significant in affecting the amount of solar radiation reaching the plant. For example, the highest radiation intensities are obtained not under clear skies, but when bright, highly reflecting clouds occur. However, the presence of low level cloud and fog will reduce the intesity of solar radiation considerably, except at high altitudes when diffuse radiation increases rapidly with overcast skies since the cloud thickness is less. The extent to which different areas of the uplands are affected by differing type and amounts of cloud cover and the resulting low light intensities which limit the growth of plants is likely to be of more importance than differences in quality of radiation. However, 'competition' for light in vegetation stands or swards is likely to be of even greater significance to plant growth.

Water and mineral nutrients

Apart from high levels of rainfall maintaining the soil at or near field capacity for most of the year, the humidity of the air is high in British upland regions. Oliver (1964) has shown for example at Craig Cerrig Gleisiad at 2,000 feet, O.D., that humidity values over 90% occur for 70% of the year; however, water could become limiting in a dry season if the soils also are freely drained. When mineral nutrients are considered, then a major limiting factor may be involved. Large areas of the uplands are subject to high rates of soil leaching, and this, together with the generally poor base status of the parent material, seriously limits the supply of mineral nutrients which are available for the growth of plants.

There is evidence by Gore (1961) working at Moor House at 1800 feet with Molinia and other species, that the growth of plants in that locality is limited by the dominating influence of climate. In experiments

in which fertilizers were applied, no significant growth response to added nutrients was obtained. However, this is not always so, as in the case of Eriophorum vaginatum at Craig Cerrig Gleisiad, (where the climate is slightly less severe) there was a marked growth response to applications of mineral nutrients particularly potassium and phosphorous (Perkins, 1961). Thus, although the effects of climate and particularly temperature are very great, other factors such as supply of mineral elements can under certain circumstances also be important in limiting the growth of plants in the uplands.

Temperature is known to have important effects in the mineral nutrition of plants. For example, although plants can absorb nitrate at low temperature, both translocation and assimilation are limited so that the rate of utilization is low. (Black 1957).

Nitrogen appears to be a limiting factor in plant growth in the tundra (Bliss 1962), and low temperatures, particularly soil temperatures, are also known to affect the uptake of nutrient elements in plants. (Zhurbitasky and Shtrausberg, 1958). There is need, however, for much more investigation in the field of the inter-relationships of mineral nutrition and temperature.

More work has been done on the adaptation of plants to variations in soil factors. Physiological adaptation to different levels of calcium and phosphorous has been observed in Trifolium repens by Snaydon (1961). Work by Snaydon and Bradshaw (1961) also showed that samples from populations of Festuca ovina growing on soil with free $CaCO_3$ present, and from soils that were low in calcium had markedly different responses to different levels of calcium when grown in solution culture. Plants from the acidic soils showed much better growth and had a better uptake of calcium at low calcium levels and poorer growth at higher levels. This adaptation by plants is a good example of intra-specific variation occurring in natural populations of plants, in relation to environmental factors, and can account for the occurrence of plants over a wide range of environmental conditions.

Not only do plants become adapted to particular levels of available nutrients, but genecological variation occurs in Calluna vulgaris in response to changes in altitude and length of growing season (Grant and Hunter 1962), and in Trifolium repens in relation to factors associated with the environmental change from leached to mesotropic flushed soils (King 1963). Apart from these genecological gradients in plant species there appears to be in some plants a nutrient retention mechanism in which the plants retain a large proportion of their nutrients from year to year. This has the effect of extending the nutrient range over which

these plants can grow successfully, as has shown to be the case in Eriophorum vaginatum (Perkins, 1961) and in Nardus stricta. Both plants grow in situations where the nutrient supply is low, Eriophorum on bogs, often in conditions where the only supply of nutrients is via rainfall and dust, and Nardus on very poor peaty podzolised soils of low nutrient status. Critical elements for the growth of these plants are phosphorous, potassium and nitrogen; they are present in relatively large quantities in leaf material compared with that found in the substrate. Leaves of both plants die-back at the end of the growing season leaving the base of the tillers to over-winter protected in the litter layer. Considerable quantities of leaf material die-back each year and if the amounts of nutrients present in the leaf material were lost from the plant system, this would be a serious drain on the nutrient economy of the plant. The plants exhibit a form of nutrient cycle which tends to conserve the nutrient elements, particularly in the younger growing tillers.

Data of the analysis of phosphorus and potassium in Nardus plant material, illustrates that the concentration of these elements is much greater in younger tillers than older tillers and particularly that in dead material. It is believed that nutrients, particularly potassium and phosphours, are translocated about the plant from moribund tillers into tillers which are in a state of maximum growth potential. Although many workers have shown that nutrients are lost from some leaf materials by processes of leaching by rain etc., the quantities lost from Eriophorum and Nardus plants by leaching are thought to be small.

Nutrient retention may be an important factor in extending the range over which these plants can grow by buffering them against low soil nutrient levels. The extent to which this retention is important in other species growing under conditions of low nutrient availability needs to be investigated. If efficient nutrient retention is present in a wide range of species then this, together with the ability of plants to adapt to different levels of nutrients in an eco-genetic manner (McMillan 1960), is of some significance in the ability of natural populations of plants to occupy habitats of poor nutrient status in the uplands.

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DISCUSSION

Ap. Griffiths (P.B.S., Aberystwyth) commented firstly on the low dry matter yields (80-390g/M^2) at the sites investigated; secondly he remarked on the low K values (c.1%) and asked whether there was a complimentary high level of Na in the vegetation, as had been shown by his own earlier work at Gogerddan.

D. Perkins agreed that the dry matter values quoted were low,

although for the preceding year they were considerably higher (570g/M^2 at Llyn Llydaw, and 660g/M^2 at Moel Eilio, no data was available for Crib y Ddysgl). Annual dry matter yields in the uplands appeared to be very variable and are the subject of continued investigations. High levels of Na had not been found in the plant material examined; there was always much more K than Na in the plants.

M. Alcock (U.C.N.W., Bangor) referred to the concept of nutrient recirculation being an adaptive mechanism and enquired whether or not grazing complicated the system.

A. Troughton (P.B.S., Aberystwyth) also suggested that recirculation might be something more general than an adaptive mechanism and recalled similar work by Williams in Australia on wheat.

D. Perkins agreed that the situation would be different where grazing removed nutrients from the plant system, but stated that the plants in the areas studied were seldom grazed. If these plants were grazed, there would be a serious loss of nutrients to the plant system, particularly where nutrients were in poor supply in the substrate. Nutrient recirculation did occur in many plants, for example in Beech (Olsen, 1948) and in Birch (Tamme, 1951). The retention of nutrients in Nardus and Eriophorum is particularly marked and appears to operate at a very high degree of efficiency. Nutrient retention in plants which were heavily grazed needed to be investigated.

B. Davies (U.C.W., Aberystwyth) enquired to what extent the low K content of dead tillers could be due to leaching by rain-water.

D. Perkins replied that this might occur to a small extent, but the depletion of K occurred very rapidly (e.g. within 14 days) and this could be followed along the length of the linear leaf, from the apex to the base, as the leaf died-back; the traslocation of nutrients had been shown to occur in Eriophorum vaginatum leaves which had been protected from rainfall.

SOIL LIMITATIONS IN THE RESEEDING OF HILL LAND

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The agronomic approach to the problem of hill land utilization in the British Isles must, of necessity, be based on ecological principles. The major point of divergence from the approach of the conservation authorities is the emphasis placed on the need to modify and revitalize the whole hill farm ecosystem through strategic land reclamation, to give in turn increased pasture production, livestock output and economic viability. Attention to the environmental factors involved remains intrinsic, and it is proposed to show in this discussion the relevance of ecology to one of the major problems of hill land improvement, the poor performance and survival of most conventional grass and clover varieties in reseeded swards.

Climate, soil and grazing management all contribute to this rapid reversion, and none of these factors can be viewed in isolation. Recent studies at Aberystwyth and Bangor, using the technique of reciprocal soil transfer over an altitudinal transect, have, however, substantiated the view that climate is the supreme influence governing the differences between the performance of varieties in the hills and lowlands (Hughes, 1965; Lovett and Alcock, 1966). Low temperatures and solar radiation, frost, high wind speed, and rainfall, all exert their pressure. Since Professor Oliver has dealt comprehensively with the upland climate of Wales at the Aberystwyth meeting, reference will only be made to the conditions encountered during 1966 at the main hill variety evaluation centres and at the headquarters of the Welsh Plant Breeding Station (Figs.I and II).

The screen temperature and global radiation recordings provide valuable comparisons between the climate of potential reclamation sites at similar altitudes in the coastal uplands and central plateau of the mid-Wales region. Syfydrin (1100 ft O.D.) is near Plas Gogerddan meteorological station (103 ft) in the Aberystwyth area on the western slopes of the Pumlumon range, while Pant-y-Dwr (1000 ft) lies in the eastern rain shadow on the Radnor-Montgomery border. It is noticeable that more 'continental' conditions prevail in the east, with colder winters, greater daily extremes of temperature, and a shorter growing season. On the other hand,

MEAN MONTHLY SCREEN TEMPERATURE

09.00 HRS. G.M.T.

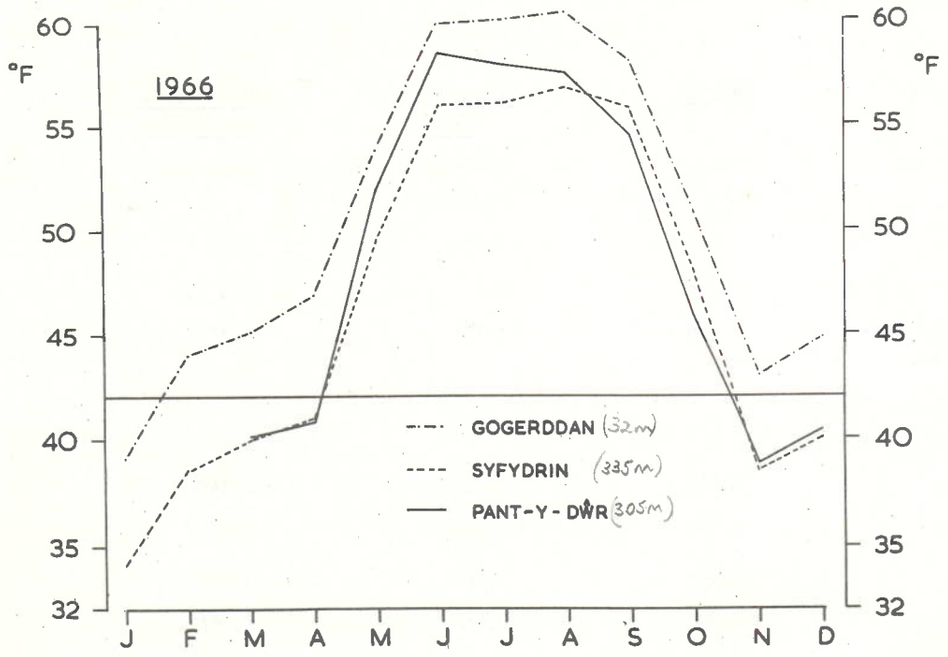

Fig. 1

TOTAL INCOMING GLOBAL RADIATION

Mean Monthly — cal. cm^{-2} day^{-1}

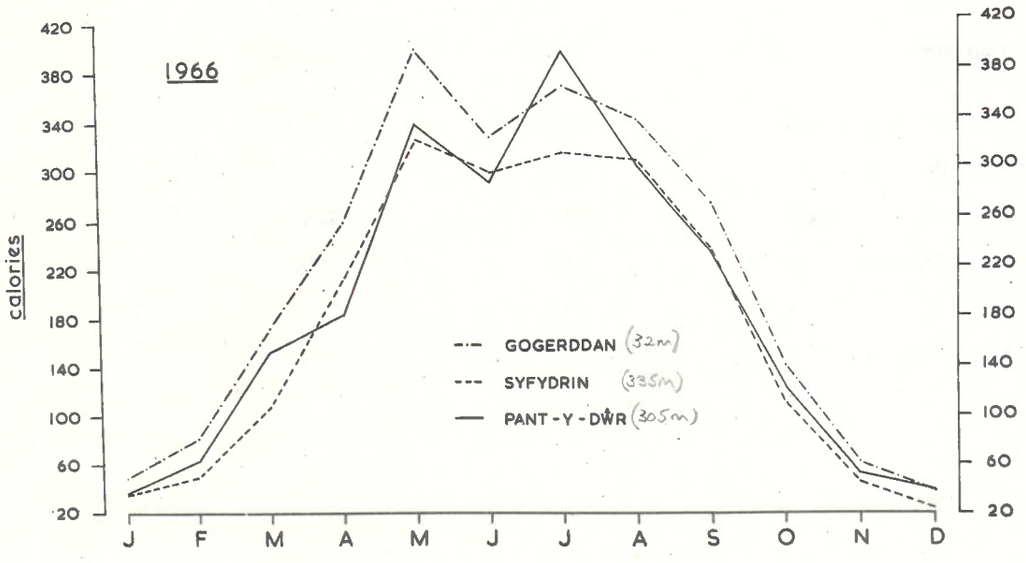

Fig. 2

TABLE 1 Summary of Soil Analyses

	1	2	3
Vegetation	Bracken	Fescue-Bent -Gorse	Deschampsia caespitosa
Soil series	Llety partly gleyd	mat Denbigh brown earth	Cegin gley
pH	4.61	4.68	4.87
%loss on ignition	18.0	16.8	12.8
Weight soil/acre million lb.	1.046	1.121	1.311
Exchangeable cations me/100 g			
Na	0.516	0.148	0.148
K	0.680	0.655	0.246
Ca	0.375	0.375	0.500
Mg	0.555	0.432	0.187
lb/acre			
Na	124	38	45
K	277	286	125
Ca	78	84	131
Mg	70	58	29
Exch. acidity me/100 g	27.2	21.2	13.6
Cation exch. capacity me/100 g	29.3	22.8	14.7
%base saturation	7.2	7.0	7.4
Lime requirement tons/acre	6.4	5.3	4.0
Extractable Al lb/acre	554	556	799
Extractable Mn lb/acre	165	103	1
Total N lb/acre	5480	6800	5430
Available N lb/acre	253	210	183
Available P lb/acre	4	4	8
Available Cu lb/acre	0.73	0.65	1.87

4	5	6	7
Calluna--Gorse	Nardus stricta	Trichophorum-Molinia-Erica	Molinia caerulea
Cegin gley	mat Denbigh brown earth	Ynys peaty gley	Caron peat
4.60	4.59	4.05	4.15
9.5	16.0	23.1	53.6
1.639	1.095	0.750	0.338
0.104	0.212	0.221	0.332
0.336	0.464	0.363	0.857
0.500	0.375	0.438	0.188
0.224	0.297	0.474	0.558
39	56	38	36
215	208	106	113
164	86	66	13
44	41	43	23
17.6	21.4	30.2	35.8
18.8	22.7	31.7	37.7
5.9	5.7	4.7	5.0
6.4	5.3	5.1	2.7
806	751	618	105
118	112	9	8
4590	6130	5340	2560
132	246	78	108
2	4	6	3
2.08	0.61	0.19	1.19

summer mean temperatures are higher at Pant-y-Dwr, and in July and August higher global, or short wave, radiation can be recorded there than at low-level coastal sites such as Gogerddan. These factors, together with lower rainfall, are very important in determining the success or failure of an individual variety, particularly where it is near its threshold for survival. White clover, for instance, has a minimum soil temperature requirement for growth and nitrogen fixation of approximately 48°F (Munro and Hughes, 1966) and reflects the improvement in summer climate more than most grasses.

