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THE NATURE AND ORIGIN OF BLANKET PEATS AND THE ROLE OF BIOPEDOLOGICAL PROCESSES

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ABSTRACT

This paper deals with the origin of blanket peats in the U.K. The latter are treated in relation to their topographic situation and their vegetated history. Blanket peat accumulation has been viewed as principally attributable to deforestation and climatic oscillations yet in topographically favourable areas, less sensitive to changes of water balance, soil and biotic factors appear to represent the true agencies by which the dynamics of soil organic matter changed in the course of time. Drainage deterioration in many areas of shallow peat may thus have been achieved through biopedological processes acting slowly over a long period of time. In this respect different soil parent materials have responded to the process of podzolization in characteristic ways. The relationship of the shallower peats with deeper adjacent deposits is discussed and probable international analogues are considered. Finally, the possible significance of these processes to contemporary environmental changes, is explored.

1. INTRODUCTION

The relationship of climate, water regime and trophic level to the occurrence of particular mire types has received much previous attention in the literature, notably in the published proceedings of the International Peat Society (Moore and Bellamy, 1973; Goodall, 1981; Moore, 1983; and IPC Congress Proceedings and Commissions). It would seem, therefore, that the various factors which promote peat accumulation are well understood. Yet, a distinction should be made between factors which merely perpetuate an organic system - those characteristics of the environment with which peat deposits now coexist - and factors which initiated the process of peat formation in the first place, which may be referred to as trigger mechanisms. In aquatic systems, such as primary water-retaining basin or lacustrine sites, the various evolutionary stages have not only been well elucidated from a variety of stratigraphic studies (Birks and Birks, 1980) but can also be observed in contemporary hydroseres. Much can therefore be inferred about the various threshold conditions governing each successive change in the biota. By contrast, it is less clear - even obscure - as to the sequence of processes responsible for the onset of peat accumulation in most non-lacustrine, water-shedding situations. Here, it is accepted that the development of a positive on-site water balance - the process of paludification (Heinselman, 1963) - is a necessary precursor both to colonization by wetland taxa and to the preservation of their remains through waterlogging. A direct and rapid relationship of this kind has clearly applied in the case of many deeper blanket peat formations (Moore, 1975). But lag-effects are often characteristic of environmental changes, and a factor or factors likely to lead to enhanced soil water content, or increasing impedance to water movement, may be expected to achieve these effects after very different lengths of time, according to the nature of the initial substrate and the drainage characteristics of each site. Indeed, they may fail to do so at all, as on slopes which are simply too steep for any drainage impedence (except flushing) to develop. Hence, a hydrological change which led to a more or less immediate increase in water levels on flat plateau or basin sites, would induce a weaker and retarded impact on the surrounding catchment where it is possible for thin peats to have accumulated so long after the initial hydrological change as to appear unrelated to it.

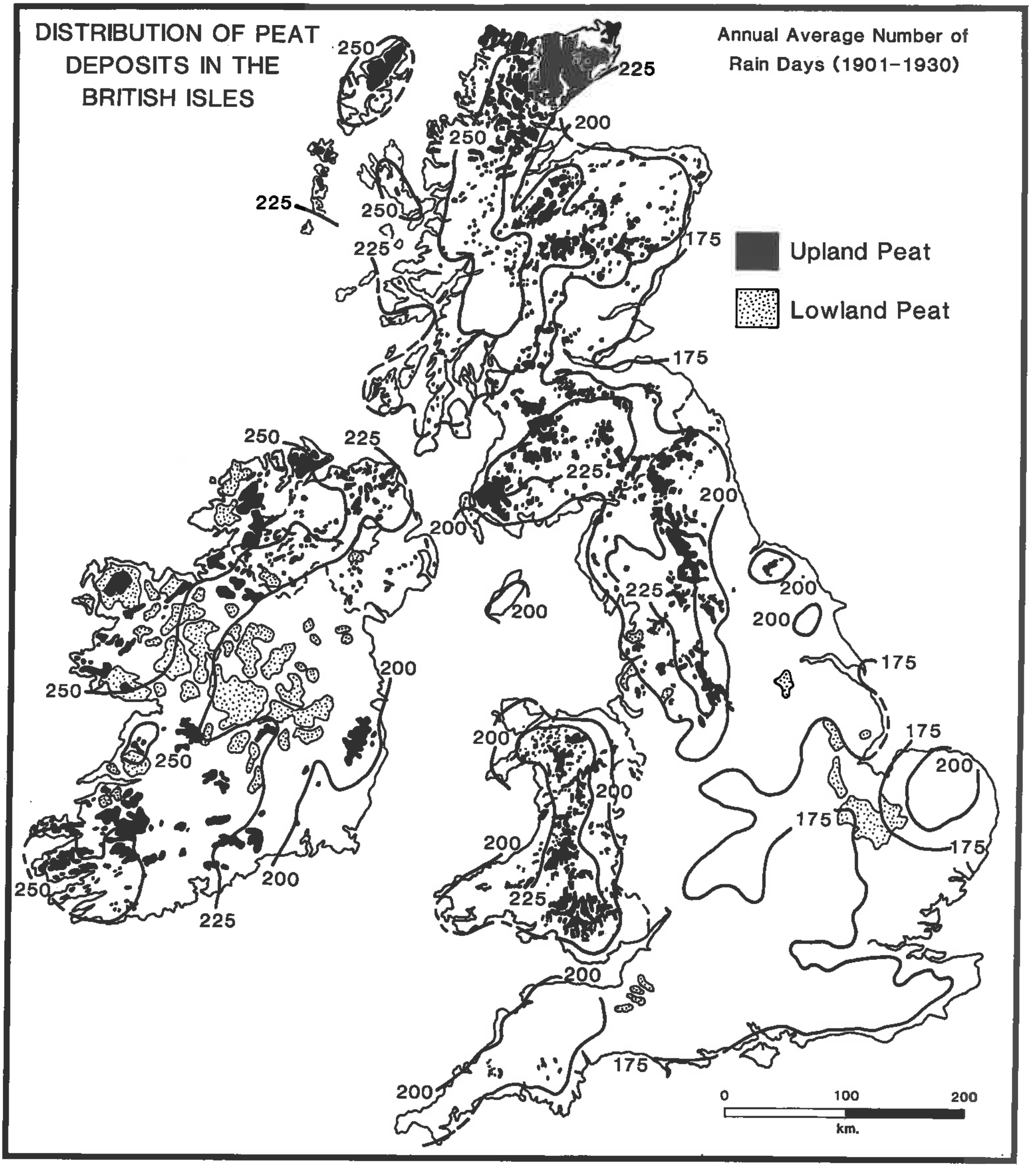

FIGURE 1. Distribution of peat deposits in the British Isles (redrawn after Taylor, 1983)

This paper is concerned with the inception of blanket peats, and in particular, the origin of thinner peats occurring on interfluves and on the edges of upland plateaux. These areas are among those most able to shed water, are therefore least liable to develop the various manifestations of waterlogging and are likely to have responded more slowly to the impact of environmental changes. Aspects of peat stratigraphy, vegetation history and various biotic and pedogenic processes will be discussed together with spatial relationships. For this reason, it is necessary to present not only a selection of the shallower peats but also examples of progressively deeper peats with which they are connected as part of the mire/soil continuum.

1.1 The landscape context

Blanket peats occupy a greater area than any other peat type in the United Kingdom (Taylor, 1983). This has been the partial consequence of the tendency of primary mires to overspill onto adjacent areas, as for example in the Silver Flowe of Galloway, Scotland (Boatman, 1983). Blanket peat, as an 'upland' formation and a 'tertiary' mire system (Moore and Bellamy, 1973), occurs at progressively lower altitudes from east to west across the British Isles, and actually forms at sea-level in western Ireland, the Hebrides and the northern Scottish mainland. In the uplands, it is found mainly on the flatter or gently sloping interfluves above about 200m O.D.; below this altitude, peats are restricted to primary basins. Above 600m O.D., various factors, especially low temperatures and frost action, conspire so to reduce biological productivity or to disturb surface materials that peats again become absent or are confined to basin sites. This generalised pattern nourishes the view that climate is the all-important control and has inspired the term 'climatic peat' (Tansley, 1939; Taylor and Smith, 1972). This refers to a blanket of peat formed under a climatic regime characterised by a relatively high precipitation : evaporation ratio (Taylor, 1976) (Fig. 1). The concept initially links the modern climate with areas of currently active peat formation but one must not lose sight of the fact that it is through the agency of site hydrology that the mechanism of peat formation must initially operate (Taylor and Smith, 1980; Taylor, 1988). Furthermore, a major problem arises if the origin of blanket mires is to be attributed to climate or climatic change, for the variety in stratigraphy and dates of onset of blanket peats are entirely at odds with

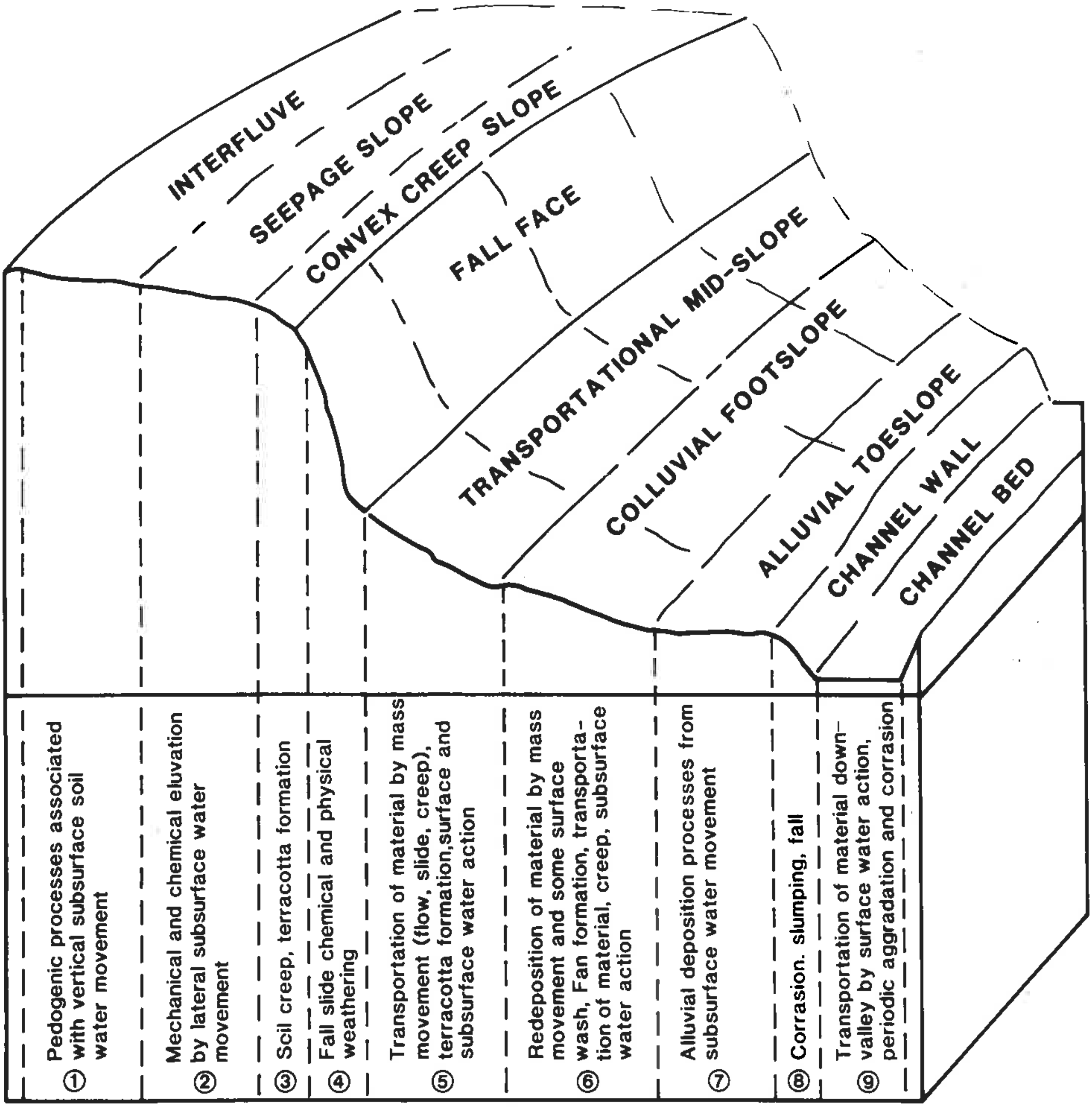

FIGURE 2. Landscape model relating soils and hydrological conditions (redrawn from Goudie 1987, after Conacher and Dalrymple 1977)

a purely climatic explanation (Simmons, 1964a, 1964b; Moore and Chater, 1969; Moore, 1970; Bostock, 1980; Chambers, 1982a, 1982b, 1983; Taylor, 1988). Indeed, examination of Table 1* shows that from this selection of data drawn from widely scattered sites, and including those discussed in this paper, there are few rewards for the person intent on generalising about relationships between elevation, locality, depth and age of onset of peat formation.

Figure 2 provides a landscape framework which has application to the morphological processes of arid and humid regions alike. It is used here to identify the loci of peat accumulation in British upland areas. Basin peats occupy the extreme right side of the diagram while plateau blanket peats occupy the extreme left. The model operates on different spatial scales with the major intermediate break of slope frequently absent so that basin and plateau formations often merge. On the other hand, many basin sites are entirely discrete units, without continuity onto adjacent moorlands; an example occurs in the Nant Ffrancon in north Wales, a peat basin in a glaciated valley now overlain in parts by mineral deposits (Seddon, 1962). The present paper is principally concerned with the nature and origin of peats in units 2 and 3 of the model, where exclusively vertical and restricted water movement give way to increasing lateral movement downslope and thereby, to reduced waterlogging. Such sites have previously been identified as 'water shedding' (Taylor and Smith, 1972, 1980), a useful label but one lacking precise definition.

In the section which follows I have selected examples of peats from different positions on the above topohydrological continuum. Basin and plateau peats correspond, respectively, with units 9 and 1 in Figure 2, intermediate sites correspond with 1-2 or 6-7, while shallow peats can best be visualised as occupying units 2-3 or, more rarely, units 5-6 in the slope sequence. Use of the term 'shallow' broadly distinguishes formations of less than 0.75m depth.

2. THE HISTORICAL CONTEXT: RESEARCH DATA

2.1 Deep basin and hill peats

At the wetter ends of the moorland spectrum (Figures 2 and 3), peats have evolved in relation to altered ground water regime whether on plateau or basin sites. Examples of basin and blanket peats in the same locality

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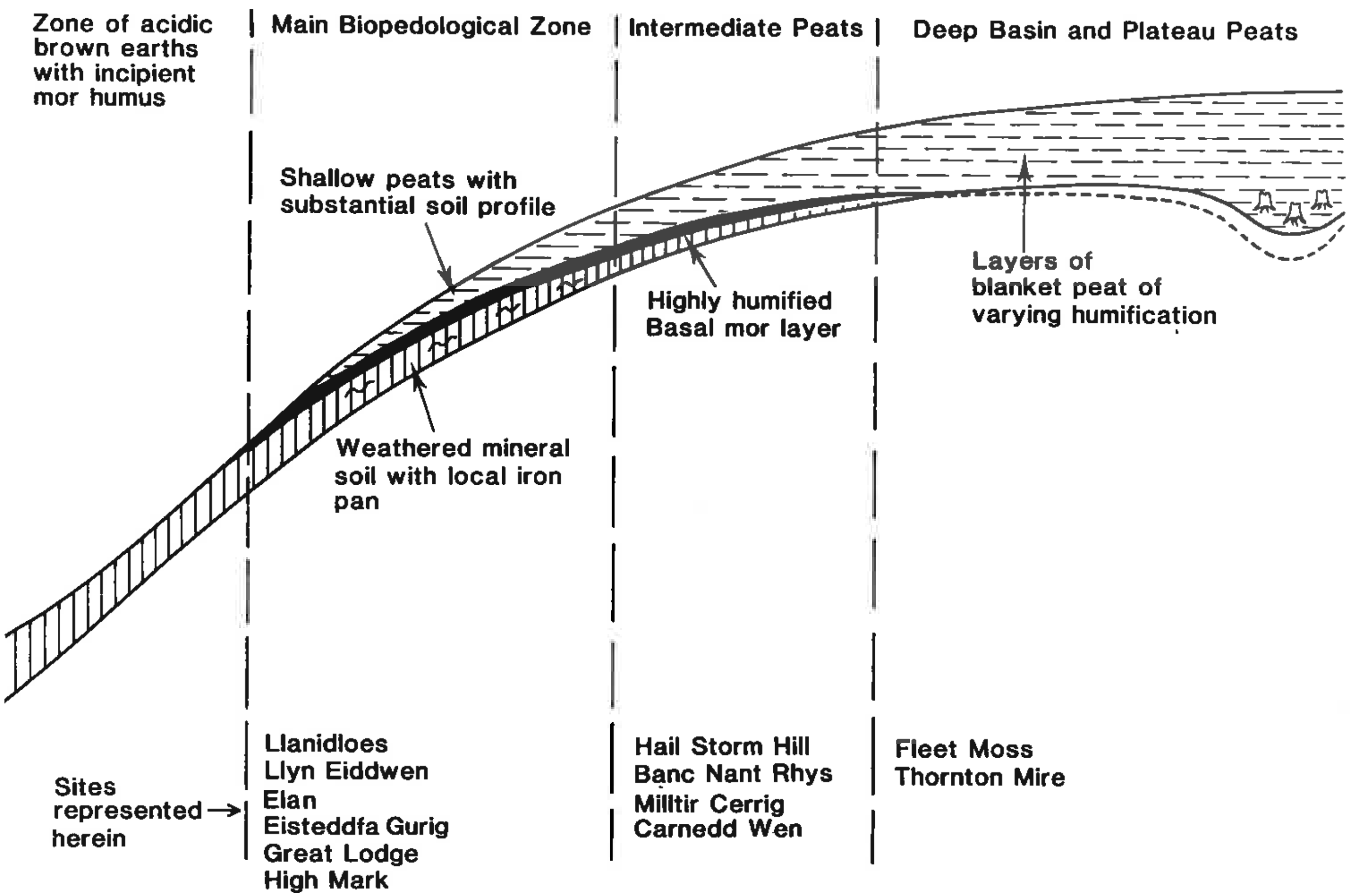
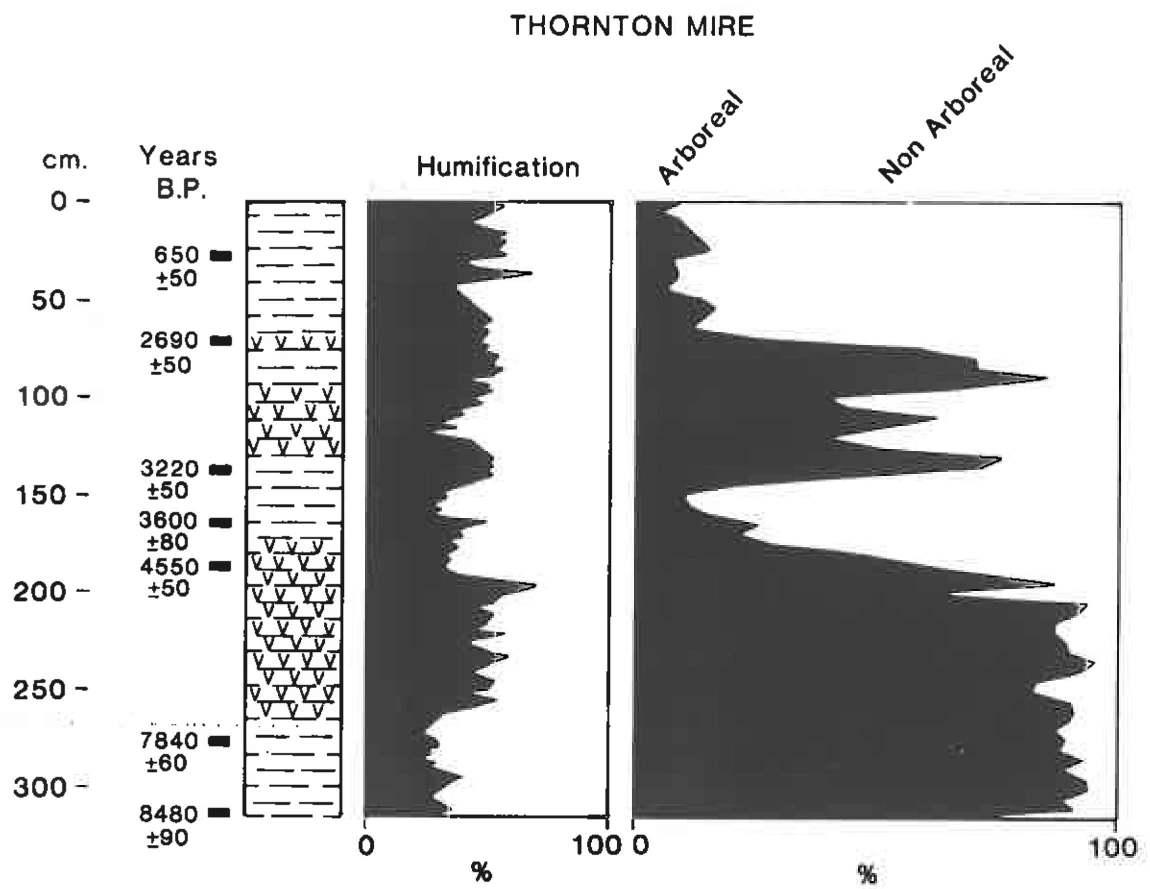