Near the Cardiganshire coast, radiation in summer decreases rapidly with elevation, particularly between 900 and 1000 ft, the present upper limit of cultivation. This is due to the presence of persistent cloud layers at this altitude formed by depressions moving in from the Atlantic. In the Alpine regions of the continent the reverse situation would obtain, with radiation increasing at very high altitudes.

Within the individual hill farm the soil factor takes over the major role in the success or failure of reseeded pastures and merits more attention than is at present given. In order to gain more insight into the soil differences existing between natural vegetation communities capable of improvement, a comprehensive survey of the soils at Pant-y-Dwr Hill Centre was undertaken with the assistance of the Chemistry Department (Table 1). Seven main areas were examined covering five soil series typical of most of the hill land in Mid-Wales (Rudeforth, 1966). Because of the relatively low rainfall (48in at Pant-y-Dwr in 1966), and high summer temperatures in Radnorshire, podzolization does not occur below approximately 1800 ft (Rudeforth, 1967), and the Hiraethog and Drosgol series typical of the western coastal areas around Syfydrin were not encountered. Nevertheless the soils formed a wide clinal sequence of freely-draining acid brown earths, gleys, peaty gleys and deep peat. The parent material throughout was drift derived from Silurian sediments and as such gave rise to a range of very infertile soils. Particle-size analysis disclosed that the mineral fraction of the surface 6 in. of soil consisted of 55-85 per cent silt, which explains the generally poor drainage of the Pant-y-Dwr area.

All chemical analyses were converted by a factor based on the measured bulk density of each soil to give the quantity of available

nutrients in lb. per acre, this being the only valid yardstick of comparison where soils differ widely in organic matter content (Stewart, 1965). The inherent low fertility of all seven areas before reclamation was highlighted by the low pH and base saturation status. Even the highest values recorded, pH 4.87 and 7.4 per cent base saturation in the Deschampsia caespitosa area, were well below the reported minima associated with the natural occurrence of indigenous white clover, effective Rhizobium populations, and even of better native hill-grasses, such as red fescue (Snaydon, 1961; King, 1962; Holding and King, 1963; Ratcliffe, 1963). Base saturation, as expected, was closely related to pH but a similar correspondence was not observed between pH and lime requirement (method of Greweling and Peech, 1960). Lime requirement is greatly influenced by the bulk density of the soil, a factor taken into consideration in the N.A.A.S. recommendations, and serious overliming could result on deep peat areas if standard agricultural dressings of 3 tons ground limestone per acre were applied. Evidence of this situation was obtained in other trials (Munro, unpublished) where complete saturation of the exchange complex with this application of calcium led to induced potassium deficiency in white clover.

While low lime applications of 1-2 tons may be appropriate on peat, much higher dressings are essential on the acid mineral soils before any attempt at reseeding is made. Lowland grass and clover varieties have a high calcium requirement and are extremely susceptible to the toxic effects of aluminium and manganese (Vose and Randall, 1962; Vose, 1963) which can be best removed by liming. In the Pant-y-Dwr soils high concentrations of extractable aluminium were found at lower pH values in the gleyed horizons of the poorer drained soils. Manganese levels were less of a problem, moderate concentrations being recorded only in some of the freer draining areas, particularly where bracken was dominant.

The application of 3 tons of ground magnesian limestone per acre to both the fescue-bent-gorse and Trichophorum-Molinia-Erica areas during ploughing and reseeding resulted in a dramatic fall in extractable aluminium and manganese (Table II). Residual toxicity could still be present, particularly for legumes, but as yet no critical trial work has been carried out.

Table II

Extractable Aluminium and Manganese in top 6 in soil

	Extr. Al ppm		Extr. Mn ppm	
	Fescue	Trichophorum	Fescue	Trichophorum
Before liming	496	894	92	6
After liming	0	15	14	3

The use of the bulk density factor in converting exchangeable cation content to lb per acre (Table I) in the top 6 inches of soil shows how fertility can be overestimated in highly organic soils by normal equal weight comparisons. This is particularly true with regard to exchangeable potassium which in peat appears high in terms of milli-equivalents per 100 g but low in lb per acre. Notable responses to applied potassium have been achieved with white clover in several trials on peat in mid-Wales (Munro, unpublished).

It is useful to compare and contrast the Pant-y-Dwr data with similar observations made in a typical fertile lowland field at Gogerddan, and also with the levels of nutrients extracted by grass crops cut and removed for conservation (Whitehead, 1966) (Table III). Two sets of figures are given for different levels of production, a moderate yield (5000 lb D.M. per acre per annum) of low quality and a high yield (10,000 lb D.M.) of good quality.

Table III

The available nutrient content of natural hill and improved lowland soils and the levels of nutrients extracted by different grass crops

	lb nutrient per acre							
	Na	K	Ca	Mg	P	N	Mn	Cu
Pant-y-Dwr mineral	38	286	84	58	4	210	103	0.65
Pant-y-Dwr peaty gley	38	106	66	43	6	78	9	0.19
Lowland mineral	131	166	4060	105	N.A.	N.A.	N.A.	N.A.
5000 lb grass D.M.	2.5	75	25	6	10	100	0.1	0.025
10,000 lb grass D.M.	50	400	150	28	50	400	2	0.15

Even with good grazing management and little loss of nutrients via stock transfer and leaching it is obvious that a steady input of

major elements, particularly calcium, nitrogen, phosphorus and potassium and probably of certain trace elements, such as copper, are essential to the maintenance of productive reseeded pastures in the hills, especially on such poor soils as the peaty gleys. When the Trichophorum area was ploughed, limed and reseeded, extreme symptoms of nitrogen deficiency were noted in S.23 perennial ryegrass. In its first harvest year S.23 without applied nitrogen produced only 300 lb D.M. per acre with a crude protein content of 10 per cent whereas a similar sward on the former mineral fescue-bent-gorse area yielded 3000 lb D.M. with 21 per cent crude protein content. Analysis of total N, did not explain this difference in the nitrogen-supplying capacity of the two soil types and determination of available N was necessary (method of Keeney and Bremner, 1966). In organic soils a high proportion of the total N is heterocyclic (Hargitai, 1964) and non-available to plants.

It is hoped that this evaluation of some of the environmental factors which influence the agronomic improvement of hill land will stress the difficulties involved. Many observers of the scene, both from overseas and Britain, tend to overlook these problems of climate and soil and often suggest short cut methods of land reclamation which will be merely ephemeral in their effect. On the other hand, proper recognition of the ecological variability of the uplands and their requirements, together with an integrated approach to improvement, will have lasting results.

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DISCUSSION

J. Taylor (U.C.W., Aberystwyth) commenting on the sharpness of the boundaries on the vegetation map of Pant-y-Dwr shown in the lecture, asked about the ease of definition of the community boundaries. J. Munro replied that the vegetation units were well defined and corresponded very closely with those of the soil map of the area.

In reply to an enquiry by B. E. Davies (U.C.W., Aberystwyth) J. Munro stated that available Nitrogen was determined by extraction with boiling water under reflux. (Keeney and Bremner, 1966), a method which has shown good correlation with the growth of perennial rye-grass: Mn was extracted from the air-dried soil with phosphoric acid.

W. Adams (U.C.W., Aberystwyth) questioned the value of selection work for resistance to Al-toxicity in grasses which had been carried out by Vose and Randall since this toxicity could readily be overcome by liming.

J. Munro agreed, as it appeared that Al-resistance was associated with low cation exchange capacity, and probably feeding values. Correct timing was more important and breeding policies were being concentrated more on over winter survival.

S. Gregory (Univ. Liverpool) suggested that the use of maximum/minimum temperatures would be more satisfactory than mean 2 a.m. temperature in the site comparisons, because of the large variation in diurnal range between summer and winter.

J. Munro replied that maximum/minimum and 4 inch soil values were also recorded continuously and showed similar trends to those of the mean 2 a.m. temperatures.

SOILS AND LAND-USE IN THE UPPER CARBONIFEROUS SHALE AND SANDSTONE REGION IN SOUTH-WESTERN IRELAND

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INTRODUCTION

In the interests of correlating soils developed under comparable conditions on either side of the Irish Sea this contribution was invited by the Welsh Soils Discussion Group. Cursory considerations have pointed to a strong similarity between the soils developed on glacial drift of Irish Sea origin in the western coastal areas of Wales and the south-east of Ireland; in the Wexford-Wicklow area these soils have been mapped as the Macamore Series (Gardiner & Ryan, 1964). The Brown Podzolic complex developed on Silurian and Ordovician shale parent materials and the soil pattern on the Namurian or Upper Carboniferous shales and sandstones on either side are further examples.

Of particular interest in this instance are the soils associated with Upper Carboniferous shales and sandstones, colloquially named the Coal Measure shales and sandstones in Ireland. These occupy three extensive, well-defined regions as well as several scattered small areas. The former include (a) the Fermanagh-Leitrim region, (b) the Castlecomer Plateau and (c) the extensive stretch from Killarney northwards across the Shannon Estuary into West Clare. Most work to date has been done on the third region and in particular in West Limerick so the considerations put forward here are confined largely to these investigations; work is in hand in parts of the other two regions. The distribution of these soils in West Limerick and their inter-relationship with other soils in the region are discussed in more detail elsewhere (Finch & Ryan, 1966). Some comparisons are drawn with the Upper Carboniferous shale and the sandstone regions of Wales.

LOCAL FEATURES

Topography

The West Limerick region comprises mainly a hill and valley topography and presents a fairly well-matured landscape of smooth, rolling ridges and long, gently sloping valleysides. The valleys run in an east-west direction. Elevation ranges from over 1,200 feet

down to sea level. Blanket bog becomes fairly prevalent about the 500 foot contour and this is taken as roughly the line between the lowland and upland soils in this region. The natural landscape features have been modified by glacial activity.

Geology

Over the greater part of the region the solid formations of Upper Carboniferous shales and sandstones are overlain to varying depths by glacial drift. Almost the entire area was glaciated during the penultimate or Saale Glaciation. This glaciation covered the valleys and most of the hills but the deposits especially on the steeper slopes were subsequently disturbed by solifluction during the ultimate or Weichsel Glaciation. The main ice-stream of the Weischel traversed the eastern edge of the West Limerick Hills without encroaching on the hills but a later re-advance of the Weichsel reworked the Saale drift materials mixing them with its own deposits, so that this north-eastern area is slightly more youthful in its glacial features and shows little solifluction effects. To the south of this area, however, evidence of solifluction is widespread; here long, smooth, gentle valley slopes and undulating broad valley bottoms prevail where the glacial drift especially at the higher elevations is frequently mantled totally or in part by blanket bog.

Climate

Rainfall. Figures for some recording stations in the vicinity are shown in Table I. The main variation is related to elevation; the rainfall varies from 46 inches at Abbeyfeale to 52 inches on Sugar Hill. The minimum rainfall occurs in April and the maximum in December. The rainfall records for a number of stations in South Wales were examined and they show a rather similar pattern.

TABLE I - Rainfall as monthly and annual averages over a 11 year period (1951 - 1962) (mm. & in.)

STATION	ALTITUDE OF STATION	TOTALS mm.	TOTALS ins.
Abbeyfeale	260 feet	1161	46
Sugar Hill	1084 feet	1316	52

Station	Jan.	Feb.	Mar.	Apr.	May	June	July	Aug.	Sept.	Oct.	Nov.	Dec
Abbeyfeale	117	90	73	61	69	58	105	94	113	115	115	157
Sugar Hill	126	91	77	72	78	82	114	120	127	128	131	171

Temperature.

Temperature values in this area of West Limerick are difficult to assess since there are no weather stations recording temperature in the hills. The nearest source of recording is on the limestone lowlands at Pallaskenry some ten miles away. Figures from there are given in Table II to provide some idea of local conditions.

TABLE II - Average reading of air temperature (^{o}F) at Pallaskenry (1952 - 1960)

	Jan.	Feb.	Mar.	Apr.	May	June	July	Aug.	Sept.	Oct.	Nov.	Dec.
A	40.1	40.4	44.7	48.1	52.9	56.7	58.9	58.7	55.8	51.1	44.7	43.6
B	46.9	47.0	51.4	55.8	60.8	64.1	65.9	66.3	62.6	47.7	51.4	49.7
C	33.2	33.7	37.9	40.3	44.9	49.2	51.8	51.0	48.9	44.4	38.9	37.4
D	56.5	56.1	59.0	64.2	71.6	74.0	73.6	73.3	69.7	65.7	59.1	56.9
E	21.4	22.3	28.2	31.0	34.6	39.6	43.5	42.4	39.0	32.7	27.4	27.4

A = Mean monthly temperature
B = Mean daily maximum
C = Mean daily minimum
D = Mean of highest each month
E = Mean of lowest each month

Temperature values in the hills will be lower generally than at Pallaskenry and somewhat less uniform over the season.

Relative Humidity

Relative humidity figures are not available for the West Limerick region but those recorded close by at Shannon Airport show a range of 69 to 92 per cent; in general it may be taken to be close to 90 per cent for long periods of the year.

Records for sunshine and frost are not available.

SOILS

The soils of the West Limerick region are quite variable. The glacial drift at the lower elevations carries wet soils, mostly Gleys and Humic Gleys together with peats. Only where the bedrock shales and sandstones approach the surface, mostly on the somewhat steeper slopes, are local areas of free-draining soils to be found. The upper

slopes are dominated by peat.

Five soil series have been mapped on the Coal Measures shales and sandstones of West Limerick together with extensive areas of blanket peat (Finch & Ryan 1966). On an area basis the ratio of Gley: Peat: Brown Earth/Podzol Groups is roughly 12: 3.5 : 3.

Gley Group

Abbeyfeale Series

The most extensive series mapped in this region is Abbeyfeale occupying close on 46,000 acres. These gley soils occur on undulating (occasionally flat or rolling) relief and over a wide range of elevation from sea-level to 1,300 feet. They are derived mainly from Saale Age glacial materials.

A description of the modal profile and analytical data for the Abbeyfeale and subsequent series are give in Finch & Ryan 1966.

The Abbeyfeale soils, by nature poorly drained, have a low base status and a surface accumulation of peaty material which varies from 0 - 9 inches in depth. The mineral profile is characterised by weak structure and by sticky to plastic consistency throughout. The relatively high silt content of their lower horizons, their weak structure and their occurrence on gentle slopes are mainly responsible for the poor drainage of these soils. Although the effects of gleying dominate, podzolisation is also evident in the profile, so the soils are classified as podzolised Humic Gleys. Roots are well developed in the surface horizon and are plentiful down to the A2 horizon; at lower depths rooting is restricted by the gley conditions.

The vegetation reflects the permanently wet and low nutrient status of these soils. Species typical of the well-drained grasslands are almost absent; instead, Juncus acutiflorus (jointed rush), J. conglomeratus, Lotus uliginosus (marsh bird's foot trefoil), Succisa pratensis (devil's bit), Carex spp. (sedges) and other moisture demanding species are found.

Associated with the Abbeyfeale soils are areas where the surface peat has been worked out or burnt over; here the soil remaining is entirely mineral. It has been classified as a podzolized Gley and mapped as a non-peaty phase of the Abbeyfeale Series. This phase occurs to a limited extent throughout the Abbeyfeale series, at similar elevations but generally on somewhat steeper slopes. The soils are of loam to silt loam texture, of low base status and are poorly drained. Apart from the different organic matter content and the somewhat more desirable structure in the surface horizons, the profile closely resembles that of the Abbeyfeale Series. The vegetation character is very similar also.