FIGURE 3. Schematic representation of the terrain and peats discussed in this paper



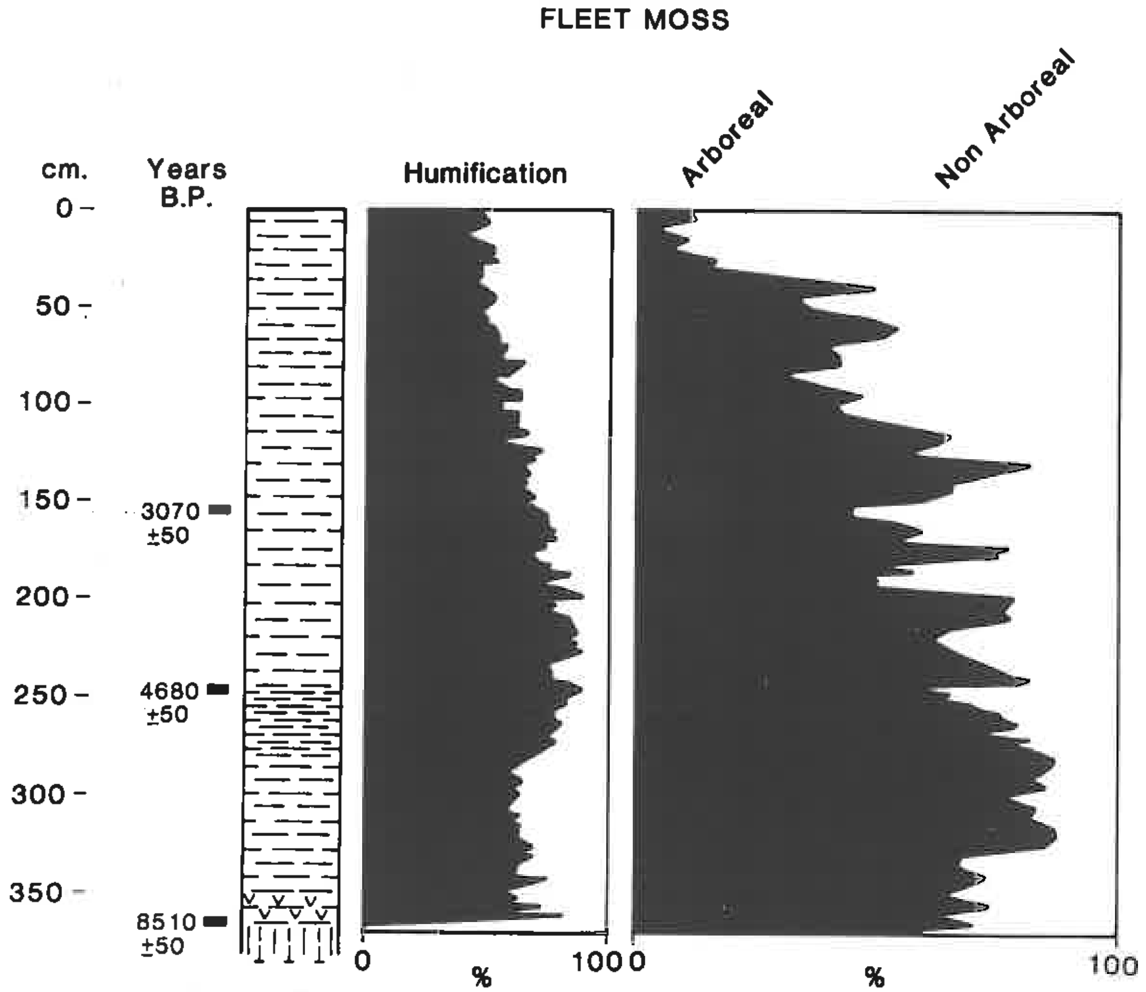


FIGURE 4. Pollen and stratigraphic diagrams for Thornton Mire 380m SD952872 and Fleet Moss 565m SD860836

are provided by Thornton Mire and Fleet Moss in Wensleydale, North Yorkshire (Figure 4) (Honeyman, 1985). The two vegetation records cover an almost identical period. While Fleet Moss shows the impact of periodic and progressive forest clearance, the Thornton Mire record shows more dramatic changes, as the site was surrounded by forested slopes which were subject to clearance during the early Bronze Age. The humification profiles reflect the changing proportion of arboreal pollen and show that tree cover : runoff relationships are reflected in the peatland hydrology. The lower values of humification at Thornton Mire, given the surprisingly similar vegetal composition of the two peats, is linked with the greater duration of waterlogging at this basin site. The datings indicate an increased rate of peat accumulation with time at both sites, independently of fluctuations in humification. This is explained by increasing acidification and the inclusion of Sphagnum as a bog-forming species. For comparison with subsequent sites, it is important to note that the blanket peat at Fleet Moss exhibits no markedly higher humification in its basal layers than occurs in the succeeding levels above.

Peat began to accumulate at both these sites during Mesolithic times, some 8500 years BP - as did a further blanket peat in Wensleydale (Honeyman, 1985). It seems certain that the trigger for peat formation at these sites was interference in the early woodlands by man. At Fleet Moss, the rapid paludification led to the burial of wood remains, below which there is only the most superficial ranker soil development.

2.2 Intermediate sites

In contrast to the deep-peat sites, others commenced organic matter accumulation under a heath-type, mor humus system which stands out as a darker, basal amorphous layer (Figure 3). The latter feature is more widely encountered than simply in the uplands, for it is seen at lower levels in Ireland and the Hebrides, and is the most prized by those who dig peat for fuel. It can vary from a mere 2-3 cm to almost 30 cm. Above this highly humified, amorphous and often greasy material, a sequence of monocotyledonous and sphagnaceous remains have accumulated, suggesting a more rapid build-up under conditions which inhibited decay. This change of peat type, however, is often gradual and may sometimes show repeated banding until only less humified material occurs. Sites displaying this kind of stratigraphy commonly have peat depths of 1-2 m, although there is no reason, in theory,

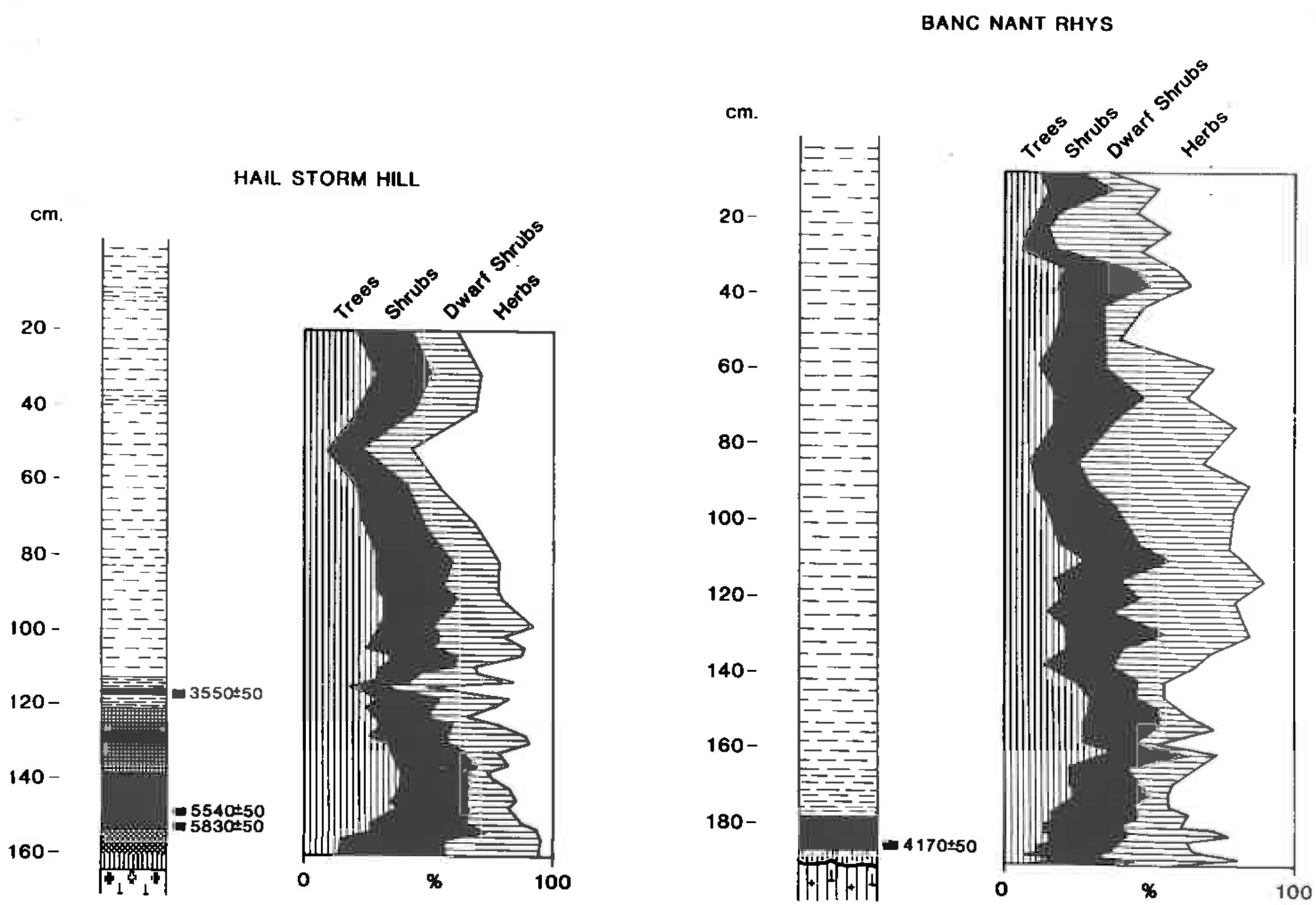


FIGURE 5. Pollen and stratigraphic diagrams for Hail Storm Hill 460m SD832189 and Banc Nant Rhys 543m SN825792

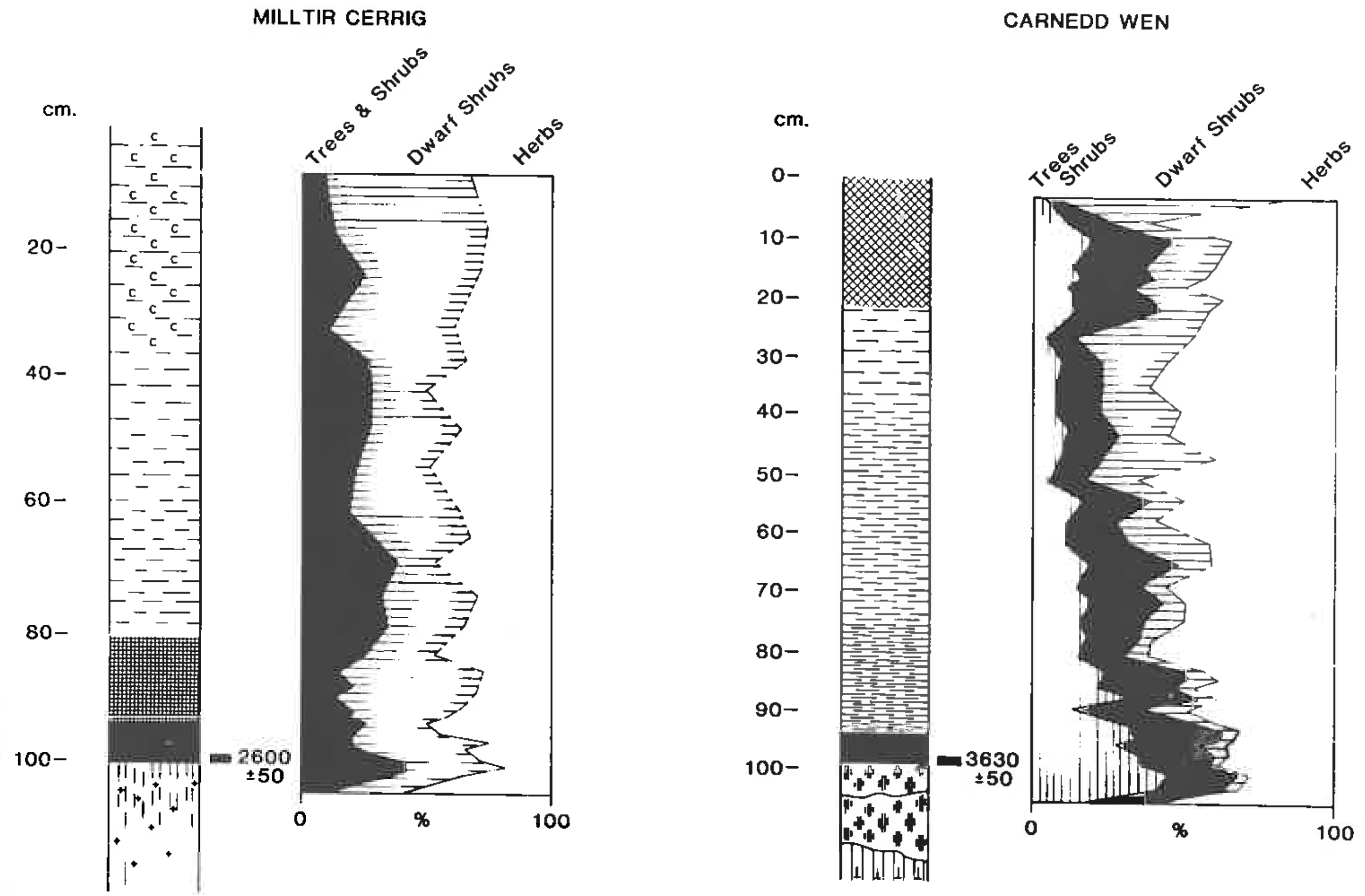


FIGURE 6. Pollen and stratigraphic diagrams for Milltir Cerrig 490m SJ020306 and Carnedd Wen 520m SH924098

why such peats should not sometimes be deeper than those of the first category, providing circumstances for peat accumulation were favourable later on in time. We present here the palaeoecological summaries of four sites (Figures 5 and 6), three from central Wales and one from the Lancashire Pennines, which, according to basal radiocarbon datings, are all much later in origin than the sites previously discussed (Figure 4). The fact that these are all shallower by more than a metre, as compared with the deep-peats described above, is in accordance with general observations of age and depth in peats, but, as is well known, this is not a relationship which need hold in every case (Table 1), especially when comparing peats in different ecosystems and trophic conditions. Chambers (1982, 1983) for example, compares blanket peats in south Wales which differ in depth by 40 cm and yet have basal C14 dates which lie within each other's standard error limits (see Coed Taf, Table 1). This shows what one might have expected, namely that two peats can begin forming at much the same time and, through differences in hydrology and/or disturbance, accumulate very different thicknesses.

It will be noted from Figures 5 and 6 that the proportion of pollen derived from arboreal taxa is substantially lower at these sites than that recorded in Figure 4. At Hail Storm Hill and Banc Nant Rhys, the basal pollen records indicate a reduction of tree pollen followed by recovery, these events being typical of the temporary clearances of earlier prehistoric times. The sites in Figure 6 have even later basal dates, lower arboreal pollen values and are shallower at about 1 m depth. For most of these sites, the pollen of heaths, e.g. Calluna, is frequent in basal organic layers while there is evidence of local drainage deterioration at and above the transition from basal amorphous to less humified peat. For example, at Carnedd Wen (Figure 6), an increase in Sphagnum is recorded above 85 cm while a similar increase occurs above 140 cm at Hail Storm Hill.

In selecting a minute sample of sites for illustrative purposes, one is conscious of the problem of representativeness, yet consistent comparisons do exist upon which validation depends. Although the definition of any 'intermediate' category may be open to varied interpretation, these sites share a process of early development with shallower peats while having an antiquity and stratigraphy more in line with deeper formations. For example, Sphagnum is a common component of this category and of the deepest peats, while it is rarely identified from the peat of shallow formations.

An intermediate degree of sub-peat pedogenesis is also apparent, which is most likely to reflect the relative lengths of earlier Holocene time before peat formation began and during which forested conditions prevailed. To explain the later histories displayed by the intermediate sites, it would appear probable that they have remained somewhat longer under a woodland cover before succumbing to peat formation. However, although they yield later peat records, it is clear that their histories, subsequent to forest clearance and prior to bog development, reflect drier heathland conditions under which soils were acquiring podzolic and gley-podzolic features. This soil development was, however, quite limited, usually being confined to 15 cm of surface mineral soil, which contrasts with the superficial ranker beneath the more ancient peats. The paludification which led to a critical change of stratigraphy at these intermediate sites is likely to have been caused in part by progressive removal of woodland or even the total loss of tree cover. It is also realistic to assume that these sites became subject to lateral paludification from wetter areas which had already formed substantial thicknesses of peat. However one views such 'intermediate' peats, their origins are clearly polygenetic.

2.3 Shallow peat sites

Sites in this category have generally less than 0.75 m of organic material, overlying a mineral soil profile within the range of 15-40 cm (Figure 3). As with previous categories, these sites have been chosen from a narrow range of altitudes and represent no deliberate attempt to present a uniform set of morphologies. Indeed, it is their differences as well as their distinctness from the deeper peats which provide insight into the factors controlling the initiation of their shallower peat formations.

The first sites to focus on the origin of these shallow peats, are on Malham Moor, north Yorkshire (Smith, 1986). They are based on loessic drift cover overlying Carboniferous Limestone (Figure 7). The soil profile on the left (Figure 7A) is a mesotrophic brown earth which has developed where the drift cover is thin over jointed limestone (Bullock, 1971). The chemical and hydrological properties of the substrate are reflected in the soil pH and characteristic biological activity. By contrast, some ten metres distant, on drift of about 2 m depth over limestone, more than 30 cm of peat has developed over a gley-podzolic soil profile (Figure 7B). Coring

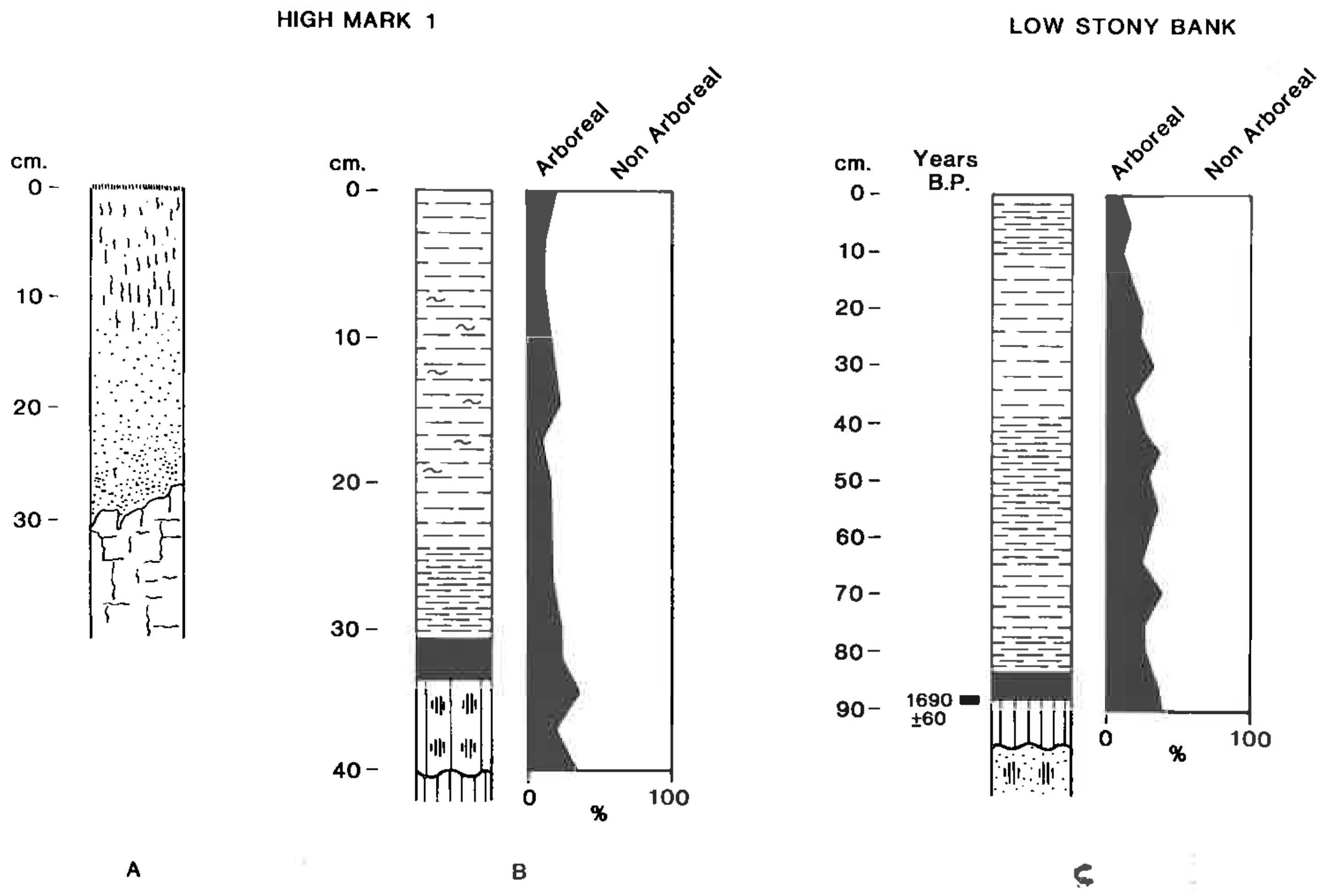


FIGURE 7. A. Soil profile and B. Combined peat and pollen record for High Mark 1 480m SD930682.
C. Pollen and stratigraphic diagram for Low Stony Bank 400m SD918650