Kilrush Series

The second series of gley soils, namely the Kilrush Series, occupies almost 26,000 acres and occurs on the more recent Weichsel glacial deposits to the north-east of the region where it is the dominant soil. The Kilrush soils occur on undulating and occasionally on rolling relief at elevations ranging from sealevel to 1,000 feet.

The Kilrush soils are poorly drained, of clay loam, silt loam and loam texture and of medium base status. The poor natural drainage is due mainly to the relatively high silt content and to the inferior

structure of these soils. The soils have been classified as Gleys and might be considered surface-water Gleys. Unlike the Gleys of the Abbeyfeale Series, these show no evidence of podzolisation by way of a leached A2 and depositional B horizon, and mainly on account of these and related features they have been distinguished from the former series. Roots are well developed in the upper horizons but are mainly restricted to this zone. The most usual vegetation is old pasture dominated by Agrostis tenuis (bent-grass), Holcus lanatus (Yorkshire fog) and Cynosurus cristatus (crested dog's tail). The rush species, Juncus effusus (soft rush) and J. articulatus (jointed rush) together with Carex ovalis (oval sedge) are always present in varying abundance depending on management.

Acid Brown Earth/Podzol Groups

Within the area of the Abbeyfeale and Kilrush soils there are some better drained associates, namely Kilfergus, Mountcollins and Knockanimpaha Series.

Kilfergus Series

This series is of very limited extent (140 acres). The soils are usually associated with undulating and rolling relief, with slopes of 2 to 6° and occasionally greater, and with elevations up to 700 feet. They occur in close association on the landscape with the Mountcollins and Kilrush soils and less closely with those of Abbeyfeale Series. The Kilfergus soils have an almost uniform (A (B) C) profile, are naturally well drained and are of shaly, gravelly loam texture; they have been classified as Acid Brown Earths. They occur on shattered Coal Measure bedrock or on glacial drift derived from this formation; the drift is more usually of the Weichsel Age.

Mountcollins Series.

The soils of this series occupy roughly 17,000 acres. They occur on undulating to rolling relief, at elevations ranging from sea-level to 700 feet. They are derived from the shattered Coal Measure bedrock or from glacial drift of this origin which may be either Saale or Weichsel Age. These soils have been classified as Brown Podzolics.

The Mountcollins soils are naturally well drained, of loam to clay loam texture and of low base status. The profile is friable throughout and contains appreciable quantities of shale fragments which further enhance the drainage properties. Roots are abundant in the surface horizons and penetrate freely to a considerable depth.

The vegetation has been classified in the grassland type called the Centaureo-Cynosuretum, typical sub-association, which includes most of the Irish pastures on well-drained soils that are not adequately manured. Species such as Luzula compestris (wood-rush), Centaurea nigra (knapweed), Senecio jacobea (ragweed) and Lotus corniculatus (bird's-foot trefoil) are always present. There is seldom a single dominant species but Trifolium repens (white clover), Lolium perenne (perennial rye-grass), Cynosurus cristatus (crested dog's-tail) and Agrostis tenuis (bent-grass) are usually abundant.

Knockanimpaha Series

This series occupies about 1,800 acres. The soils, which

are well-developed Podzols, occur in close association with those of the Abbeyfeale Series throughout the southern portion of the West Limerick hill region. They are found only at elevations greater than 700 feet, on the rolling relief and the variable slopes (2 to 20°) of the small scarp faces prevalent in this area. Because of the slopes and the solifluction effects prevailing, the soils are mainly derived from the Upper Carboniferous shale and sandstone bedrock and from related colluvial materials.

The Knockanimpaha soils generally are of organic, gravelly loam texture and of low base status. The profile is moderately deep and is shaly throughout; it is characterised by a distinct A2 horizon usually overlying a disintegrating textural B horizon, a thin iron-pan and a diffuse, iron-enriched horizon. Occasionally the iron-pan is impermeable resulting in impeded drainage and mottling of the overlying horizons and in restriction of root penetration. But where the soils have been cultivated only relics of the iron-pan are visible, and the profile is free draining throughout, and roots penetrate freely. Localised pockets of a more peaty phase of this series have been noted on the more gentle slopes; this phase was difficult to delineate at the scale of mapping employed and has not been mapped separately. These soils normally carry old pasture dominated by Agrostis tenuis (bent-grass) and Festuca rubra (red fescue). Many of the pastures are dotted with clumps of Juncus effusus (soft rush). Heather (Calluna vulgaris), common on the peaty soils occurring at higher elevations, is present to a minor degree.

Peat

The peat deposits in West Limerick occur almost exclusively as blanket bog and to the extent of about 20,000 acres. In many cases these peats have been cut over for fuel in the past and are still being cut in places.

The blanket peats in West Limerick represent the largest single area in the county still possessing a natural vegetation. Many of the plant species represented do not occur outside of peat bogs. The most constant and abundant species are Erica tetralix (cross-leaved heath), Scirpus cespitosus (deer-'grass'), Calluna vulgaris (heather), Narthecium ossifragum (bog asphodel), Molinia caerulea (purple moor-grass) together with many Sphagnum spp. (bog mosses).

DISCUSSION

Soils

The dominant soil cover associated with the Upper Carboniferous or Coal Measure shale and sandstone materials in the West Limerick region comprises poorly drained mineral and organic soils. Over 80 percent of the region carries Humic Gleys, Gleys and Peats with almost two-thirds occupied by the Gley groups alone. The remaining soils are better drained naturally but almost one-tenth of these are degraded Podzols. The wet gley and peat soils almost exclusively overlie glacial drift; the better drained soils tend to occur more on shattered bedrock or on thin or more permeable glacial drift parent

materials. When compared with County Limerick as a whole the preponderance of poorly-drained, difficult soils in association with the Upper Carboniferous landscape becomes more obvious. In County Limerick (Finch & Ryan, 1966), 43 per cent of the soils are naturally free-draining and some 50 per cent poorly drained compared to roughly 20 and 80 per cent respectively in West Limerick. In County Wexford (Gardiner & Ryan, 1964), devoid of Coal Measure formations, the well-drained soils represent roughly 62 per cent and the poorly drained soils roughly 31 per cent, the balance being of mixed drainage. In close proximity to the Wexford county boundary, under fairly comparable climatic conditions, the Coal Measure materials of the Castlecomer Plateau are again dominated by poorly drained soils (Conry & Ryan, 1967). This soil pattern is repeated in Ireland wherever these formations occur.

The poorly drained nature of the extensive wet soils associated with the Coal Measure materials is due to an undesirable combination of climate and soil physical features, in particular texture and structure (Quinn & Ryan 1962). The combined silt and clay fractions in the lower horizons of the Abbeyfeale and Kilrush profiles for instance are in the region of 70 to 80 per cent of the total mechanical fraction (< 2 mm) and silt alone is in excess of 40 per cent. The clays are in a highly dispersed form with little tendency to aggregate. These features combined with weak, very poorly developed structure provides for a low degree of porosity and slow permeability which under Irish climatic conditions is far from conducive to good internal drainage and aeration. Besides the glacial drift materials of Coal Measure origin are mostly intractable and poorly permeable leading to a perched watertable even on good slopes due to the slow rate of seepage through the subsoil.

For long periods of the year the soils are very wet and this coupled with the very poor structure reduces mechanical soil strength to minimum. Mechanical cultivation of the soils in this state causes severe puddling, compaction of the surface layers and a further deterioration of the structure and the porosity. Uncontrolled, heavy stocking with grazing animals is equally detrimental leading to poaching damage and attendant problems of pasture deterioration and rush infestation.

An important feature of many of these wet soils is the high organic matter status in the surface. The normal content of these soils may range from 6 - 15 per cent, with values of 20 per cent and higher where there is a tendency to peat formation. From the agricultural point of

view the quality of the organic matter is usually inferior since the carbon/nitrogen ratio may be in the 12 to 20 range indicating poor conditions for nitrogen release.

Whereas these soils have many physical defects, their shortcomings chemically (and biologically) must be considered also. They are poor in lime and fertiliser amendments and the availability of various nutrient elements to plants must be considered quite different from that applicable to well-drained soils. The availability and uptake of trace elements such as cobalt are also influenced by the drainage regime (Walsh et.al. 1956)

Due to the slightly higher rainfall, the slightly lower temperatures, the higher relative humidity and the more intense cloud cover prevailing, peat formation is far more widespread on the Upper Carboniferous shale and sandstone materials in Ireland than in Wales. Thick peat as blanket bog occurs at sea-level on the west coast of Ireland whilst at a similar latitude it only becomes well expressed above 1,200 feet in South Wales. So also peaty podzolized gley soils occur at sea-level in the west of Ireland but appear only at about 1,200 feet in South Wales. Podzolisation on the Coal Measures is manifest at lower elevations in Ireland also, starting at 700 feet in the West Limerick Hills, (at 1,000 feet in the Castlecomer area in the east of Ireland) whilst it appears at 1,200 feet in South Wales. Whilst the soils in West Limerick are very similar to those in South Wales on the same parent materials the degree of degradation is more pronounced leading to a higher proportion of poor, difficult soils and to a distribution pattern in keeping with the somewhat more undesirable climatic regime.

Land Use

Except for the limited area of the well drained arable soils of the Mountcollins and Kilfergus Series the use-suitability of the soils of the West Limerick region is very restricted.

Gley Soils

The soils both of the Abbeyfeale and Kilrush Series have a limited use-range. Because of their many physical defects they are not suited generally to tillage cropping and their optimum agricultural use is in grass production. The extensive occurrence of rush (Juncus spp.) in the pastures throughout the area, even on sloping terrain, reflects the dense, slowly permeable nature of the soils and current management practices.

Poaching by grazing stock is a real problem. With drainage

to improve the stockcarrying capacity of the pastures and to extend the grazing season somewhat, with liming as required and with proper manuring, high yields of good quality grass can be produced. Management needs to be of a high standard, however, to avoid severe poaching and to control rush infestation, and must include the conservation of surplus summer grass to provide for a long period of indoor feeding. With good management, stocking intensity on these pastures could be raised to a cow equivalent per 2 acres in many cases. Dairying is the main farm enterprise on these soils; current stocking intensity may be as low as 5 acres per cow.

These wet soils can be adapted to highly productive forestry after appropriate drainage and establishment techniques. The spruces - particularly Sitka spruce - are especially suited to these soils. Only very limited areas are devoted to forestry, however.

Other Mineral Soils

The only soils in the region that could be considered as truly arable under modern farming conditions are those in the Brown Earth/Brown Podzolic categories, namely, the Kilfergus and Mountcollins Series. These soils have a wide use-range. They are well drained and permeable with moderately well-developed structure and are suitable for the production of most tillage crops and for pasture. Vegetables can be grown successfully where the elevation does not exceed about 500 feet; above this level rainfall and cloud cover are somewhat excessive. For improved output, the present levels of lime and fertilisers must be increased in most cases.

For pasture production these soils have a decided advantage in certain respects over those of the Abbeyfeale and Kilrush Series with which they are associated on the landscape. Due to better internal drainage and more desirable structure, they provide growth earlier in spring and later in autumn. Besides, the soils are less prone to poaching which results in better utilization of the pasture. Greatly increased production from grassland on these soils is possible through better management practices, including lime and fertiliser use as required. A stocking intensity of one cow equivalent to 1.3 acres should be attainable. Where neglected, pastures tend to revert very rapidly to inferior swards and to become colonised mainly by bracken and gorse.

Generally these are excellent forest soils although not devoted to any extent to this enterprise.

The Knockanimpaha podzol soils have a very limited use-range.

They are located in areas of high elevation (mainly above 700 feet), and mainly on moderately steep slopes; usually they have an iron-pan at some depth in the profile which restricts root development and, to some extent, water movement also. Because of the nature of the parent material together with the relatively cold, wet conditions prevailing at such altitudes, the soils have been leached and base depleted. They are, therefore, very acid, and in many instances poorly decomposed organic matter has accumulated to varying depth at the surface. Lime and nutrient levels are very low, and the natural vegetation consists of the poorer type grasses with heather, furze and bracken. The inconvenience of applying lime and fertilisers adds to the difficulty of improving these soils.

The Knockanimpaha soils are mainly suitable only for extensive grazing. A considerable increase in stock-carrying capacity can be expected where manuring and some over-seeding of the sward are practicable (O'Toole et al., 1965). Cobalt deficiency is a serious problem, particularly in sheep under intensive stocking.

On the more favourable sites certain forest species do moderately well on these soils.

Peats

The areas of blanket bog in the West Limerick region are not devoted to any extent to agricultural enterprises and very little amelioration has been attempted in recent times. Low intensity rough grazing and some cutting for fuel are the main uses. No doubt, as has been shown elsewherein the country (O'Toole et al., 1965), with modern development techniques sizeable areas of this peat have a capacity for very high levels of production in grass and other crops.

Considerations of Future Land-Use

The mineral soils devoted in regular manner to agriculture in West Limerick comprise some 72,000 acres of wet, difficult soils and some 17,000 acres of free-draining arable soils. (The remainder, roughly 22,000 acres, are peats and podzols). With modern farming methods and current economic conditions what trends are likely on those agricultural soils in the years ahead?

The concept of land quality has changed radically in recent years with the advent of fertilisers to supplement the soil's supply of essential plant nutrients, but land-use practice has not always changed accordingly. With modern fertiliser technology, considerations of natural nutrient fertility have become subordinate to physical problems

such as poor drainage, 'heavy' texture, and weak structure, which are much more difficult and costly to rectify. Besides, a copious farm labour supply no longer obtains, and its replacement by machinery has drastically altered the feasible cultural and management practices on many soils.

The well-drained arable soils are better adapted to the new techniques than those in the lower classes. In these, the major limiting factor to production in the past has been their poor native nutrient supply and in many cases also their acid conditions. Appropriate lime and fertiliser applications, based on soil analyses and experience of crop requirements easily overcome these problems. These soils, too, despite their somewhat defective structure, can withstand better the impact of heavy, modern machinery; they cultivate more easily and could withstand limited tillage cropping in a well-balanced, well-managed rotation. Pastures on these soils can give early growth in spring and can be highly stocked over a prolonged grazing season without undue physical damage. These soils then offer greater latitude in cropping practice and production than those with more adverse physical conditions.

In the wet, difficult soils, on the other hand, physical limitations, especially poor drainage and weak structure, are foremost. In the days when labour supply permitted constant attention to artificial drainage and to systems of hand cultivation (e.g. ridge and furrow) conducive to improving drainage and maintaining structure, such problems were greatly alleviated. These soils, however, are far less adaptable to modern cultural practices. Their structure deteriorates drastically under the impact of heavy machinery, and only under the most proficient drainage system and with a very high level of management can their true potential be realised. Even then they are limited very much to grass production, and although these soils can equal or even surpass the levels of grass production obtained on the well drained soils, management requirements are far greater if the output is to be fully utilized. Their previous advantage of somewhat higher natural nutrient levels than their well-drained counterparts, has lost considerable merit due to changed technology and contemporary practices.