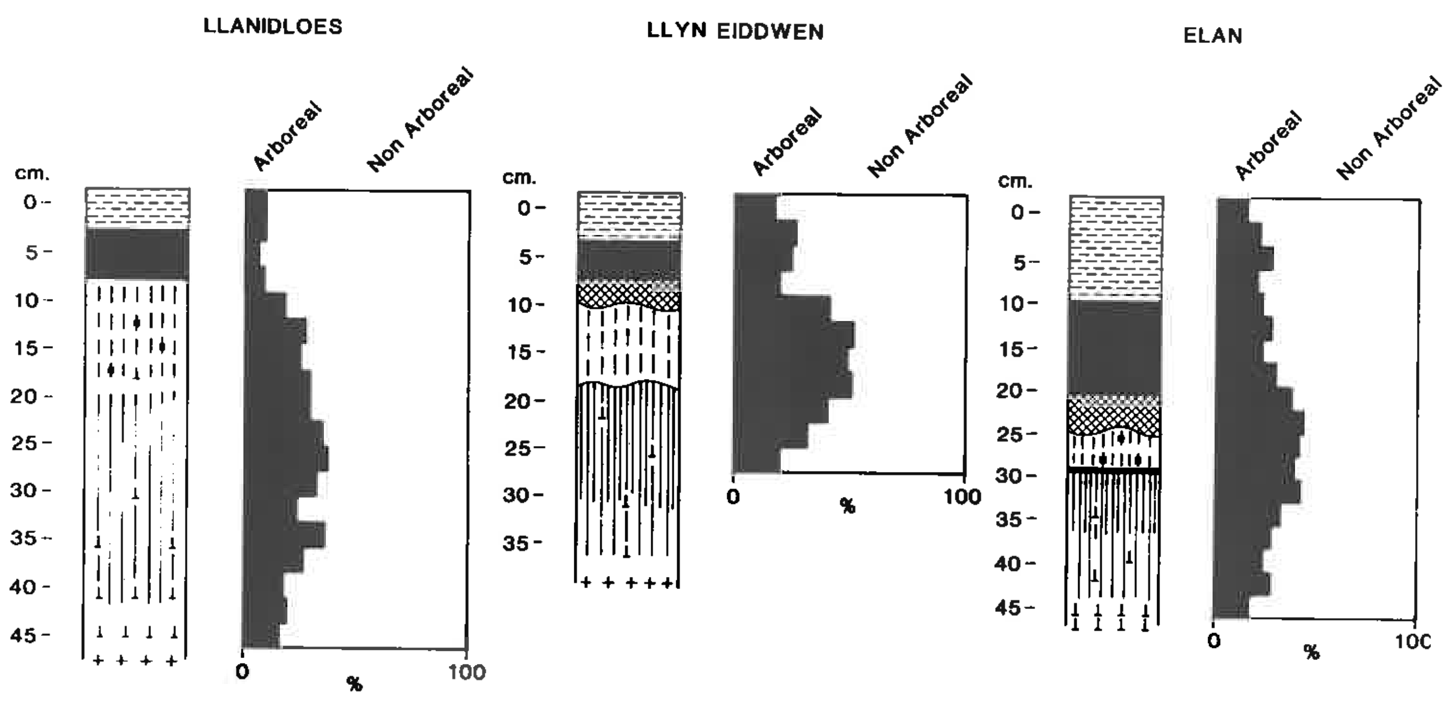


FIGURE 8. Pollen and soil profile diagrams for A. Llanidloes 435m SN905832. B. Llyn Eiddwen 330m SN607677 and C. Elan 450m SN915715

reveals that the substrate is the same, stone-free, loessal drift. The conclusion to be drawn is that, where the drift cover is thicker, it has become acidified, and this has set the site on a diametrically opposed pedological pathway.

The summary pollen diagram (Figure 7B) shows that open heath and grassland have persisted throughout the recorded time span. The latter may well be of the order of 1500 years, in view of the similarity of this record with a further, but deeper, radiocarbon-dated peat (Figure 7C) some 400 metres distant, and the fact that the basal mor humus itself represents very many years of slow residual accumulation. These records would appear to show that any forest cover had been lost well before peat formation began, thus allowing a lengthy period for these sites to develop a grassy-heath vegetation under the prevailing pastoral land use.

The next group of sites, from central Wales (Figures 8A-C), show a probable evolutionary sequence for soils developing from shales, mudstones and associated drifts (Smith and Taylor, 1969; Taylor and Smith, 1972, 1980). The parent material, common to all three sites and giving rise to dominantly silty soils, is a periglacially-modified Silurian shale. Figure 8A represents a podzolic soil profile with incipient gleying in the eluvial horizon. It is on a narrow interfluve from which site drainage is generally good. It will be noted that the profile is the deepest of the three, perhaps because the original rooting of forest trees exploited this water-shedding site to greater depth. Figures 8B/C represent sites on upper slope flanks (see again Figures 2 and 3). The surface horizon in C is fully gleyed with an indurated iron pan at its base. It appears that mor humus has already been succeeded by wetter peat accumulation with the surface vegetation now consisting of Nardus, Molinia, and Eriophorum. Profile B has a thinly developed iron pan at the base of a heavily mottled, eluvial horizon suggesting that its developmental position is intermediate between A and C.

Further sites show that the development sequence 8A-C may continue to proceed with or without man's assistance. Thus the sites of Ffair Rhos (Smith, 1970) and Eisteddfa Gurig (Figure 8A) indicate that, with further thickening of the upper, less humified peat, the buried mineral soil becomes gleyed, leading to morphological changes and to the gradual dispersion of ancient iron pans (Smith, 1987). The Eisteddfa Gurig site shows that man's

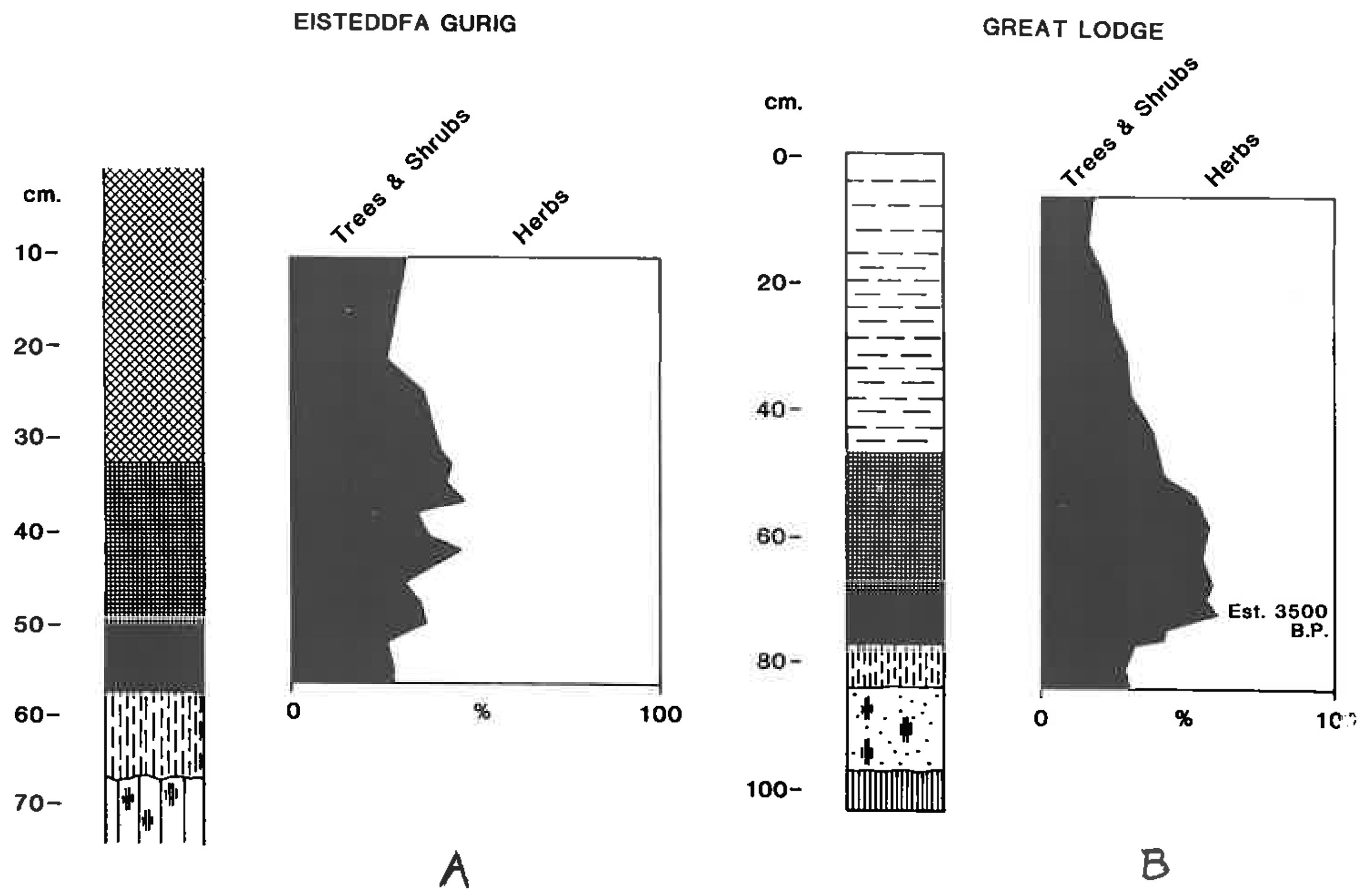


FIGURE 9. Pollen and stratigraphic diagrams for <u>Eisteddfa Gurig</u> 518m SN855845 and <u>Great Lodge</u> 450m SD834189

impact must not be overlooked, for the upper organic layer (cross-hatched) is heavily charged with mineral grains resulting from slope-wash. This has produced a much more compact deposit overlying the basal raw humus.