But the most significant difference obtaining between these contrasting soils is their relative versatility in terms of the alternative uses for which they are inherently suitable. This is important in coping with changing economic and social circumstance and market demands. On soils where the possible use-range is wide, the

selection of the particular land-use which should be followed can be geared largely to current economic circumstances. For the soils of limited use-range, on the other hand, the use adopted will be largely independent of economic circumstances, since the inherent character of the soils restricts their use possibilities.

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DISCUSSION

W. Adams (U.C.W., Aberystwyth), R. I. Davies (U.C.N.W., Bangor) Ap Griffiths (P.B.S., Aberystwyth) and Harris (F.T.S., Capel Curig) all commented on the difficulties encountered in drainage and the methods employed to improve drainage, and A. Edwards (N.A.A.S., Cardiff) drew a comparison with the conditions encountered in S. Caernarvonshire where orthodox drainage of the very wet soils was difficult and ineffective.

In reply T. Finch said that the Government schemes which had been tried encountered difficulties since in soils with a high silt content drains tend to close and seal up after 3 years. Of the various methods that have been tried in Ireland, pipe and stone drains are favoured, although the former are ineffective at depths greater than 18" and the latter, although efficient, are expensive.

E. M. Bridges (U.C., Swansea) commented that a similar climosequence of soils to that described can be observed on glacial drifts derived from Carboniferous rocks in England and South Wales. In the Midlands this parent material gave rise to a surface-water gley

soil with pronounced structure, sub-angular blocky in the A horizon, and coarse prismatic in the BG horizon. In South Wales, because of the moister climate and tendency for peaty mat formation, soils rarely dry out and subsurface structure development is poor.

SOIL SURVEY FOR FORESTRY PURPOSES IN UPLAND WALES

D. G. PYATT
(Forestry Commission)

The Forestry Commission has carried out soil surveys at a scale of 6 inches to 1 mile in four forests of upland Wales. These are Clocaenog (Denbigh), Hafren and Kerry (Montgomery) and Dovey (Montgomery and Merioneth), which together total 36,000 acres.

The surveys are directly aimed at facilitating the silviculture and management of the forests in the region and therefore the soil mapping units adopted are modifications of the accepted Soil Series for Silurian and Ordovician rocks in Wales (Ball 1960, 1963). Emphasis is laid on profile drainage class and depth of rootable soil in the following list of forest soils.

THE SOILS OF UPLAND FORESTS IN MID AND NORTH WALES

A. Shallow brown earths and Deep brown earths, freely drained.

These correspond in the main to Denbigh series steep phase, and Denbigh series, normal phase respectively.

I will consider them together here because they have many features in common. Both are normal brown earths with mull or moder humus, free drainage and good structure throughout. Rooting depth in the shallow type is less than 24 inches, the soil occurring on steep slopes, while the deep type provides a rootable depth of over 36 inches and occurs on gentle to moderate slopes; both occur at relatively low elevations below about 1100 feet. The ground vegetation is extremely vigorous, and usually dominated by bracken and bramble.

B. Ochreous brown earths, usually with superficial gleying.

These correspond in the main with Manod series, but in part may include steep or upland phases of Denbigh series.

While soils in Clocaenog forest in North Wales conform closely with the freely drained Manod series (so-called brown podzolic soil) of Ball, in Mid Wales, the soils with brightly ochreous subsoils (Munsell colour 7.5 YR 5/6 or 10 YR 5/6) invariably display a degree of gleying in the subsurface horizon. I do not wish on this occasion to get deeply involved in the controversy as to whether podzolisation is or is not the process responsible for the nature of the B horizon, although I personally

think the evidence indicates an intense loss of silica from the whole profile as being the major soil forming process (Crompton 1960, Perrin 1965) which favours the adoption of a name such as "ochreous brown earth" (Avery, 1956, 1966). The superficial gleying phenomenon has been described by Crampton (1965a) for the so-called 'podzols with gleying' in the South Wales Coalfield area.

The humus form is usually a moder or very thin greasy mor, the partially gleyed, coarsely blocky structured A/Eg horizon is about 6 inches thick and overlies the crumb or fine blocky structured B horizon. Rootable depth is usually moderately deep, 24-36 inches, and the soil occurs on moderate to steep, lower and middle slopes between 800 and 1300 feet. It is one of the most extensive soils in Mid-Wales. Ground vegetation usually consists of fine grasses and bracken.

C. "Intergrade Soil"

This soil, while clearly representing a transition stage both in its topographic posiction as well as in its profile morphology, between the previous type and the ironpan soil (D-typical Hiraethog series) has sufficient properties of importance to forestry to be worthy of separate recognition. It is closer to the concept of the Hiraethog series as described by Ball for North Wales than to the Manod, but is distinguished from the Hiraethog in having less than two inches of amorphous peat, a less distinct and continuous pale greyish Eg (= A2g) horizon, at most only a trace of an iron pan, and a different ground vegetation. In addition the intergrade soil frequently has a somewhat paler coloured B horizon than the rich ochreous colour of the Hiraethog, with slight mottling, apparently due to lateral seepage of water down the slope. The structure of the gleyed subsurface horizon is weak.

The soil provides a rootable depth of 24-36 inches and occurs on the convex or neutral, steep upper slopes, at elevations between 1200 and 1500 feet. It was not mapped in Clocaenog forest, as it is not prominent there.

The ground vegetation is a characteristic and important feature, consisting of Calluna, Vaccinium myrtillus and Ulex gallii (dwarf gorse), with an understorey of Sphagnum moss.

D. Ironpan soil (Crompton 1958, FitzPatrick 1964)

This conforms to the central concept of the Hiraethog series (peaty gleyed podzol).

An amophorous peat layer averaging 8 inches thick overlies a 2

inches thick pale greyish Eg (=A2g) mineral horizon, in turn followed by a thin ironpan (which may not be continuous), and then the 6-18 inches thick prominent ochreous B horizon, friable, crumb structured and evidently quite aerated.

The rootable depth, assuming penetration of the ironpan, varies from moderately shallow (less than 24 inches) on hilltop sites to deep (up to about 40 inches) on upper hill slopes. The ground vegetation in Mid Wales is normally dominated by Molinia, with Calluna present in small proportions, but in Clocaenog forest, Calluna is often dominant, being replaced by Nardus where grazing or burning has been intensive.

E. Alluvial soil

This soil appears to conform at least in part with the Conway series, consisting of alluvial material of rather variable composition, with ground-water gleying effects. The subsoil is mineral and strongly gleyed, but the upper layers are variable and often include peat or peaty mineral material.

The soil is potentially deeply rootable given deep drainage.

The ground vegetation is vigorous and grassy (Deschampsia caespitosa dominant), with Juncus effusus.

The alluvial soils are not extensive in upland forests, being found principally as thin strips along the main rivers.

F. Mineral Gley

In part the mineral gley corresponds with the non-calcareous surface-water gley Cegin series, including in a few places the somewhat better drained Sannan series, that is, an impeded, fine textured soil on glacial till. Included in the type as mapped in upland forests however, are flush-gley soils, also lacking peat, but with frequently only a shallow depth of mineral soil over the bedrock. These latter soils may represent flushed and non-peaty variants of the "shallow peaty gley". The flush gleys occur either as narrow ribbons running down the hillsides or as wide bands spreading out below spring lines. The more typical Cegin soils occur on the lower concave slopes of the valleys.

Rooting is frequently shallow on this soil due to poor aeration of the subsoil and careful drainage is required to make better use of the soils potential. Ground vegetation is dominated by Deschampsia caespitosa, with some Juncus.

G. Deep peaty gley

Considerable variation in thickness of mineral soil overlying

bedrock was encountered in peaty gleys in Mid Wales, and because of the significance of this in artificial drainage operations, a sub-division was made into shallow and deept types.

The deep peaty gley corresponds fairly closely to the Ynys series as described by Ball (1960, 1963) in North Wales, and here includes amorphous peat up to 18 inches (averaging 6 - 8 inches) in thickness over impeded silty clay to silty clay loam till. The depth of mineral soil even in this type, however, rarely exceeds 36 inches in Mid Wales, but the peaty gley mapped in Clocaenog forest lies on till about 4 feet deep.

In general the deep peaty gleys in Mid Wales are found on the lower valley slopes, or in major basins up to quite high elevations. In Clocaenog forest typical Ynys series is very extensive; in the higher rainfall of the west of the forest it forms a blanket over most of the gentle to moderate slopes.

The deep peaty gley is potentially rootable to a depth exceeding 24 inches, given deep and intensive artificial drainage. Without this only moderately shallow (12-24 inches) rooting can be expected.

Molinia, with some Juncus effusus is ubiquitous on this soil type.

H. Shallow peaty gley. (only mapped in Mid Wales)

The peat averages 6 inches in thickness, but overlies a strongly gleyed mineral soil less than 18 inches deep over the bedrock.

Utilisable depth is thus potentially less than 24 inches, and is further reduced by poor aeration in the mineral layers. Artificial drainage of this soil is essential if a reasonable rooting depth is to be achieved, but will be difficult due to the shallowness of the soil and the irregularity of the topography on which it occurs.

The shallow peaty gley is found on the hill tops and upper slopes over 1100 feet, often on undulating ground containing frequent knolls where bedrock may be exposed.

Molinia is usually dominant but Calluna can be important in places.

I. Flushed basin peat and Raised basin peat

Basin peats exceed 18 inches in depth and occur in relatively small depressional sites at all elevations. They were included by Ball (1963) in the Caron series.

Flushed basin peat is usually less than 48 inches in depth and

is of the blackish amorphous type, and has a vegetation of Juncus effusus, Molinia, Deschampsia caespitosa and Cirsium vulgare.

Raised basin peat usually exceeds 48 inches in depth and has an upper layer of brownish fibrous peat, with a vegetation containing Calluna, Eriophorum vaginatum and Sphagnum, with Trichophorum in the deeper examples, but lacking Juncus, Deschampsia and Cirsium. The two types are always mapped separately in forest soil surveys, but in Mid Wales have been considered as one site type as they are less distinct than in Clocaenog forest.

Rootable depth is dependent on the effectiveness of the artificial drainage.

J. Hill Peat and Shallow peat over bedrock

Hill peat may be defined as an oligotrophic peat exceeding 18 inches in depth developed on non-flushed situations, usually ridge tops or plateaux. It frequently overlies an ironpan soil, but may also develop on a peaty gley type of profile, (usually the shallow peaty gley in Mid Wales).

Essentially the same kind of peat in similar topographic situations may be less than 18 inches depth where it overlies bedrock. This type is mapped separately, but is usually included in the same site type as the deep hill peat. The shallow type is found on steep erosional slopes at high elevations or on stabilised scree, and bedrock exposures are not uncommon.

Hill peat is an extensive soil type in the western part of Clocaenog above 1300 feet elevation and above 1500 feet in Mid Wales. Hagging is widespread and has reached an advanced stage on the eastern side of Plynlymon in Hafren forest, but was less apparent in Dovey and Clocaenog forests. Hill peat is absent from Kerry forest where the rainfall is less then 50 inches, although high plateaux conditions are well represented there.

SOILS AND SILVICULTURE IN UPLAND WALES

The chief aspects of silviculture which are affected by soil/site type are choice of species, cultivation, drainage, fertilisation, weeding and windthrow.

1. Choice of species

The choice of major forest species is based on ecological and economic criteria.

The freely drained brown earths are suitable for a wide range of species being fertile soils occurring at low elevations in fairly sheltered positions. The most productive species are likely to be Douglas fir, Western hemlock and Sitka and Norway spruces, and probably including Grand fir although this has been little tested to date.

The ochreous brown earths occur at higher elevations where exposure has to be reckoned with, although soil conditions are favourable for many conifers. The two spruces are ideally suited, Sitka being the more resistant to exposure, but Douglas fir, Western hemlock and Japanese or Hybrid Larches do well in the more sheltered situations.

The alluvial soil and mineral gley may be better used by Norway spruce than by Sitka in frosty sites near the valley bottoms, but the reverse applies to the intergrade, ironpan, shallow and deep peaty gleys, which are too exposed for Norway spruce.

Sitka spruce is thus the first choice for most of the ground over about 1000 feet, the exceptions being the deep peats. The flushed basin peat will in fact grow satisfactory Sitka spruce unless frosty, when Lodgepole pine is preferable. This species should also be the first choice for the poor deep peats, that is raised bog and hill peat, being much more tolerant of these conditions than spruces.

Exposure may limit planting to below 1800-2200 feet depending on local geomorphic shelter.

2. Cultivation

Where slope permits, ploughing is almost universally used for the preparation of bare ground for planting in upland areas, and confers the following benefits: a weed-free planting site, improved soil aeration, and quicker nutrient release from decaying vegetation and/or peat.

On the gleys and peats single or double-mouldboard, so-called drainage ploughs are used, usually in the direction of greatest slope, to produce spaced planting ridges and furrows which remove excess surface-water. These are then linked to a deep contour drainage system. Double mouldboard (DMB) ploughs are much quicker and cheaper per acre than the single mouldboard (SMB) versions, and although their drainage effect is obviously less this is not considered to be an important factor when deep contour drainage is provided.

The soils that do not require deep drainage are usually cultivated with a tine plough to give planting ridges also at 5 - 6 feet spacing. The tine plough is a robust implement but used in this way gives limited

deep cultivation effect, it would probably be better employed if modified slightly and used for deep complete cultivation of the intergrade and ironpan soils. The productivity of these soils should increase with increasing intensity of deep cultivation, that is, be a maximum when peat, gleyed A/Eg horizon, ironpan and a part of the B horizon are thoroughly mixed together. This is simply an endeavour to produce from these soils the conditions of the normal (ungleyed) ochreous brown earths. That this can be done by repeated cultivations is evident from examinations of agricultural soils in the area. Complete cultivation on the intergrade and ironpan soils should also eliminate the problem of 'check' in young plantations (see below).

3. Drainage

On bare ground, following DMB or SMB ploughing in the direction of greatest slope, deep drains are ploughed close to the contour and the whole system of channels linked up to the existing watercourses as an integrated cultivation/drainage system. At present ploughs capable of producing a 36 inches deep drain are only available for deep peats, and less than ideal depths have to be accepted on peaty gleys and mineral gleys.

However, tractor-mounted hydraulic diggers are very effective in the gleys, albeit much slower and more expensive than ploughs. These machines are also used to carry out deep drainage in existing plantations which were formed before suitable machinery became available or perhaps before the need for very intensive and deep drainage was fully appreciated. New ploughs are being developed which it is hoped will be used for draining the considerable acreage of the young existing plantations through which either the tractor can force a passage or in which racks may first have to be cut. It is open to speculation whether older plantations, that is those which have reached the thinning stage, can be expected to respond to improved drainage before serious wind damage necessitates their replacement. Research work is being pressed ahead as a matter of urgency in Wales and in other parts of Britain as it is evident that there is a vast acreage of stands on sites which have a high windthrow hazard (see below).

4. Fertilisation

Responses have been obtained to phosphate, potash and nitrogen fertiliser applications on certain soils in upland Wales (Holmes, 1963). Present recommended practices are as follows:

Phosphate: should be given at time of planting on all soils except the brown earths, alluvial soil and mineral gley. In existing plantations broadcast top dressings may be applied if deficiency symptoms arise. Additional applications may be required on the poor deep peats, usually mixed with potash (q.v.).

Potash: is only required on the poor deep peats, and is usually applied as a PK mixture as a broadcast top dressing when deficiency symptoms appear.

Nitrogen: is at present used in combination with phosphate to alleviate 'check'.

5. Weeding

The fertile brown earths (site type A) have very vigorous bramble and bracken under light tree cover such as larch, and this is not only a nuisance during tending operations but is a downright liability during regeneration. Dense crowned, shade-bearing species such as Douglas fir, Western hemlock and Grand fir are an advantage under potentially weedy conditions as they maintain a reasonably clean forest floor.

The only other serious weed problem is that which arises when spruces planted in ericaceous vegetation do not establish themselves quickly enough to shade it out. This is likely to happen on ground which cannot be ploughed due to steepness of slope. The trees go into a form of 'check', in which they generally remain apparently healthy yet put on little height growth. Several hundred acres of crops in this condition exist in Mid Wales forests, mainly on the intergrade soil, but there is a certain amount on the ironpan soil also. In Glocaenog forest, in a lower rainfall of some 40 inches per annum 'checked' spruce was occasionally seen in ericaceous vegetation on mineral gley and peaty gley as well as on ironpan soil.

The composition of the vegetation of most of these checked sites is very characteristic and consists of Calluna, Vaccinium myrtillus, Ulex gallii (dwarf gorse), with an understorey of Sphagnum. Molinia is usually present in small proportions, tree growth being noticeably better where this species is abundant.

Various techniques have been tried to alleviate check symptoms and have met with varying degrees of success. Fertilisers have often failed to produce responses but it has recently been discovered that, provided heavy doses are given, phosphate increases height growth appreciably in the second year after treatment. Urea is usually

given in addition to phosphate as foliage analysis has also revealed low nitrogen levels. The standard rates now used are 3 cwt./acre triple-superphosphate + 1¾ cwt./acre urea.

6. Windthrow

Early windthrow is associated with poorly drained, shallowly rooted soils, especially in exposed situations, and occurs on the alluvial soil, gleys and deep peats when crops exceed about 40 feet in height unless effective deep drainage is provided. The ironpan soils on hill tops where there is little rootable soil beneath the pan may also produce windthrow susceptible crops.

Wind damage is already an important problem in Clocaenog and Kerry forests where old crops occur, but in Hafren and Dovey forests the gleys and peats at present carry rather young crops and windthrow is as yet fairly insignificant.

Topographic exposure influences the time of damage (i.e. the height crops reach): (Pyatt 1966), and the most severely exposed localities on shallow peaty gley, shallow peat over rock, and ironpan soil and possibly also on the other gleys and peats may necessitate the management of crops on short rotations. If this unfortunate circumstance has to be accepted then it will probably lead to several modifications to the silvicultural practices in such crops.

A special form of topographic survey is being carried out which may enable zones of different exposure level to be objectively defined and mapped. The method involves the use of a clinometer to measure the inclination of the skyline in different compass directions, the sum of the angles measured representing the degree of shelter of the location. While such a survey gives an apparently valid map of exposure levels it remains to be seen whether it is more effective for predicting windthrow than a subjective exposure map or a normal topographic map.

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DISCUSSION

In reply to an enquiry by E. M. Bridges (U.C.W., Swansea) D. G. Pyatt replied that none of the work on Welsh forests had yet been published but that articles on forests in the Scottish Borderland had been published in "Scottish Forestry".

ECONOMIC ASPECTS OF UPLAND LAND USE

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Interest in a rational approach to the use of land in Britain is of fairly recent origin. It has long been accepted that land has two major uses - rural and urban development - and that the demand for land for urban use would grow over time. But the use of rural land has been traditionally thought of almost exclusively in terms of agriculture, and any demand for the use of rural land by non-agricultural interests has been strongly and consistently opposed. More recently, these demands have increased: additional land in rural areas is required for water conservation purposes to meet the needs of an increasing population and of growing industries; there is currently an increasing awareness of the scientific value of specific areas in rural Britain; the Forestry Commission needs additional land to meet their planting targets; more land is required for recreational purposes, to give people the opportunity to enjoy their leisure in rural surroundings.

The requirements of these various land-using activities can be fulfilled in the upland areas of Britain. To achieve a rational use of these upland areas, we must accept three basic principles.

1. Farmers have no sacrosanct right to the use of land any more than has any other individual wishing to develop land for non-farm purposes. The fact that over 80 per cent of the total land acreage of Britain is currently used for agricultural purposes is historical, and should not influence our decision as to the future use to which land should be put.
2. Non-agricultural activities have a legitimate right to acquire land in rural areas; this right must be recognised and provided for.
3. The right to use land by any individual or institution (State or private) must be proved. This involves the selection and use of criteria by which the claims of competing activities for a given area of land can be measured.

When we consider the use to which land in any country is put, we find that a variety of factors influence the land owner. Basically, land use is a function of environmental factors - climate,

topography, aspect, soil structure etc. - but where such factors permit of more than one activity, the landowner is presented with a choice problem. In arriving at a decision between two or more activities, the private individual may be influenced by personal, subjective motives - an interest in shooting, or amenity considerations; the use of rural land by State institutions is often determined on social or strategic grounds. In fact, we find, in practice that economic motives are not necessarily decisive in respect of land use in Britain.

Yet, in selecting a criterion by which we may, objectively, compare the claims of a variety of competitive activities for a given area of land, we find that the economic implications of the alternative activities provides us with our best measuring rod. This, for two reasons:-

a) It enables us to make valid comparisons between quantifiable and non-quantifiable objectives. In other words, the economic criterion enables us to ascribe a value to objectives which in themselves are incapable of direct evaluation. If, for instance, we compare two activities, one geared to the production of a tangible end product (food) and the other to the provision of employment in rural areas through afforestation, and we discover that the net income from food production is £10 an acre, while that for forestry is only £7 an acre, we can evaluate the cost of pursuing an essentially social objective (employment, which in itself cannot be measured) at £3 an acre. This represents the opportunity cost to society of pursuing a social policy and it is clearly important that society is aware of the cost involved in pursuing non-economic objectives.

b) The economic criterion is acceptable and necessary in respect of land-use by virtue of the economic relationships which the use of land itself brings into being. Land itself is an economic commodity; it is a natural factor of production, limited in quantity and specific in location. It is a scarce, natural resource, which possesses value. Thus, in respect of land use, we are concerned with the use of a scarce, valuable economic good (land) in association with other scarce, valuable economic goods (labour and capital), to produce end products (food, timber, pleasure, water etc.) which in themselves are economic in that they are scarce relative to demand

and possess a value concept.

It is therefore logical to consider competitive forms of land use from an economic standpoint, in an attempt to discover which form makes the 'best' use of land.

In considering the economic aspects of upland use in any country, three separate problems are involved -

(a) the choice of area within which the assessment of land use is to be made;

(b) the choice of methodology, by reference to which the financial calculations will be made;

(c) the choice of criteria, by which the relative merits of the alternative activities will be assessed.

1. The Choice of Area

Initially, the choice of area will be determined by outside interests. It may be as small as a farm; it may be as large as a county or a geographical region. But the size of the area under review is of relatively secondary importance, except insofar as a large area may make the exercise more complicated. What is of paramount importance is that the area, regardless of its size, is homogeneous in respect of those factors which influence its productivity under the activities under review - these factors include soil type, rainfall, altitude, temperature, aspect and other physical features. Hence it is likely that a large area will need to be broken down into smaller units, each representing a homogeneous type of the given activity; small areas may be sufficiently homogeneous in themselves, and may require no further breakdown, but we should never assume that smallness and homogeneity necessarily go hand in hand.

In considering the area, initially we should break down the existing broad pattern of land use into a systematic pattern of homogeneous uses. Since agriculture is invariably the 'sitting tenant', this will mean classifying farming according to type. We should then impose on the area under review, classified in respect of its present use, the alternative uses, likewise classified into homogeneous types. If we consider, for instance, three land using activities - agriculture, forestry, and recreation. The purpose of the exercise is not to compare A, F and R, but rather to compare a specific type of A against a specific type of F and against a specific type of R. It is imperative that such a classification be undertaken,

otherwise we are likely to conclude, irrationally, that the whole region should remain in agriculture, or be transferred to forestry, whereas parts of the region, characterised by a peculiar type of forestry may be economically more attractive than the type of farming currently practised there.

2. The Choice of Methodology

One of the most critical differences between alternative land using activities is in respect of the length of their respective production cycles. For instance, land devoted to agriculture yields a fairly early and continuous return (agricultural rotations rarely exceed a year in duration) whereas at the other extreme the return on forest land is substantially nothing for about twenty years after planting and is not fully realized for perhaps half a century or more. Hence a profit calculation based on the straightforward difference between annual gross income and expenditure (as is customary in agricultural economics) is a meaningless indication of the relative economic values of activities with widely differing production cycles.

To overcome this 'time-factor' effect, it is necessary to discount all items of revenue and expenditure incurred over the life of the longest activity under review, and to relate the resultant 'discounted margin' to a similarly discounted margin calculated over a similar time period in respect of the other activities. Discounting thereby enables us to assess the 'present work' of any long term investment. In effect, it implies answering two questions:

a) On the expenditure side, how much money would an investor need to set aside today (at a given rate of discount) to finance an expenditure of £X in 4 years' time?

b) On the revenue side, what is the worth, or value, today of an income of £X which an investor will earn in 4 years' time (at a given rate of discount)?

Let us consider an example. An investor intends to spend £20 in 15 years' time (at 5% discount); he expects to receive £40 in 30 years' time (also at 5% discount). What is the present net value of his investment? Let X = expenditure and Y = income. Then,

$$\text{Present value} = \frac{Y}{(1.0p)^n} - \frac{X}{(1.0p)^n}$$

where p = discount rate, and n = years in which income is received,

and expenditure is incurred. Therefore,

$$\text{Present value} = \frac{£40}{(1.05)^{30}} - \frac{£20}{(1.05)^{15}} = (-)\ t.0.4.$$

Thus, both revenues and expenditures are brought to a common period of time (the present), as a means of overcoming the time element involved in the production process.

3. The Choice of Criterion

The basic measure of profitability is the margin between discounted receipts and discounted costs. This is termed the Net Discounted Revenue (N.D.R.). But N.D.R. merely indicates the absolute size of the 'surplus' (if any) obtainable from the alternative land using activities under review. In order to compare the relative profitability of these activities, it is necessary to relate the N.D.R. to a common factor input. Two common inputs are suggested - land and capital.

1. N.D.R. per acre, measures the 'surplus' accruing to land. It is a useful measure in respect of activities whose intensities of land use are similar; clearly it is a meaningless criterion when applied to a situation whereby a land using activity is being compared with a non-land using one. On the other hand, its usefulness is increased if the cost of land is excluded from the cost side of the calculations, so that the 'surplus' N.D.R. includes both the return to the land and the profit to the landowners. Used in this way, N.D.R. per acre measures the maximum price the landowner could afford to pay for his land and break even on the transaction. It sets a ceiling on the price of land - an important consideration in times of land scarcity and inflated land prices.

2. N.D.R. per £100 Capital - this measures the now familiar cost-benefit relationship which may exist within activities. It merely relates the net benefit of the activity to the capital incurred in its production. It may be presented either in the form of a ratio, or in the form of a financial figure.

3. Discounted Cash Flow Rate of Return - In addition to the above criteria, landowners having to borrow money, either from lending institutions or possibly from their own pockets need to know the critical rate at which such borrowing may be made. This is determined by the D.C.F. Rate of Return, which represents that discount rate at which the N.D.R. is zero. It measures, therefore, the

TABLE 1 : THE PROFITABILITY OF FORESTRY AND LIVESTOCK REARING IN MID WALES

(1) To the Private Owner

	3%		5%		7%	
	A	F	A	F	A	F
Net Discounted Revenue (£ / acre)	23	147	-30	50	-51	11
Capital (£/acre)	48	61	48	51	48	43
N.D.R. per £100 Capital	48	241	-63	98	-106	26

	A	F
Discounted Cash Flow Rate of Return (%)	$3\frac{3}{4}$	8

(2) To the Nation

	3%		5%		7%	
	A	F	A	F	A	F
Net Discounted Revenue (£ / acre)	-67	112	-88	17	-102	-19
Capital (£ /acre)	51	95	51	84	51	74
N.D.R. per £100 Capital	-131	118	-173	20	-200	-26

	A	F
Discounted Cash Flow Rate of Return(%)	$\frac{1}{4}$	$5\frac{3}{4}$

TABLE 2 : THE PROFITABILITY OF FORESTRY AND HILL SHEEP FARMING IN MID WALES

(1) To the Private Owner

	3%		5%		7%	
	A	F	A	F	A	F
Net Discounted Revenue (£ /acre)	-19	12	-15	-15	-13	-20
Capital (£ /acre)	24	52	24	43	24	37
N.D.R. per £100 Capital	-79	23	-63	-35	-54	-54

	A	F
Discounted Cash Flow Rate of Return (%)	Negative	$3\frac{1}{2}$

(2) To the Nation

	3%		5%		7%	
	A	F	A	F	A	F
Net Discounted Revenue (£ / acre)	-32	-11	-23	-37	-15	-42
Capital (£ / acre)	25	76	25	65	25	57
N.D.R. per £100 Capital	-128	-14	-92	-57	-60	-74

	A	F
Discounted Cash Flow Rate of Return (%)	Negative	$2\frac{1}{4}$

the maximum borrowing rate that the landowner can afford to stand, and still break even on the investment. Graphical calculation of the D.C.F. Rate of Return is shown in Fig. 1.

The Application of the Methodology in Upland Areas

For illustrative purposes, two areas in Mid-Wales have been selected, and within each agriculture has been compared with afforestry:-

1. An area in Radnorshire, characterised by livestock-rearing farming, comprising the parishes of Llanyre and Llanfihangel Helygen, situated on the Breconshire border, about ten miles south of Rhayader and adjacent to the urban parish of Llandrindod. The area lies within the boundaries of Coed Sarnau Forest.

2. An area in Merionethshire, characterised by hill sheep farming comprising the parishes of Llanddwywe uwch y Graig, Llanelltyd and Llanfachreth - situated between Dolgellau in the South and Trawsfynydd in the north, Ganllwyd in the west and Llanuwchllyn in the east. These three parishes form part of Coed-y-Brenin Forest - one of the largest State forests in Wales.

The financial results of the economic assessment of agriculture and forestry in these two areas is presented in Tables 1 and 2 and Figs. 3 and 4.

Our conclusions, based essentially and entirely on the financial implications of the two activities in the sample areas would be

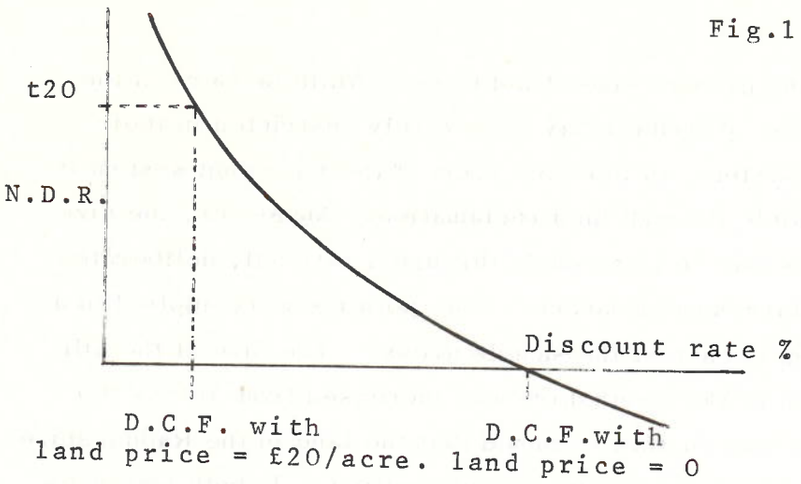
a) in the Radnorshire area, forestry both to the private individual and to the nation is to be preferred to livestock rearing. Here a transference of land from its present use (farming) to an alternative use (forestry) would be economically justifiable.

b) in the Merionethshire area, characterised by intensive hill sheep grazing, both agriculture and forestry are economically unattractive, except private afforestation at a discount rate less than $3\frac{1}{2}\%$. In fact, subsidised agriculture in this area, incurs a loss even before any interest charge on borrowed capital is incurred.