The vegetation records of sites 8A-C and 9A have been discussed elsewhere and interpreted as developing from a light woodland cover under which heathland and, subsequently, wet moorland taxa established themselves (and see Walker, 1976). Of major ecological importance is that tree pollen had substantially declined by the time that the raw humus was forming. In the lower soil layers, very little pollen is now recognizable but large numbers of fern spores have survived from previously wooded conditions. Correlation of these records with deeper upland peats in central Wales (Smith and Taylor, 1969; Smith, 1970; Moore and Chater, 1976; Walker, 1976) suggests that they present a broadly post-Late Bronze Age record.

A final site, Great Lodge, on the Rossendale Moors in the Lancashire Pennines, has similar features to the foregoing sites but has no iron pan (Figure 9B). In this locality, the mineral soil has developed from the Fletcher Grit formation giving rise to dominantly sandy textures, although periglacial processes have caused mixing of surface materials. The pollen record shows similarity with the later part of the Hail Storm Hill record (Figure 5) such that a tentative dating of the base of Great Lodge can be given. There is some suggestion that, following an early clearance episode, forest re-asserted itself but that heath and moorland plants, which had become established during the early mor phase, later became dominated by sedge and moss. The mineral soil below 77 cm shows organic staining and strong mottling in a sandy matrix while below 97 cm an increasingly clay-enriched sand has developed the characteristic blue-grey colour of gley. The implications of such features will be discussed in section 3.

2.4 A broader survey of peat characteristics

Figure 10 shows the results of a more extensive survey of upland blanket peats carried out in different areas over a number of years, including the sites discussed here and those of other researchers. Its primary purpose is to identify variations in the depth of basal mor humus the greater the overall depth of the peat deposit. It will be noted that shallower peats feature the mor profile prominently while increasingly deeper formations tend not to display this feature or to do so erratically as if special

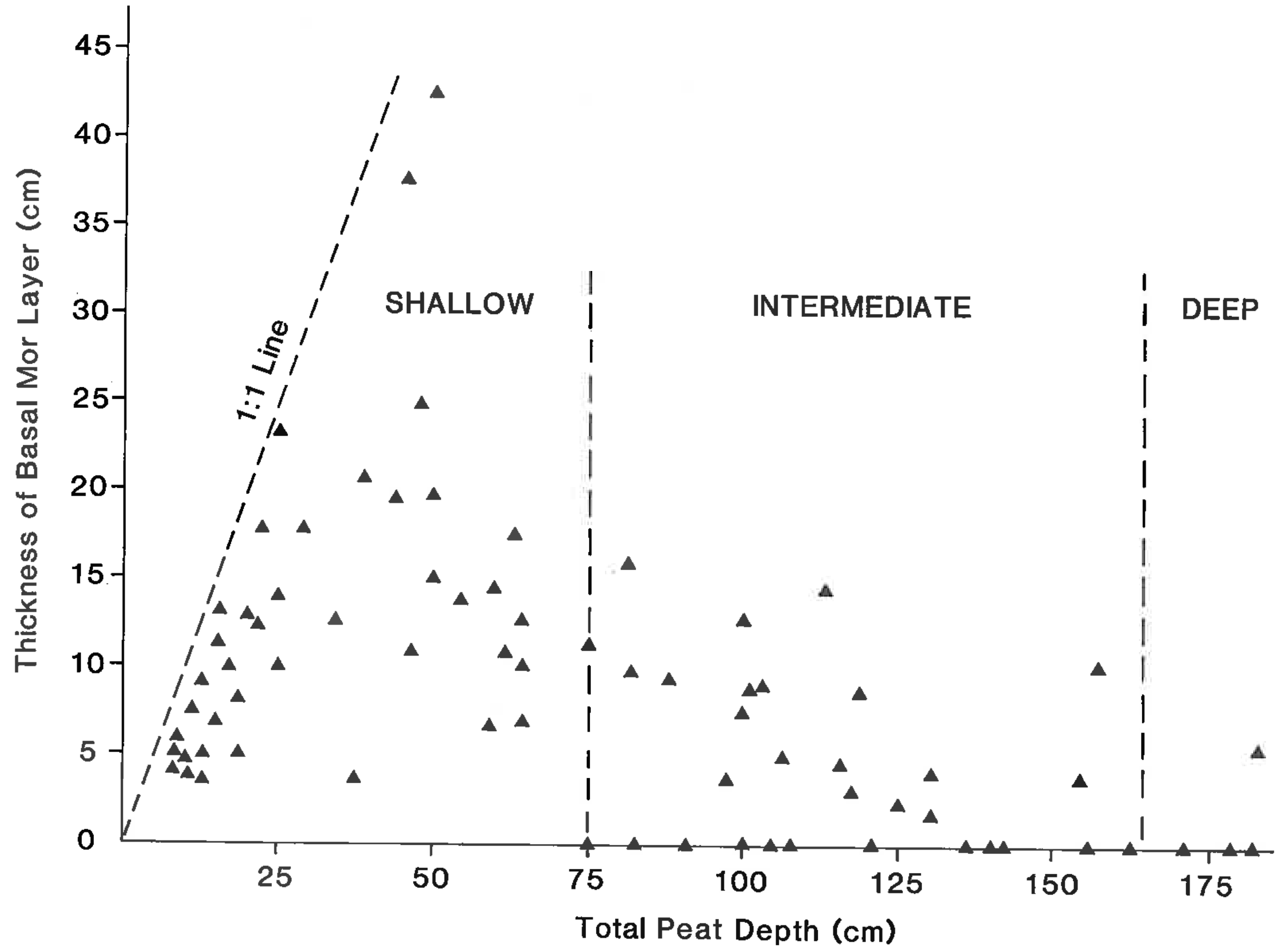


FIGURE 10. The relationship between basal mor thickness and total peat depth for selected blanket peats

circumstances have applied in particular cases.

The initial question one might ask is whether there is a critical maximum depth at which raw humus gives way to less humified peat. There is clearly no consistent pattern in this respect which must mean that mor deepening as such, is a comparatively minor factor in generating paludification. The transition from basal mor to less-humified peat would seem then, in most cases, to be attributable to the independent operation of pedo-hydrological factors, singly or in combination. Figure 10 equally argues against the view that the 'mor' represents merely a basal layer arising from the gradual metamorphosis and compaction of peats as they age. However, field observations have shown that where extreme thicknesses of 'mor' are recorded this may not be true basal mor but the remnants of a once wetter peat which has become substantially humified. One has therefore to accept that while primary mor layers are a reality, high humification may have developed especially in shallower peats as a result of their vulnerability to dehydration in recent centuries.

A further problem warranting closer examination is why basal mor layers are thinner, less predictable and very often absent in the deeper peats. The simple explanation, as already offered, centres on the more rapid early accumulation of organic remains on sites more prone to waterlogging, as related to siting and the degree of provocation by early human activities. Nevertheless, we should give thought to post-depositional alterations which may have taken place in the peat mass and its mineral subsoil. Just as solvent action removes weatherable ions from mineral soil and may reduce the dimensions of buried soil profiles so also do humic substances have a finite existence - unless it can be claimed that they are sealed in a virtually closed system. It is therefore likely that a slow, continuous loss of amorphous humic material has taken place from the base of peat deposits by solvent action. The rate and amount of such loss may be expected to vary according to sub-peat drainage and the antiquity of original peat formation. It is probably significant that charcoal, fragments of which can often be recovered from mor layers, is not infrequently identified from the peat/soil interface. While this may survive from human activities coeval with the onset of peat formation its residual build-up from the degradation of surrounding peat is another possibility. There is also no doubt that lateral seepage of water takes place at peat/soil interfaces as

TABLE 1. Basal radiocarbon dates for selected peats in upland Britain - arranged by altitude

Location	Altitude m	National Grid Ref	Depth cm	Date C14 yrs B.P.	Source
Brecon Beacons (W)	715	SO 043196	102	4380 ± 70	Chambers
Fountains Fell (P)	623	SD 871708	142	5000 ± 100	Smith
Cefn Ffordd (W)	600	SN 906032	26	3625 ± 80	Chambers
Lowther Hill (S)	595	NS 885113	54	4010 ± 50	Taylor
Fleet Moss (P)	565	SD 860836	360	8510 ± 50	Honeyman
Penhill (P)	549	SE 038858	180	4820 ± 50	Honeyman
Banc Nant Rhys (W)	543	SN 825792	185	3870 ± 50	Taylor
Carnedd Wen (W)	520	SH 924098	100	3630 ± 50	Taylor
Glaslyn (W)	490	SN 828932	140	2740 ± 50	Taylor
Milltyr Cerrig (W)	490	SJ 020306	100	2600 ± 50	Taylor
Whirley Gill (P)	488	SD 970940	350	8950 ± 80	Honeyman
Hail Storm Hill (P)	460	SD 832189	155	5830 ± 50	Taylor
Skerry Hill (NI)	415	D 143207	145	3360 ± 50	Taylor
Cefn Gwernffrwd (W)	400	SN 738494	69	3465 ± 70	Chambers
Coed Taf A (W)	400	SN 988108	30	1435 ± 55	Chambers
Coed Taf B (W)	400	SN 989108	72	1310 ± 70	Chambers
Low Stony Bank (P)	400	SD 918650	90	1690 ± 60	Smith
Torfichen Hill (S)	395	NT 346532	35	1700 ± 50	Taylor
Thornton Mire (P)*	380	SD 952872	320	8480 ± 90	Honeyman
Lanshaw (P)*	370	SE 129454	270	10250 ± 100	Bannister
Skell Moor I (P)	320	SE 172696	25	3880 ± 100	Tinsley
Upper Skell Gill I (P)	290	SE 177693	140	3700 ± 150	Tinsley
North Gill Wood (P)	267	SE 167726	190	1050 ± 90	Tinsley

(P) Pennines ... (W) Wales ... (S) Scotland ... (NI) Ulster

* Basin/Valley site

can be observed in peat gullies. While this would be one obvious means of removing the finer fraction of basal peats its efficacy would be enhanced wherever the latter had developed structural cracks through contraction in exceptional droughts.