We may therefore ask ourselves: To what use should such land be put? Two alternatives are possible: we may identify the causes for the low productivity of the land under the stated activities, and attempt to remedy them; alternatively we may consider the possibility of using such land for other purposes.

1. Low Productivity - The data presented in Tables 1 and 2 is based on the current systems of farming practised in the areas,

Fig.1



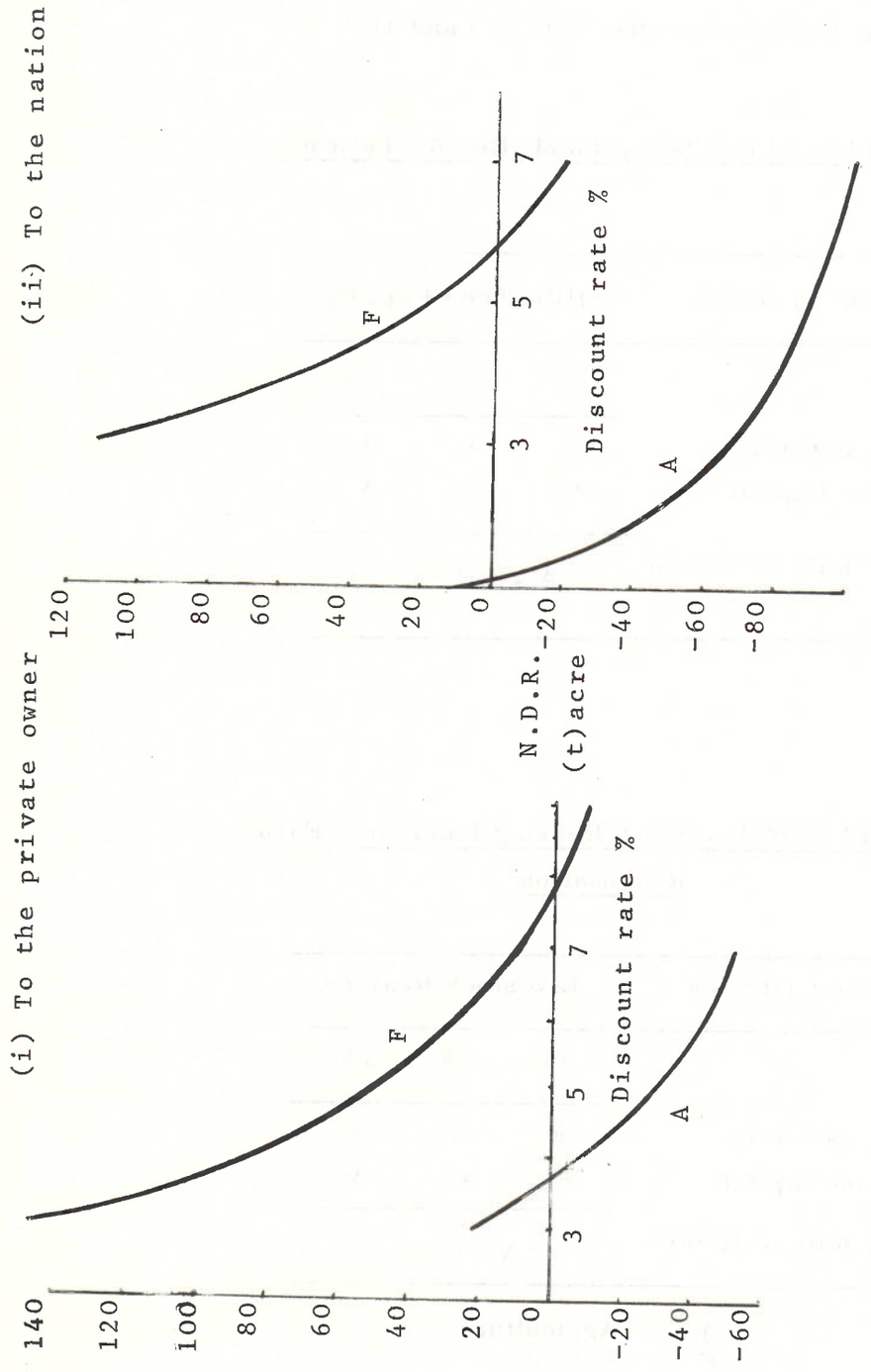


Fig.2 The Calculation of the D.C.F. Rate of Return from Agriculture and Forestry. (Livestock Rearing Farming)

A:- Agriculture F:- Farming.

allied to the present size of holdings. While farmers in the upland areas of Britain may be severely restricted in their choice of system, an intensification of their present system is often possible through land reclamation. Moreover, the size of holdings may be increased, through a rational, deliberate policy of farm amalgamation. Both policies were applied to a model farm in each of the sample areas. The size of the hill sheep farm in Merionethshire was increased from 100 to 300 acres; it was further assumed that the land in the Radnorshire area was reclaimed and its use intensified. In both instances the effect was to increase the profitability of farming to a level at which it competed efficiently with forestry, except at a low discount rate in Radnorshire (See Tables 3 and 4).

Table 3

Preferred Use of Hill Sheep Land after Reclamation

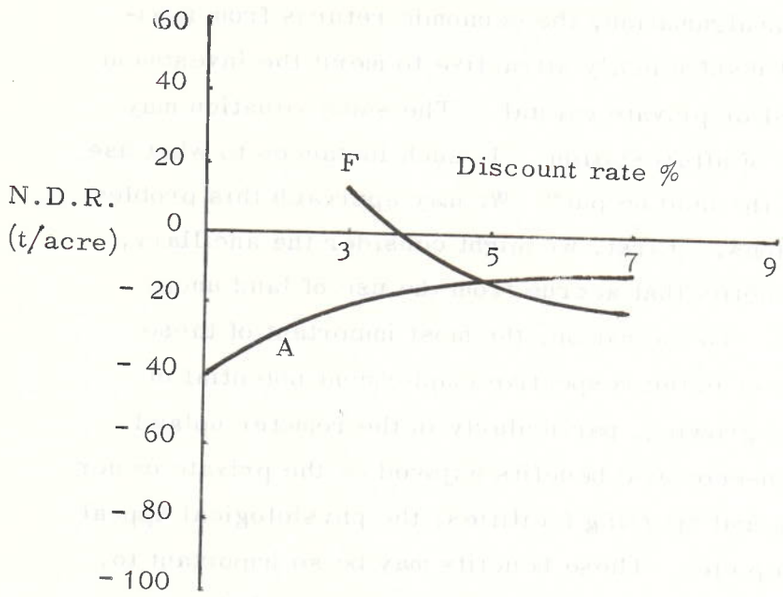
Economic Criterion	Hill Sheep Farming		
	3%	5%	7%
N.D.R. per acre	A	A	A
Return on Capital	A	A	A
D.C.F. Rate of Return	A = 10¼%		

Table 4

Preferred Use of Livestock Rearing Land after Farm Reclamation

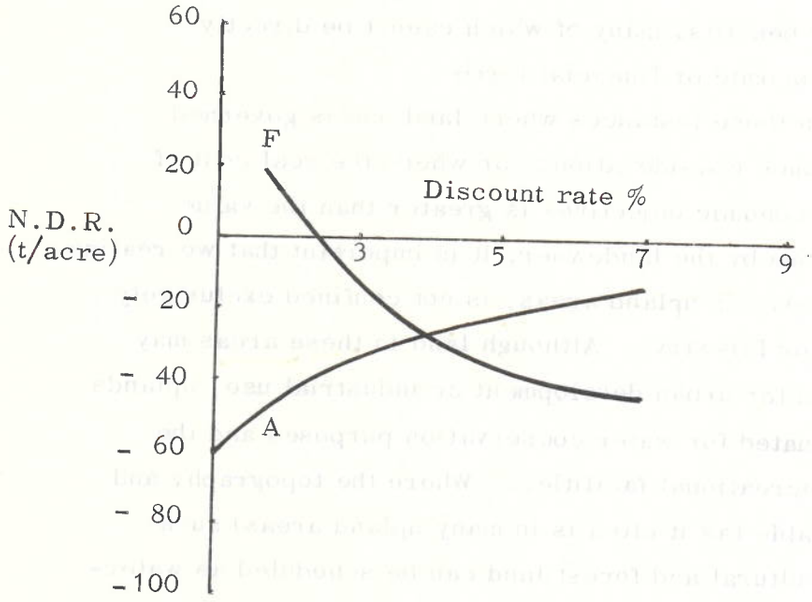
Economic Criterion	Livestock Rearing		
	3%	5%	7%
N.D.R. per acre	F	A	A
Return on Capital	F	A	A
D.C.F. Rate of Return	A = 11%		

A = Agriculture
F = Forestry



(1) To the Private Owner

A. = Agriculture F = Forestry



(2) To the Nation

Fig. 3

The calculation of the D.C.F. Rate of Return from Agriculture and Forestry (Hill sheep Farming).

2. Alternative Uses - These remedies do not always prove successful however. There are instances where, even after reclamation or amalgamation, the economic returns from agriculture are still insufficiently attractive to merit the investment of either national or private capital. The same situation may apply in respect of afforestation. In such instances to what use can, or should, the land be put? We may approach this problem from two directions. First, we might consider the ancillary, imponderable benefits that accrue from the use of land under given activities. To the nation, the most important of these benefits at present is the respective employment potential of farming and tree growing, particularly in the remoter upland areas. The non-economic benefits enjoyed by the private owner include shooting and sporting facilities, the physiological appeal of land ownership etc. These benefits may be so important to, or highly valued by, the landowner that an activity that appears to be economically unattractive may still be considered worthwhile. Such an approach does not invalidate the economic conclusions derived from a purely financial comparison of the alternative. Rather the economic assessment can, in such circumstances be instrumental in measuring the real cost of these ancillary benefits, many of which cannot be directly measured in economic or financial terms.

Second, in those instances where land use is governed solely by economic considerations, or where the real cost of pursuing non-economic objectives is greater than the value attributed to them by the landowner, it is important that we realize that land use, even in upland areas, is not confined exclusively to agriculture or forestry. Although land in these areas may not be required for urban development or industrial use, uplands are ideally situated for water conservation purposes and the provision of recreational facilities. Where the topography and climate is suitable (as it often is in many upland areas) such marginal agricultural and forest land can be scheduled as water-gathering grounds. In other cases, the natural advantages of upland areas - geographical, environmental, topographical, physical - may be exploited through its recreational development.

An economic assessment of upland use enables us to identify objectively, within a given region, those parts which are best suited for specific purposes, and thereby facilitates a more efficient and a fuller use of such areas.

PROBLEMS RESULTING FROM THE EXPLOITATION OF UPLAND WATER RESOURCES

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As a result of a century of water resource exploitation, during which time the potential of the empty uplands has been called upon to satisfy the demands of the densely populated lowlands, the hill-country of Britain is virtually littered with reservoirs which store and exploit upland water resources. Moreover, not only are their numbers being increased annually, but as has been recently stressed by the Water Resources Board, this tendency can be expected to continue at least until 1980, and even longer if coastal barrages and desalinification do not prove to be feasible or economic. It is therefore clear that, whatever reactions may be to such upland reservoirs, we must learn to live with them. Attitudes must needs be positive and constructive rather than negative and prohibitive, so that research and policy are focused on minimizing any harmful effects and maximizing any potential benefits.

In this connection there are considerable differences between the possibilities and limitations presented and imposed by impounding reservoirs for direct abstraction of water, and those of strictly river-control reservoirs. In the former case there is an undoubted need to ensure and maintain purity of the water source, and this is in effect a charge laid upon the water undertakings by Parliament in the interests of public health. The water thus stored is then abstracted at the reservoir and transported to the consuming area by aqueduct and pipe-line. In contrast, the control resevoir exists to ensure a reliable minimum flow of water down the river, so that the required quantity of water can be abstracted downstream at the most convenient point near to the consumer. As pollution of the water is therefore likely to occur in transit along the natural open aqueduct of the river, thus requiring modern large-scale purification on abstraction, catchment management and control is neither as rigid nor as intensive as in the case of the more traditional impounding abstraction reservoir.

Whichever type of reservoir is involved, one basic loss to the upland environment must follow from the reservoir construction, namely the drowning of valley-bottom land and any farmsteads on

it. For the agriculture of the valley this is usually critical, for it is this land which normally provides fodder and grazing for the winter period, and which thus influences the level of agricultural activity within the valley. Furthermore, alternative farm sites are often not feasible.

If the reservoir is for direct abstraction, however, the needs of water purity impose further limitations on agriculture. To obviate harmful organic pollution, houses and farms within the catchment are frequently prohibited. Moreover, the type of livestock permitted leads to the exclusion of cattle from the hills, with only sheep being allowed. Additionally, the possibility of upgrading marginal pastures by means of fertilizers is also prevented, again in the interests of water purity. In the case of control reservoirs, in contrast, such restrictions are markedly less stringent, and may even be completely absent, especially in tributary valleys of the catchment which will experience little or no harmful effects to their farming economy as a result of the reservoir construction.

In both cases, however, the exploiting authority does have an interest in the plant cover of the catchment, and in forms of land management, in so far as these affect rates of run-off to the reservoir, retention of water in the soil, reduction in total water yield, and also rates of siltation in the reservoir. A preference for water-retentive peat surfaces seems apparent in some cases, though this may simply reflect the nature of the specific environment. Afforestation also often plays a role in catchment area management, though its contribution in smoothing out the rate of release of water to the reservoir, and in the reduction of siltation, may be partially off-set by a tendency to reduce the total amount of water available. A critical consideration, however, is often the additional economic return over a 30 - 50 year period of the forestry products, this, under present day conditions, usually being greater than that from any pre-existing upland farming economy.

There is also the question of potential contribution of upland catchments and reservoirs to amenity and recreation facilities for the urban population of this country. This largely hinges on the degree of access that is permitted, both to the catchment and to the water area. The exclusionist policy often adopted to preserve purity of source can affect the hill-walker and rambler as much as the car driver and the water-sports enthusiast, and it is perhaps

the rigid application of such policies in the Thirlmere catchment, for example, which has contributed to the opposition to further water resource exploitation in the Lake District.

With control reservoirs, however, such as Llyn Celyn in the Tryweryn Valley, availability of access is the rule, and in such cases reservoirs could be used to provide new sites for water sports and activities in areas where they did not exist before. For the less energetic, too, the aesthetic pleasure of open water surfaces within upland valleys, and the possibilities of fishing or even of pleasure boats, could well lead to a considerable increase in tourism as a local rural industry. There are obvious problems here, in that an excessive increase in tourist traffic could easily lead to a greater destruction of the rural character of the area than would the reservoir itself. Furthermore, to ensure the attractiveness of the new environment requires a deliberate and conscious attempt at landscaping, especially around the dam itself, throughout a long period of time, and even then it is not really possible to eliminate the unpleasant results of a fluctuating lake level and shoreline. Despite the problems, however, such developments should be encouraged and expanded, for they both contribute to the economy of the rural areas concerned and also provide an increase in open-air amenities that are sorely needed.