It is evident also from Table 1 that very different rates of peat accumulation have characterised different sites. Some of the shallower blanket peats recorded in Figure 10 clearly have no basal mor layer and therefore began as wet peats. These may include some relatively recent formations but are mostly peats which have lost momentum in time or have been subject to various forms of disturbance, for example Skell Moor I and Fountains Fell in Table 1, to name but two. It is to be regretted that so few dates are available for very shallow peats while for the deeper peats the interest in C14 dating has focussed on palynologically interesting horizons rather than the problem of peat origins.

For convenience, three depth classes of peat have been discussed in the foregoing sections but it will be appreciated from Figure 10, that generalisations concerning depth and basal peat morphology cannot be forced beyond a certain point. Indeed, while each category may be identifiable within a given locality, the variable rates of peat accumulation in different areas make divisions on the basis of absolute depths of little overall validity. Furthermore, much additional field data needs to be collected from a wider scatter of upland localities before greater confidence can be attached to the general trend evident in Figure 10.

3. DISCUSSION

3.1 Primary and secondary environmental changes

In this paper, the spotlight is placed on changes which are likely to have taken place in the period between an earlier woodland cover and its replacement by blanket peat. The reasons advanced for the eventual disappearance of upland tree cover have tended to change in time. Earlier ideas centred on climatic changes from the beginning of the Atlantic period (7000 BP) (Conway, 1947, 1954) to the sub-Boreal and especially the sub-Atlantic period (2800 BP) (Godwin 1940, 1975). It is of interest to note that Godwin had regarded blanket peat initiation as a natural outcome of soil development in upland, high rainfall areas although he himself had never published these views (Godwin, 1964). This, of course, recognized that soil factors contributed to peat formation but the view was offered in too general a form, it did not especially commend itself to the field evidence and was never seriously adopted. But following Moore (1975) there does now seem to be overwhelming palaeoecological and archaeological evidence for human interference as the prime cause of the loss of early forests. This is not to say that every part of the most exposed terrain, wherever it occurred, had tree cover at one time. It is acknowledged that light woodland, scrub or even open areas persisted from late-Devensian times through the Holocene and these may have offered the earliest open hunting grounds for Mesolithic man from where his influence progressively spread outwards (Simmons, 1975). We must now consider along which pathways peat formation could have been induced.

A fundamental consequence of deforestation or the gradual degradation of upland woods would have been an increased amount of runoff as a result of reduced transpiration and interception (Moore, 1975; Robinson and Newson, 1986). The resulting higher levels of available soil moisture caused waterlogging of a sufficiently protracted nature on the wetter sites to generate peat, as witnessed by the frequent burial of tree remains on lower slopes and in basin sites. On drier, water-shedding areas, increased leaching and significant alterations in nutrient balance would have occurred. In this paper I take the functional onset of peat development to be when, to a major extent, the ground-layer vegetation is no longer rooted in mineral soil. In this case the surface deposition of organic matter is no longer part of a soil nutrient cycle but of a system dependent upon atmospherically-derived nutrients, except when flushed. As a working hypothesis, the transition from a basal raw humus or mor layer to less humified peat is taken to signify such a change while the entire thickness of organic matter is described as peat for convenience only.

From the peat stratigraphy, it is evident that, although the majority of deeper peats appear initially to have been associated with bog species, substantial areas ('intermediate' and 'shallow' peats herein) display a dark basal organic layer of distinctly higher humification, formed under a heathland rather than a bog association. This would support the large amount of palaeoecological research which indicates that the rate and extent of local tree loss from the uplands was highly variable. The wide range of dates for the onset of blanket peat formation would appear to confirm this variability (Simmons, 1964a, 1964b; Moore and Chater, 1969; Moore, 1970; Smith, 1975; Bostock, 1980; Chambers, 1982a, 1982b, 1983; Taylor, 1988). Thus, metachronous peat initiation dates have not only been claimed for different regions of Britain but have been obtained for different parts of the same moorland area, which adds justification to the approach towards blanket peats adopted in this paper.

On sites most able to shed moisture, a variable pattern of woodland decline would similarly have occurred and it is probable that trees persisted for longer on sites which provided more suitable, drier conditions for regeneration. Trees remaining on these drier sites would, in turn, have protected them from a tendency towards paludification. These areas eventually became dominated by a ground layer of heath and related species while the limited nutrient budget of this flora must have been a key factor in intensifying the leaching of soil profiles. The release of chelating agents from leaves and litter of heath plants accelerated the development of podzolic soils, in which the downward translocation of sesquioxides is paralleled by the development of a slow-decomposing, surface, mor-humus layer. Various implications of this podzolidation will now be discussed.

3.2 Pedological processes

The downward displacement of hydrated oxides of iron and aluminium depends on the existence of acids and chelating agents released into acid soils in which earthworm and bacterial activity is virtually absent. In the case of iron-cemented sandstones and their associated drift soils, the removal of iron releases mainly quartzose grains which provide a coarse matrix through which finer products of weathering and biodegradation can move. These latter materials accumulate in the less weathered subsoil and may coat the parent material at the base of the profile. This process normally allows the later movement of humic materials which form a layer above the maximum zone of iron accumulation. While the depleted surface mineral soil remains open-textured, the illuvial horizon becomes less able to transmit water on account of its increased bulk density through cementation by iron and/or accumulation of clay (Figure 9B). By contrast, shales, mudstones and their associated drift soils exhibit a contrasted pedogenic sequence. Here the key process appears to be the liberation of much silt-sized material (including quartz, feldspars, micas and ferromagnesian minerals), as iron cement is weathered from the primary rock fragments. This initially generates a weathered surface horizon in which pockets of gleying develop as permeability is reduced. At this stage, plant roots begin to avoid the gleyed zones, tending to create a pseudo-prismatic structure. In time, these mottled areas merge to form a more or less continuous surface gley horizon, with an indurated iron pan at its base, reflecting the sharp redox gradient between the surface layer and subsoil, and recalling the sequence in Figures 8A-C and the profile Figure 7B. The iron pan also confirms that podzolisation of these soils involves a two-stage process - an initial aerobic leaching facilitated by chelating agents and a subsequent redox diffusion process associated with a gleyed surface horizon (Smith, 1987).

What then were the consequences of such pedological changes for vegetation growing on the surface? In the case of the sandy substrate, drainage deterioration depends on a densification and increased water holding capacity of the subsoil, and therefore rooting in mineral soil would not be affected until a relatively advanced stage had been reached. On mudstones, however, surface drainage impedence commences with the development of localised mottling and increases as the gleyed horizon develops. Subsequently, the combination of gley horizon and iron pan provides a basis for a change from podzolic mor humus to peat formation as earlier defined. As drainage restriction progresses, the roots of heath species become inhibited leading to an increase of sedges and mosses and, as old root channels in the surface soil degenerate, paludification is reinforced (Figure 11).

3.3 Biotic processes

But the accumulation of surface organic matter has often been regarded as the cause of surface gleying and iron pan development rather than its consequence. The main problem, however, with the latter view is that it offers no explanation of what initially triggered peat accumulation on sites which showed no early predisposition to waterlogging, and it over-emphasises present-day interrelationships, e.g. the common association of peats with gleys beneath.

Certain situations do, nevertheless, warrant closer examination. The first is where deep peats extend their range laterally from basin or plateau sites. This is known as lateral paludification and would naturally lead to intergrading boundaries between peat types. The second situation relates