The exploitation of upland water resources also leads to other beneficial influences upon the rural economy. The new and improved roads that are usually made, with better alignments and greater ease of access, provide positive social and economic assets, especially for the farmer in the catchment and its tributaries. Furthermore, employment is created not only in terms of water management itself (which is usually only a small element) but also in such related developments as forestry and tourism, where these are encouraged and allowed to flourish.

Quite apart from this, the water resources developed in the uplands primarily for the benefit of the lowland urban dweller also often provide water for the rural area itself. This is frequently obtained by abstraction from the aqueduct en route to the city, as with the Liverpool supply from Lake Vyrnwy which is utilized by a large number of intervening rural districts. In this context the purity of the water at source is a positive asset to the small undertaking, which would find it financially difficult to install the necessary purification works to use the less pure river water released via a controlling resevoir.

These upland catchments also present both the need and the opportunity for a wide range of scientific enquiry. Basic to the whole problem is the gathering of hydrological data and their full and effective analysis - without these studies, in much greater breadth and depth than at present, no truly valid estimate of the resource base, its potential for development and the requirements for its efficient exploitation on a multi-purpose basis, will ever be possible. Such measurement and evaluation is now the responsibility of the River Authorites, backed by the Water Resources Board, but there is ample scope for contributions from research workers outside these bodies.

The influence of reservoir development, and of the policies of land management adopted, upon ecological relationships in general is also a valuable field of study, in both an academic and an applied sense. Furthermore, the possible impact of such developments upon soil moisture, water table levels, and local and micro-climatic conditions also require systematic investigation, for there is but limited observational evidence currently available. Finally, the different policies of catchment area management which are practised need comparative assessment, in terms of both their hydrological and their economic effectiveness. It is in these management policies that are concentrated many of the possibilities of mitigating the undesirable characteristics apparent in the present-day exploitation of upland water resources. Thus optimal utilization of such upland areas could become possible, in the sense of broad-scale conservation rather than narrow preservation of this natural resource base.

DISCUSSION

G. ap Griffiths (P.B.S., Aberystwyth) enquired what the proportion of domestic to industrail consumption was and asked what the effect of metering the former might be. S. Gregory replied that the proportion was negligble.

R. I. Davies (U.C.N.W., Bangor) suggested the use of salt water for certain domestic purposes but S. Gregory replied that the cost of installing an alternative pipe system would be prohibitive.

In reply to an enquiry of Miss J. Morgan (Agri. Land Service, Aberystwyth) S. Gregory suggested that the effect of afforestation might be that trees would retain more water, resulting in less run-off and large scale flooding, or that

there might be a nett loss of water due to evapo-transpiration. The effects of coniferous plantations would be extended through the year whilst those of deciduous woodlands would vary over the year; the retentive capacity of the soil might also be changed. As yet, the full effects were not proven either way.

R. P. Bower (U.C.N.W., Bangor) remarked that the area around Llyn Alwyn had been afforestated in 1950, and asked whether any data relating to the effect on rainfall were available. S. Gregory replied that he was not aware of any published data and that it was probably too early to detect effects. silting-up however, could be an important problem at an early stage.

J. Taylor (U.C.W., Aberystwyth) suggested that catchment areas might prove useful units as a basis for developmental planning, and P. James (U.C.N.W., Bangor) said that although no study had been made of the economic viability of catchment areas, they should be considered as sub-units.

S. Gregory noted that the new River Authorities were now able to influence the development of Upland areas, and that pressure from them would increase.

THE NEW SYSTEM OF LAND CLASSIFICATION WITH SPECIAL REFERENCE TO WALES

MISS J. MORGAN

Agricultural Land Service, Aberystwyth

The main purpose of this classification of agricultural land is for use in consultations between the Ministry of Agriculture, Fisheries and Food and other Government Departments and local planning authorities regarding the choice of areas for non-agricultural development. It has long been an important objective of planning policy that good agricultural land should not be taken for development when less valuable land could reasonably be used instead.

If this objective is to be achieved, regard must be paid not only to the agricultural value of an area relative to that of other land in its immediate vicinity but also relative to that of other land in the country as a whole. The Land Classification Survey carried out in the early 1940's under the direction of Professor Stamp has been used for many years to facilitate such comparisions, and has been of great value as a guide in development control. Since it was completed, however, technological and economic changes have increased the productivity of some types of land more than that of others, while for some areas Soil Survey maps are now available, making possible more accurate and detailed mapping of the boundaries between different grades of land. A Study Group was therefore set up in 1962 to examine systems of classification used in this country and elsewhere, and to recommend an appropriate system for the purpose described.

The Study Group consisted of specialists in the various relevant fields, together with members of the Research Group of the Agricultural Land Service. (Its composition and the conclusions embodied in its first report are described in the Ministry's Technical Report No.11, "Agricultural Land Classification.").

None of the classifications examined by the Study Group had been designed for the purposed which the Group had in mind, and consequently none was suitable for adoption without considerable modification. The Group in fact concluded at a relatively early stage that a system devised for one purpose will never be that most suitable for another purpose, even though it may be helpful in the absence of anything else. The Group also decided that as land developed for most urban uses is permanently lost to agriculture,

the classification should be based on the relatively unchanging physical factors, site, soils and climate, rather than on the shorter-term factors such as farm size and layout, standard of fixed equipment etc., which also influence the level of agricultural production at any point in time. At the same time it was recognised that a physical classification would be subject to many limitations. Amongst the more important of these are the difficulties of determining the inherent value of different combinations of physical factors in such a way that they can be ranked on a single scale. It also became evident that despite the appreciable increase of scientific data over the past fifteen years, it is still difficult to place a physical system on an exact scientific basis with precisely defined grades since

(i) soil maps are only available for limited parts of the country,

(ii) data on meso-climates fall short of what is desirable,

(iii) there is no comprehensive information on the relationship between physical factors and the productivity of land.

NB

It was clear, therefore, that in devising a suitable physical classification the main problem would be to reduce its subjective limitations to a minimum.

Under the new system land is classified into five grades according to the extent to which physical factors impose long-term limitations on its use. The limitations operate in one or more of four principal ways: they may affect the range of crops which can be grown, the level of yield, the consistency of yield and/or the cost of obtaining it. The grades vary from Grade 1 - land with very minor or no physical limitations to agricultural use, to Grade 5 - land of little agricultural value because of very severe limitations of soil, relief, or climate.

The land classification survey of Wales is not yet completed, but three one-inch maps so far published by the Ministry are three Welsh sheets - O.S. Sheets 10 (Denbigh), 153 (Swansea) and 154 (Cardiff). The Study Group Specialists agreed that land at altitudes of more than 1000 feet which has more than 60 inches mean annual rainfall, or land with a high proportion of very steep slopes (greater than 1 in 3) should not generally be placed in a grade higher than Grade 5. The coalfield moorlands of Sheets 153 and 154 largely consist of land at altitudes exceeding 1000 feet with a mean annual rainfall exceeding 60 inches, while many of the valley sides have

gradients greater than 1 in 3, and these areas have been graded accordingly. Dr. Crampton's reconnaissance soil survey has shown that they closely correspond with areas of deep peaty and peaty gleyed soils (Hirwaun and Rhondda Series) on the more level areas and podzolic soils (Garth Hill Series) on steep slopes. Soils of these and similar series have also been placed in Grade 5 where they occur at lower elevations or in areas of less rainfall. The Study Group likewise suggested that land over 600 feet which has over 50 inches mean annual rainfall, or with a higher proportion of slopes between 1 in 5 and 1 in 3, should not be placed in a grade above 4, nor should areas of poorly or very poorly drained soils on clay substrata. Similarly, areas at altitudes of more than 400 feet which have more than 40 inches annual rainfall (45 inches in Northwest England, West Wales and the West Country) would not normally be graded above Grade 3.

An examination of the published relief and rainfall maps in relation to the Study Group's recommendations will immediately show how little of Wales can be expected to fall into Grades 1 and 2 of the new system of classification even where soils are favourable. Much if not most of the Welsh uplands will be placed in Grades 4 and 5 on relief and climate alone, and the amount of Grade 5 land will be increased when allowance is made for the occurrence of podzols and other "mountain" soils at high altitudes where rainfall is less than 60 inches per annum, (e.g. Radnor Forest). It is of interest to note how frequently soil scientists from other parts of the country describe Welsh soils such as the Denbigh series as "good arable soils - under suitable climatic conditions." Unfortunately climatic conditions (particularly rainfall) over most of Wales are such that arable cropping on an extensive scale cannot be considered practicable, and this is inevitable reflected in the grading.

An attempt has been made, using information derived from the June Agricultural Returns together with average output data calculated by the Ministry's Economics Division and adjusted locally by officers of N.A.A.S., to calculate standard net output data for areas classified in various grades. The problems associated with making estimates of this kind - particularly the effects of different levels of management and the influence of traditional systems of farming in some areas - have not yet been resolved, and it is therefore impossible to quote any figures with confidence.

DISCUSSION

Mr. J. Taylor (U.C.W., Aberystwyth) suggested that the effects of different standards of management could be reduced by selecting the "best" farms in an area for comparison.

Miss Morgan replied that Dr. O'Connor had made some calculations on this basis for farms on soils derived from Liassic deposits in Somerset but had found that the variation between farms was not reduced.

Dr. ap Griffiths (P.B.S., Aberystwyth) suggested that sale prices of agricultural land might provide either a basis for classification or a check on the physical grading.

Miss Morgan said that the Study Group had considered the possibility of using sale prices and also rents as indices of agricultural "value" and had rejected them since both were too subject to influence by factors other than those whose effects it was desired to measure. Building prices were so far above the price of even the best agricultural land (the price of land usually being a relatively small proportion of the price of the completed building) that the differences in agricultural prices of the best and worst land is small in comparison.

In reply to the further suggestion that if the price of food were allowed to reach its "true" level agricultural land would command a price competitive with that which urban developers were prepared to pay, Miss Morgan said that the price of farm produce is unlikely to be allowed to rise very far above world food prices. This country had been committed to a policy of relatively cheap food for social and other reasons for many years and it was therefore unlikely that a situation would develop in the foreseeable future in which the agricultural price of land could compete with its building price. This, however, was no reason why action should not be taken to safeguard our resources of the best agricultural land.

In reply to a further question by Mr. J. Taylor (U.C.W., Aberystwyth) Miss Morgan said that the cultivated peatlands of the Fens and the Ormskirk area of Lancashire were considered to be Grade 1 land.

GENERAL DISCUSSION

Written Contribution by
M. B. ALCOCK
University College of North Wales, Bangor,
Department of Agriculture

The growth of sown grasses was studied in an upland site (Ffridd 950' O.D.) and one mile away at a lowland site (20' O.D.) on the College Farm (U.C.N.W., Bangor). The separate influence of climate and weather as opposed to the influence of soil on yield was estimated using a technique of soil exchange. Soil to the depth of 9" and in plots measuring 7 x 5 yards was exchanged between the sites. (Figure 1). Perennial ryegrass (Var. S24) was sown on these plots and the central 6 x 4 yards used for measurement of yield. In order that soil pH, nitrogen, phosphate and potash should not limit growth and create nutritional differences between the sites they were adjusted with fertiliser to a common high level on the basis of soil analysis. Nitrogen in particular was applied at 10 day intervals through the season at a rate equivalent to 2lb nitrogen per acre per day.

The difference in dry matter yield between the sites is shown in Fig. 2. The bottom part of the figure indicates the relative influence of soil and climate on this difference in yield. The main difference occurred in early spring with the lowland yielding more than the ffridd. This was mainly due to the differences in the climate. Of 12 climatic variables measured, yield was most highly correlated with 4" soil maximum temperature, expressed in Fig. 3 as weekly means and as accumulated degrees above 42°F. Further statistical analysis (Alcock et al. 1967) indicated a causal relationship between accumulated degrees and yield and that the high correlation was not merely an artifact or relating two accumulating variables. Differences between sites in spring could therefore be largely explained in terms of soil temperature. This in itself, however, is positively correlated with radiation, grass minimum temperature, and maximum air temperature and negatively correlated with wind speed relative humidity and soil water content. Many of these other variables also show differences between the sites.

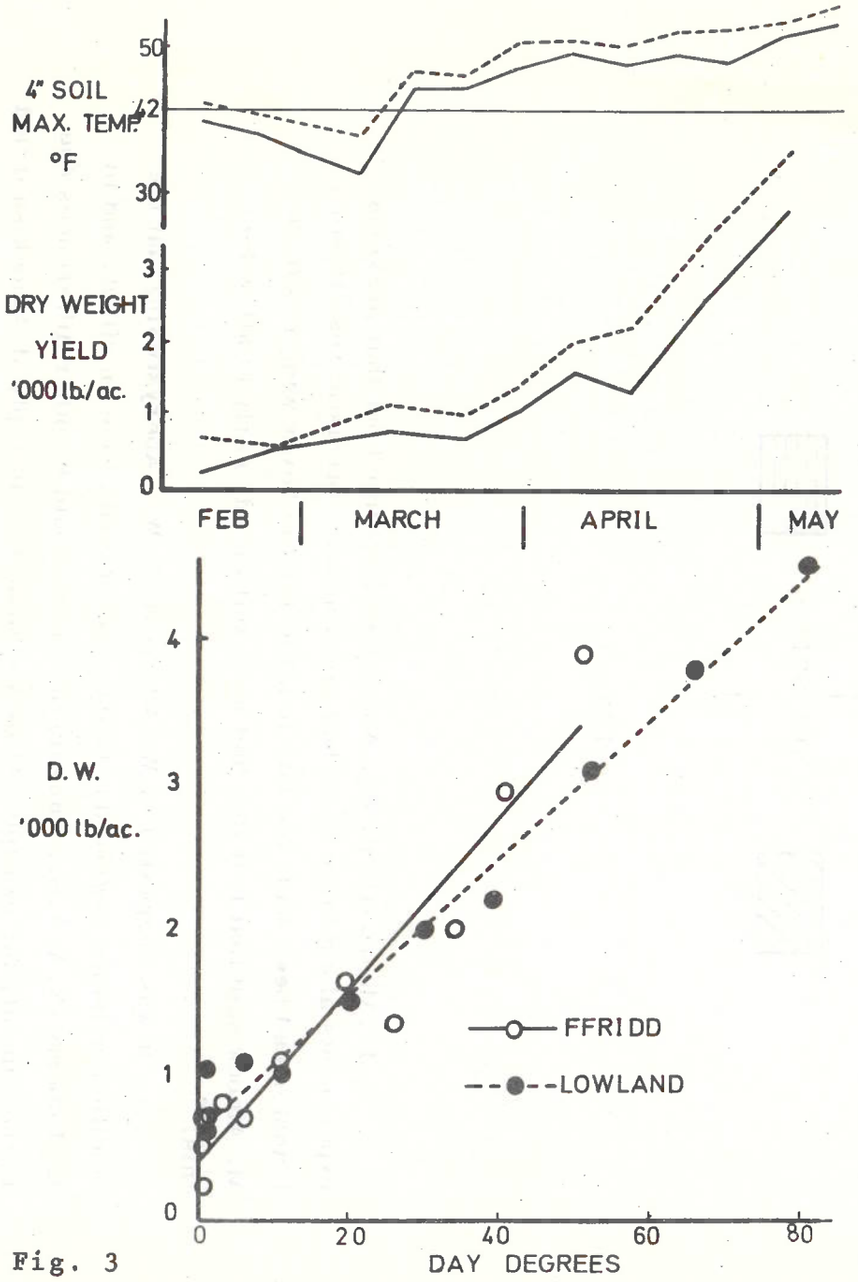
4" SOIL
MAX. TEMP.
°F
50
42
30
DRY WEIGHT
YIELD
'000 lb./ac.
3
2
1
0
FEB
MARCH
APRIL
MAY
D.W.
'000 lb/ac.
4
3
2
1
0
FFRIDD
LOWLAND
0
20
40
60
80
DAY DEGREES

Fig. 3

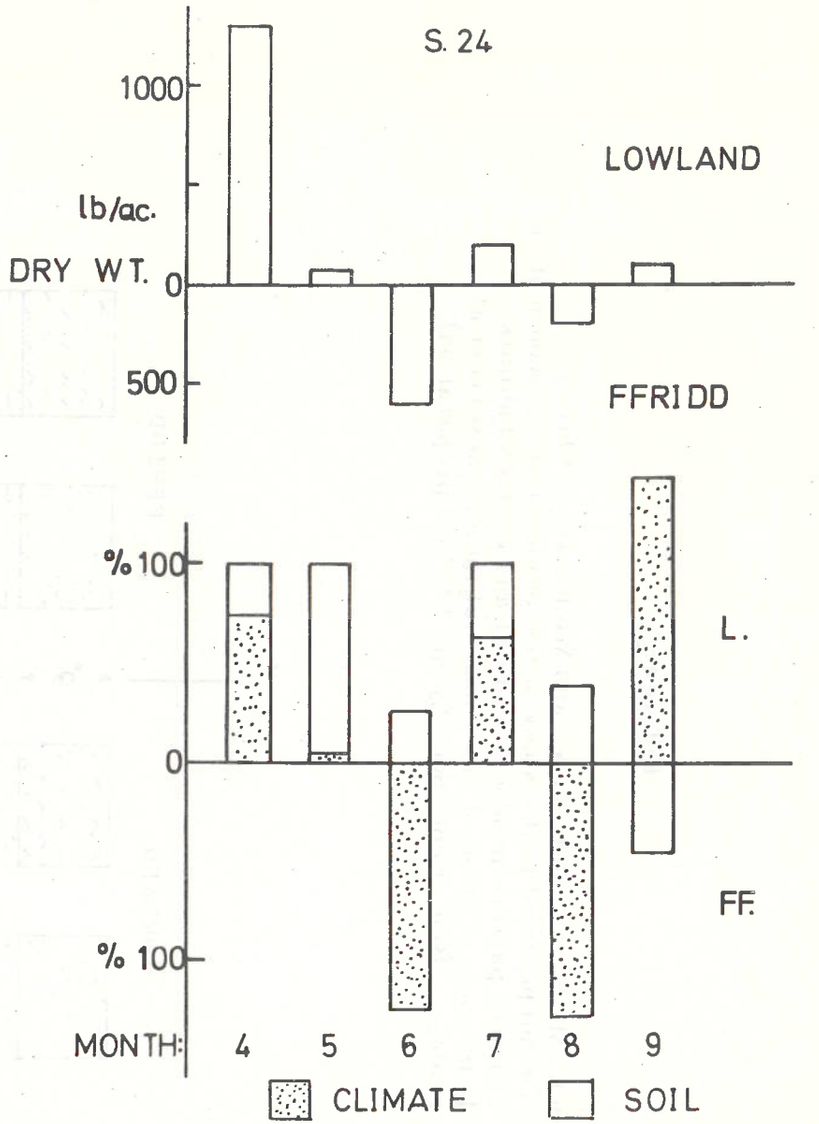
S. 24
1000
LOWLAND
lb/ac.
DRY WT.
0
500
FFRIDD
% 100
L.
0
FF.
% 100
MONTH:
4
5
6
7
8
9
CLIMATE
SOIL

Fig. 2

References

Alcock, M. B., Lovett, J. V. and Machin D. 1967. Technique used in the study of the influence of environment on primary pasture production in hill and lowland habitats. In the measurement of environmental factors in terrestial ecology. Brit. Ecol. Soc. Symp. 1967 (in preparation).

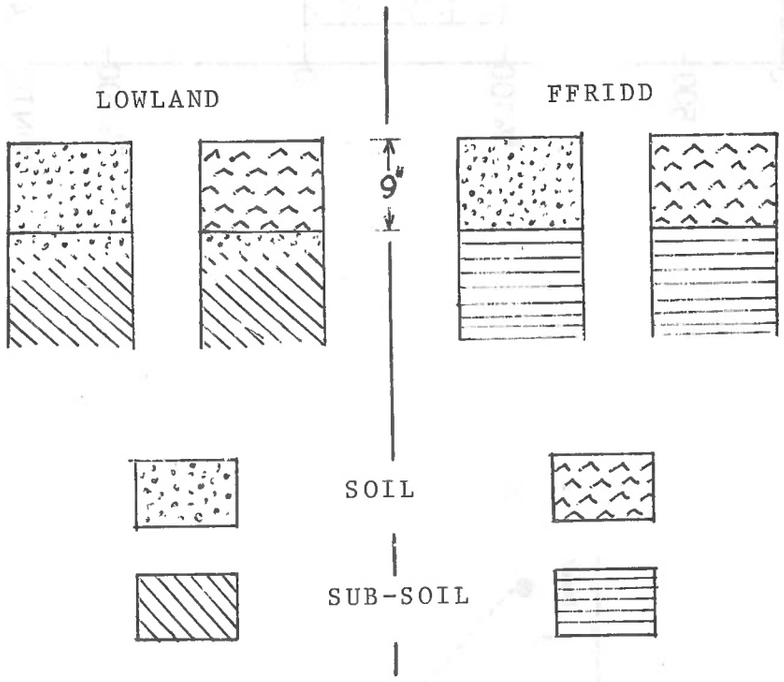

FIG. 1

J. Munro (P. B. S., Aberystwyth) pointed out that previous experiments along these lines had given unduly optimistic results since transfer had been made too late to allow for the "over winter" effect. M. Alcock said that transfer had been sufficiently early to allow for this.

It was suggested by W. Adams (U.C.W., Aberystwyth) that the modified moisture regime due to the subsoil could have an effect, and by E. Roberts (N.A.A.S., Bangor) that there could be other differences due to the subsoil, for example Al or Mn toxicity. In reply M. Alcock said that such effects, at depths greater than the general rooting depth, would not be limiting.

GENERAL DISCUSSION

The general Discussion during the day centred on the theme of podsolisation.

C. Crampton, (Soil Survey, Cardiff) observed that impoverished soils under long standing afforestation in S. Wales were often improved, compared to soils under grass cover, due to the greater movement of water produced within the profile. Conversely deforestation could result in impoverishment.

D. G. Pyatt (Forestry Comm., Edinburgh) also pointed out that afforestation usually involved the drainage of peaty gleys to enhance rooting stability. Deforestation could result in the formation of an Fe-pan with increasing surface wetness. True podsolisation, involving chelation of Fe, was perhaps a different process which could be promoted by conifers.

W. Adams and R. Smith (U.C.W., Aberystwyth) both commented on the particular type of podsolisation observed in shale-derived soils where, possibly due to a change in texture, conditions changed with time from aerobic to gleying.

R. I. Davies (U.C.N.W., Bangor) stressed the importance of defining clearly such terms as podsol and podsolisation. The process of podsolisation involved organic substances derived from the growing plant rather than from the litter, and podsols formed under aerobic as distinct from anaerobic (gleying) conditions. The ability of trees to change the pedogenetic pattern had been noted by Robinson, but "good" and "bad" were poor, subjective terms to use in describing the effects.

FIELD MEETING

May 10th, 1967

C. B. CRAMPTON

Soil Survey of England and Wales, Rothamsted Experimental Station, Harpenden, Herts

The South Wales Field Meeting was held Wednesday, 10th May, in the Brecon Beacons National Park. At the Mountain Centre for the Park initial discussions were about the productivity of Breconshire soils, and the desirability and schemes for their reclamation, with Mynydd Fforest as one example. When the appendix to Report No.8 was prepared it had been intended to commence the field meeting on Mynydd Forest, but subsequent establishment of a Centre provided a unique opportunity for the Group to become familiar with the Park environs and its problems. The Centre is on Mynydd Illtyd, and deforestation of the area around had been achieved by successive settlements of the British, Irish and Scottish.

The Group ascended the North front of the Brecon Beacons, with halts at ruins of a very ancient hafod where transhumance was discussed, and at several places where odd relationships between soils and flora on the North front could be contrasted with typical relationships elsewhere. In the absence of intense grazing because of exposure and inaccessibility, a flora elsewhere associated with drier soils which were once extensive on the Beacons, has been preserved on them despite a changing edaphic environment, and is now associated with peaty and gleyed soils.

Keen discussions on the desirability of afforestation in the Park developed during the ascent of the North front. Afforestation of flatter and boggy parts in the West of the Park was generally accepted, but there were considerable reservations concerning the idea of even limited afforestation in the East which has great scenic attraction. The present landscape is a "grass desert" but during Bronze Age times, for example, oak forest covered much of the region. As the soils (and climate) have changed since then, it would be impossible to re-establish a similar forest.

The meeting's success owes much to cooperation from staff of the Mountain Centre and Military Range. A detailed Guide to the excursion is available as an Appendix to Report No.8.

SECRETARY'S REPORT: SEASON 1966/1967

Membership of the group has increased during this season, both of Ordinary and Temporary members, and both classes roughly in the ration 4 : 3. Sales of the Reports were less, but this probably can be entirely accounted for without implying a falling off in interest in the Group's publications. Reports 1, 2 and 3 became out of print during the year and requests for these had to be refused. Owing to the changes in the Sec./Treasurer's address there was some delay in dealing with requests and for accounting reasons some of this years sales will be shown in next year's account.

The Secretary/Treasurer's duties fall into two sharply distinguished spheres of activity - the task of arranging the programme and that of selling copies of the Reports. For the former it is an advantage to have yearly changes of location, but it is a serious disadvantage for the latter. To overcome this difficulty I would suggest that when the Secretary/Treasurer is not located in Aberystwyth, an accommodation address should be arranged in Aberystwyth for the purpose of selling the Reports, and published as such.

The continued success of the Group depends on maitaining a demand for a Report of useful quality.

The years programme can be briefly summarised as follows:-

Theme for the Session	- Upland Soils, genesis, classification and uses.
November 16th 1966	- Papers were read and discussed on the subject 'Factors in Upland Soil Formation' This meeting was intended to cover the theoretical aspects of the subject.
February 15th, 1967	- Papers were read and discussed on the subject 'The practical utilisation of the Uplands' This meeting was given to discussing the applied aspects of the subject.
May 10th, 1967	Field meeting to study the soils of the Brecon Beacons.

G. H. A. Edwards
Honorary Secretary/Treasurer 1966/67.

WELSH SOILS DISCUSSION GROUP

INCOME AND EXPENDITURE ACCOUNT: AUGUST 18TH, 1966 to JUNE 26TH, 1967

	Income	£. s. d.
1.	Balance from 1965/66	80.11. 2
2.	Membership:- 57 full @ £1/-/-	57. - -
	46 temp. @ 2/6d	5.15 -
3.	Report Sales:-	
	No. 2 1 @ 7/6d	7. 6
	No. 3 1 @ 7/6d	7. 6
	No. 4 9 @ 10/-	4.10. -
	No. 5 14 @ 10/-	7. - -
	No. 6 14 @ 10/-	7. - -
	No. 7 17 @ 10/-	8.10. -
4.	Reprint Sales:	39.15. -
5.	Recovered from last year's debts: Invoices	2.11. 11
	Membership	2. - -
	In cash at meetings	3. 4. 3
6.	Postage recovered:	1.16. 5
7.	Interest from Deposit Account	1.13. 10
		222. 2. 7

	Expenditure	£. s. d.
1.	To Welsh Plant Breeding Station for printing Report No.7	75. - -
2.	Sec/Treasurer's expenses:-	
	Stationery	2. 9. 4
	Postage - Notices of meetings	3. 6. 1
	Postage - Report No. 7	1. 1. 4
	Postage - Correspondence	1.12. 7
	Postage - Invoice Book	3. 9. 8
3.	Loss on lunch at W.P.B.S.	5. -
4.	Loss on dollar sale	3. 5
5.	Bank Charges	5. -
6.	Sums unrecovered from this year's sales:	17. - -
7.	Cash at Bank: Current A/c	91.10. 2
	Deposit A/c	26. - -
		222. 2. 7

Audited and in the light of the information supplied found correct:

T. BOWEN,
M.A.F.F., Llanishen,
Cardiff.

LIST OF MEMBERS 1966/1967

NAME	ADDRESS	NATURE OF WORK
Dr. W. A. Adams	Dept. Biochemistry, U.C.W., Aberystwyth.	Lecturer in Soil Science
Mr. B. J. Alloway	Dept. Geography, Penglais, U.C.W. Aberystwyth.	Research Student (Soil)
Dr. M. B. Alcock	Dept. Agriculture, U.C.N.W., Bangor.	Crop Physiologist
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Mr. D. Ball	Nature Conservancy, Penrhos Rd., Bangor.	Pedologist
Miss J. M. Bannister	Dept.Biochem. & Soil Science, U.C.N.W., Bangor.	Student
Mr. F. C. Best	15 Belmont, Forestry Commission, Shrewsbury.	
Mr. R. P. Bower	Dept. Biochem. & Soil Science, U.C.N.W., Bangor	Research Student (Soils)
Mr. E. M. Bridges	Dept. Geography, U.College, Singleton Park, Swansea.	Lecturer in Pedology.
Mr. C. P. Burnham	Dept. Soil Science, Univ. of Aberdeen, Old Aberdeen.	Lecturer
Mr. W. Campbell	Plant Pathology Dept., N.A.A.S., Trawscoed, Aberystwyth.	Advisory Officer
Miss J. Carter	Dept. Geography, Univ. of Manchester, Manchester 13.	
Dr. A. Charles	Welsh Plant Breeding Station, Gogerddan, Aberystwyth.	Agronomist
Dr. C. Crampton	N.A.A.S., Gov't. Bldgs., Ty Glas Rd., Llanishen, Cardiff.	Soil Survey
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Mr. R. I. Davies	Dept. Biochem. & Soil Science, U.C.N.W., Bangor.	Senior Lecturer in Soil Science
Mr. J. W. Donovan	The Burren, Dingle Lane, Crundall, Haverfordwest, Pembs.	Land Drainage & Water Supply Officer M.A.F.F.
Mr. G. H. A. Edwards	N.A.A.S., Ty Glas Rd., Llanishen, Cardiff.	Advisory Soil Scientist
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Mr. J.D. Gwynn Jones	Welsh Dept., Plas Crug, Aberystwyth.	
Mr. B. Kear	Geography Dept., The University, Manchester 13.	
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Mr. D. Kinloch	Dept. Forestry, U.C.N.W., Bangor.	Lecturer
Dr. Neil Livesey	c/o Dept. Agronomy Soils, State Coll., Mississippi, USA	Soil Scientist
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Mr. R. C. Samuel	Stormways, Gwbert-on-Sea, Cardigan.	
Mr. R. T. Smith.	Dept. Geography, U.C.W., Aberystwyth.	Research Student (Soils)
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