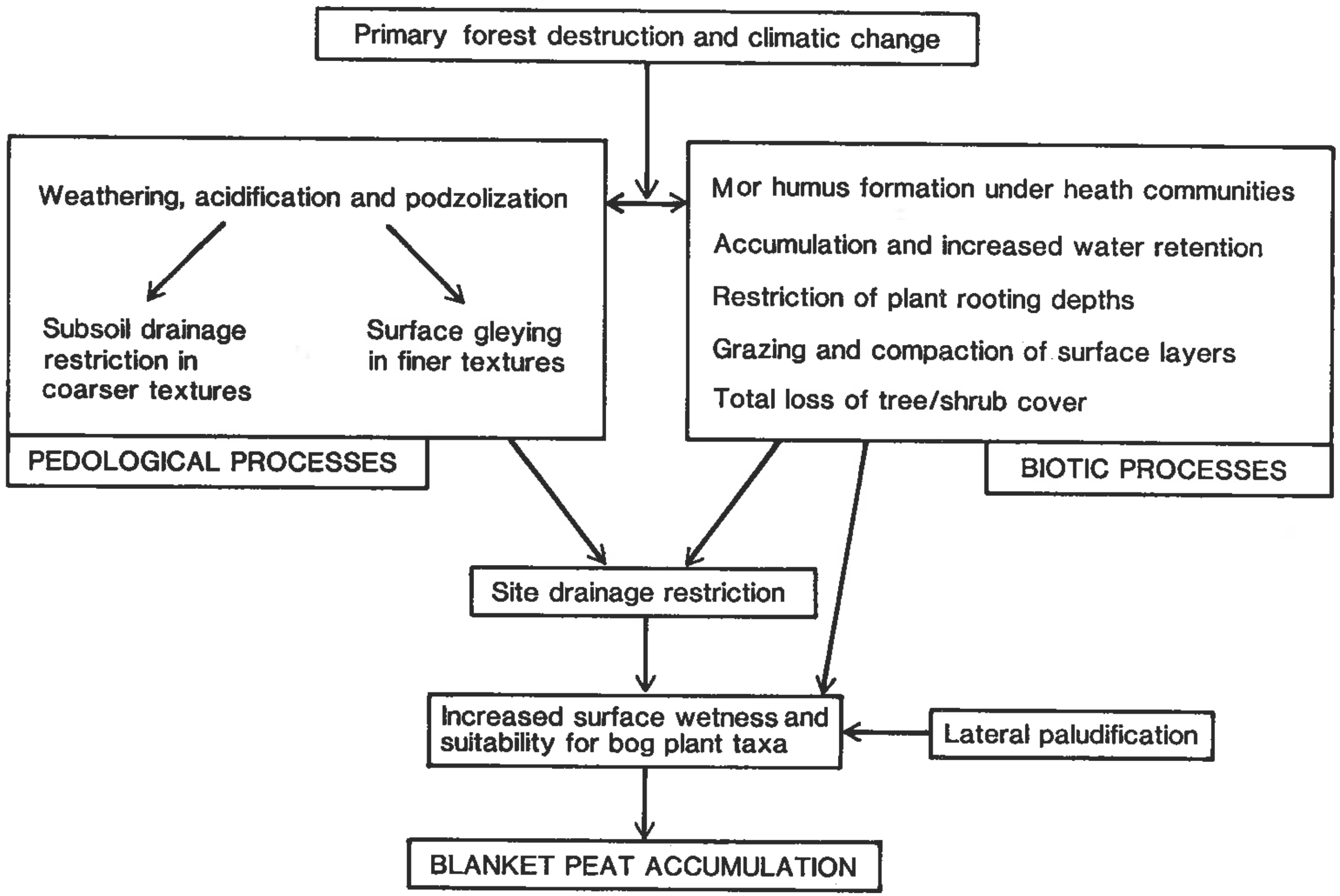


FIGURE 11. Factors in the inception of shallow blanket peats

to the slow build-up of mor humus, which, while it may not have imposed gley conditions on the soil below, could have helped maintain soil wetness. For example, as mor layers deepen, plant roots will decreasingly occupy mineral soil; so the latter deteriorates structurally, thus assisting any predisposition towards gleying (Figure 11). Thirdly, a further biotic influence has been that of prehistoric and historic land use. It is here that we encounter factors which could either have promoted or inhibited peat development. Burning and drainage are factors which have diminished peat formation and led locally to erosion while grazing and periodic burning under open woodland conditions would have materially altered the prospects for tree regeneration (Moore, 1973; Merryfield and Moore, 1974; Simmons, 1975; Atherden, 1976; Jones, 1976; Smith, 1981; Taylor, 1980). A further effect of grazing animals, particularly the larger beasts, would have been to compact the turf layer. Gifford and Hawkins (1978) present infiltration data from ungrazed and heavily-grazed land which shows that grazing often reduces infiltration by at least 50% and in some cases - perhaps the moister sites or heavier textures - by up to 80%. The latter process, together with the reduction of more palatable-species, may have aided colonization by acid bog taxa and therefore accelerated paludification (Maguire, 1984). Although much would have depended on the relative intensities of grazing and burning, the latter are activities which must have contributed to the inception of peats particularly as charcoal is often found at the base of peats, is abundant in mor layers and can be found throughout some peat deposits (Atherden, 1979; Simmons and Innes, 1981).

It is considered here that the above biotic processes enable many different upland areas to exhibit similar soil and peat morphologies and to participate in a bio-pedological origin for some of their peat cover, irrespective of the direction given to soil development by individual parent materials. Furthermore, the inconsistent relative depths of mor and overlying peat encountered in the field (Figure 10), seem to confirm a polygenetic origin within the shallower blanket peats, such that either pedological or biotic processes have played the dominant role on given sites and in different parts of the country. It is clear that in combination these processes, although in most cases slow-acting over long periods, have provided an important supplement to more direct - even obligatory - forms of waterlogging and peat formation (Figure 11).

3.4 Spatial relationships between peats

In the last 25 years of major advances in soil science, there have been a number of applications of morpho-hydrological models to the mapping of soils and the assessment of terrain and land capability classes (Bibby and Mackney, 1969; Davidson, 1980; Gerard, 1981; Huggett, 1975). Nevertheless, each terrain unit comprises a continuum of individual profiles and, for this reason, it must not be assumed that soil parent materials should respond in a uniform manner to long-term processes. Not only do variations in lithology and structure occur, but there are subtle variations in glacial and periglacial drift substrates. A variable degree of paludification and subsequent peat development is therefore to be expected even within areas broadly designated as of one particular peat type. For example, among the shallow peats, individual sites have developed 30-40 cm of sedge peat above basal mor humus while adjacent sites have a mere 15 cm of mor. It is clear, too, that aspects of moorland management, particularly drainage networks, have arrested peat development at a particular stage and have led to peat degradation and erosion. These factors and the resulting inconsistencies in peat depths have discouraged attempts to rationalise the complex patterns of upland blanket peats and they frustrate attempts to set up any formal series of transects. A further reason why peat depths are unpredictable is due to the uneven sub-peat topography and its frequent lack of coincidence with the contemporary ground surface.

Peats of differing depth merge to form a hydrological continuum although in the British uplands the lower margins are so truncated that a grading boundary to non-peaty soils is rarely open to study. It is well known that as peats develop they progressively influence the hydrology of surrounding areas. It is accepted, therefore, that lateral paludification has taken place on both micro- and macro-scales (i.e. within and between the main peat classes defined herein) from poorly drained plateaux, from ancient water courses, and even upslope from valley and basin situations (Chambers, 1982; Edwards and Hirons, 1982). This process, as exemplified in the 'intermediate' category sites, admits of an inevitable polygenesis throughout peatlands but especially in areas which resisted peat formation until comparatively late in prehistoric times.

The characteristics and antiquity of different upland blanket peats can therefore be understood as reflecting (1) the capacity of particular sites and areas to shed surface moisture, (2) their proximity to axes or areas of saturation and (3) the periodicity and intensity of culturally-induced, ecological disturbance.

3.5 International analogues

Regarding the shallower blanket peats, one notes the variety of possible pathways by which peat may have begun to form on areas less sensitive to direct waterlogging (Figure 11). For this reason, analogues elsewhere would appear probable, if only because such environments need not possess highly specialised characteristics. Prerequisites are cool or cold temperate climates accompanied by acidic or acidifiable substrates which are initially freely-draining. Analogues to the shallow blanket peats are indeed encountered in maritime Alaska (Ugolini and Mann, 1979) and in Newfoundland (Wells and Pollett, 1983), both situations where surface restriction of drainage appears to be related to stage of vegetation and soil development rather than topography or other externally-acting factors.

The general formation of blanket-type peats is undoubtedly more widespread, including the Canadian Muskeg (Radforth and Brawner, 1977) and northern Eurasian peats and, by implication, the northern Canadian peats (Sorenson, 1977) together with southern hemisphere formations in South Island New Zealand, the Falkland Islands and southern Chile. More isolated blanket peats also occur on tropical mountains.

3.6 Relevance to contemporary processes

How much relevance do the processes discussed in this paper have for the prediction of future environments? The answer to this question partly rests on the relationship between cause and effect in environmental change. On the one hand, there are cases where a system experiences discontinuous change and flips from one apparently stable state to another - the effects of volcanic activity, imbalances between predators and prey or the sudden development of mire in a topographic hollow which formerly bore woodland - all represent examples of this kind (Smith, 1984; Trudgill, 1988). On the other hand, a characteristic of many kinds of environmental changes, especially those related to secular climate change - is that they exhibit a lag relationship or attainment of critical threshold conditions only after the prolonged operation of slow-acting processes (Smith, 1984). Soil systems are particularly prone to such delayed effects. For example, much of the world's soil erosion problem results from prolonged aggravation of the biotic controls on soil stability. This paper has similarly attempted to show the long-term results of processes triggered by environmental changes occurring certainly hundreds and probably thousands of years before bequeathing their legacy as peat formation.

Taking due note that the development of various blanket peats has only occurred after forest removal, it is not unrealistic to suggest that with the logging of boreal woodlands without adequate restocking and with the advancing blight of 'Waldsterben' across central and eastern Europe and eastern North America, further expansion of heath and bog species may well be accompanied by peat development in years to come. Under the influence of multiple pollutants (World Resources, 1986), it would seem unlikely that normal regeneration of these woodlands will be possible, so that the combination of increased moisture effectiveness and an expansion of heath and wetland ground flora would seem to provide the context for future biopedological changes. Furthermore, recent models of the earth's atmospheric circulation, with elevated CO_2 levels, not only drive warming influences further poleward but suggest an envigorated zonal atmospheric circulation at higher latitudes compared to present norms. The consequent rainfall increases in higher latitudes could well have widespread repercussions on peat-forming ecosystems, some more immediate, others, according to ground conditions, with their effects substantially retarded. The resulting reduced fire frequency in the northern boreal zone (cf Sorenson, 1977) could well invite more substantial moss and lichen accumulation with concomitant inhibition of tree regeneration in this sensitive ecotone.

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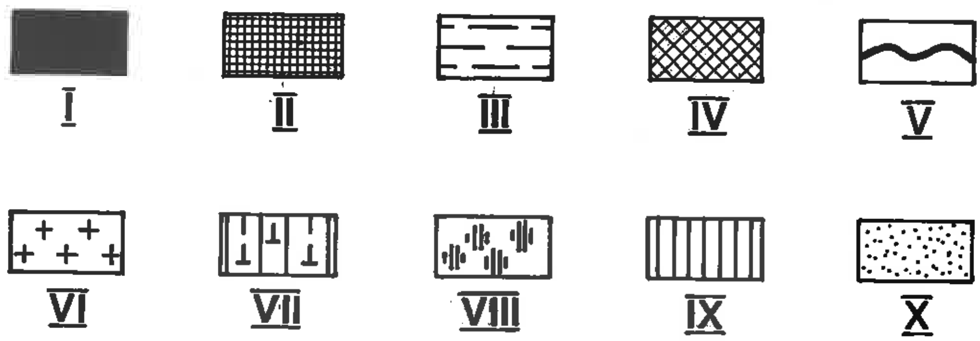
APPENDIX

Symbols used for peat and soil sections



I. Highly humified peat (H = 8-10).

II. Well humified peat (H = 6-7).

III. Fibrous, mainly monocotyledonous peat (H = 1-5); line spacing signifies humification; C = Calluna remains; V = wood remains; wavy lines = Sphagnum.

IV. Organo-mineral horizon deriving from colluvial process or downward movement of humic substances.

V. Iron pan.

VI. Parent rock *in situ*.

VII. Weathering parent material.

VIII. Mottled or gleyed horizon.

IX. Silty clay matrix.

X. Sandy matrix.

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CAPTIONS TO FIGURES

Figure 1 Distribution of peat deposits in the British Isles (redrawn after Taylor, 1983)

Figure 2 Landscape model relating soils and hydrological conditions (redrawn from Goudie 1987, after Conacher and Dalrymple 1977)

Figure 3 Schematic representation of the terrain and peats discussed in this paper

Figure 4 Pollen and stratigraphic diagrams for Thornton Mire 380m SD952872 and Fleet Moss 565m SD860836

Figure 5 Pollen and straigraphic diagrams for Hail Storm Hill 460m SD832189 and Banc Nant Rhys 543m SH924098

Figure 6 Pollen and stratigraphic diagrams for Milltir Cerrig 490m SJ020306 and Carnedd Wen 520m SH924098

Figure 7 A. Soil profile and B. Combined peat and pollen record for High Mark 1 480m SD930682. C. Pollen and stratigraphic diagram for Low Stony Bank 400m SD918650

Figure 8 Pollen and soil profile diagrams for A. Llanidloes 435m SN905832. B. Llyn Eiddwen 330m SN607677 and C. Elan 450m SN915715

Figure 9 Pollen and stratigraphic diagrams for Eisteddfa Gurig 518m SN855845 and Great Lodge 450m SD834189

Figure 10 The relationship between basal mor thickness and total peat depth for selected blanket peats

Figure 11 Factors in the inception of shallow blanket peats