Holocene blanket peat development in south west Scotland; the roles of human activity, climate change and vegetation change.

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Abstract

This thesis examines the role of autogenic and allogenic forces in determining the timing and development of blanket peat initiation and how the occurrence and growth of blanket peat subsequently constrains human activities. A number of factors involved in the formation of blanket peat have been defined in the literature, in particular the roles of climate change, soil processes and anthropogenic effects, tested in this thesis from a typical peat-covered upland in south west Scotland. Tests are developed from a multi-proxy approach and by comparing peat-stratigraphic and palaeoecological records from a series of nine ^{14}C dated peat profiles from a single hillside.

A detailed examination of the sequence and timing of blanket peat initiation in the Holocene Epoch is presented from a case study from the head of the Glen App valley, Lagafater, south west Scotland. The evidence was taken from a total of nine peat transects at 215m OD, 300m OD and 400m OD where agricultural, hydrological and micro-climatic effects are expected to have differed and had different impacts on soils and vegetation. Samples were retrieved from the top, middle and bottom of a gently undulating slope at each altitude. This has allowed a localised picture of peat initiation to be obtained from each locality and with changes in altitude, allowed for an analysis of the factors responsible up and down slope and the identification of synchronous autogenic forces.

A number of analytical techniques have been used. Pollen analysis was undertaken as the principal method of vegetation reconstruction at all sites, particularly through the initiation horizon. Variations in mire-surface wetness, determined through dry bulk density and humification analysis, were also employed to generate a record of probable changes in effective precipitation and the effect these may have had on the accumulation rate of the blanket peat. In order to attempt to answer the question of when blanket peat was initiated and to establish the synchroneity of changes, twenty nine AMS ^{14}C dates were obtained.

The evidence suggests that blanket peat developed during the Mesolithic period, through to the early Bronze Age. It substantiates an anthropogenic forcing factor for palaeohydrological changes, with early landscape management and cereal cultivation accelerating the process of blanket peat initiation. With progressive changes in precipitation interacting with factors such as weathering of bedrock and vegetation cover, the local landscape at Lagafater was covered by blanket peat by the early Bronze Age. The radiocarbon chronology obtained from the multi-proxy records allowed the synthesis of these data sets and the definition of Holocene vegetation change, climate change and the history of human impact throughout the early prehistoric era across this landscape.

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Chapter 1 Introduction

1.1 *The Study of Peat Initiation in south-west Scotland*

It is estimated that blanket peat covers 1.4 million hectares of Scotland (Lindsay 1995) but there is considerable difficulty in understanding how and why this has developed, in particular the relative impact of human activity, vegetation change and climate change (Barber 1981; Frenzel 1983). The aim of this thesis is to present a detailed multi-proxy study of an area of blanket peat in south-west Scotland, in order to examine the link between wetland vegetation change and the broader regional pattern of climate change and human activity. This study will contribute to our understanding of why peat developed in south-west Scotland and will provide an insight into the general uncertainty of peat bog development in Scotland. In particular, the study will examine the date of the onset of peat initiation in south-west Scotland, the human and climatic interactions at this point of change, and the importance of micro-scale topographical factors in understanding blanket peat initiation and accumulation processes. The study will also look at the mechanisms and causes of blanket peat inception in the context of human settlement patterns at Lagafater, south-west Scotland, and will characterise and date the onset of the Holocene landscape that is present in the area today, identifying periods of climatic change and human activity over the last 5000 years.

A detailed palynological study from the Scottish south-west mainland is presented from an area at the head of the Glen App valley, north of Glen Luce and Stranraer (see Figure 1.1). The south-west of Scotland contains a rich archaeological record within a topographically varied region, which provides the opportunity to study peat development across several geomorphological, ecological, archaeological and climatic zones of transition. To date, little palaeoenvironmental evidence has been linked to the richness of the early prehistoric archaeology in this region and this will form a key element in the thesis. Three peat transects were taken at different altitudinal positions, from 230m OD, 300m OD and 400m OD, where the impact of agriculture will have had different effects on the soil. Nine detailed peat sections were excavated in full and were subject to three key proxy methods: palynology, humification and dry bulk density analyses. This will allow a suitably detailed evaluation of peat initiation and accumulation to be obtained from each locality in order to permit an analysis of the initiation factors responsible up and down slope, as well as the rates of local peat growth.

Figure 1.1: The south-west of Scotland showing the Lagafater study area

1.2 *Choice of Location*

Blanket peat initiation work has previously concentrated on the northern Highlands of Scotland, and in particular the regions of Caithness in the east, Sutherland, Inverasdale and Wester Ross to the west, as well as central Highland areas such as Rannoch Moor, and the more exposed islands off the west coast such as the Western Isles (e.g. Birks & Madsen 1979; Charman 1992, 1994, 1995; Fossitt 1990; Lindsay *et al* 1988; Robinson 1986). In addition, much palynological and climate based work has been carried out on *isolated* lowland raised bogs throughout Great Britain (Barber *et al* 1994; Hughes 2000). Moreover, very few reliable age determinations occur from the bottom sections of mires that could be used to estimate the timing of initiation (Korhola 1995).

This project therefore developed as a response to gaps within the published literature as to the magnitude and spatial scale of blanket peat spread, the factors preceding blanket peat initiation, the date and cause of this phenomenon, as well as the under-representation of data from the south-west of Scotland, particularly given the richness of early prehistoric archaeology in the region. Within this area, blanket peat ranges from under 150m OD to over 500m OD, providing the opportunity to study blanket peat development and initiation factors as well as human interaction over a range of altitudes. South-west Scotland provided the opportunity to focus on an area where little work had been undertaken on the tracts of undisturbed blanket peat at Glen Luce (Figure 1.1). A new approach to understanding the development of the peatland landscape could be undertaken on the well-preserved peat profiles, and a local assessment of human activity and impact could be made based on the richness of the archaeology in the lowlands of south-west Scotland. A series of undisturbed raised mires also co-exist in lowland situations acting as complementary palaeoecological resources.

1.3 *Methods Used*

A series of three coring transects at 230m OD, 300m OD and 400m OD were taken across sloping ground, and complete peat profiles were obtained at nine locations from the top, middle and bottom of each slope following intensive probing of the area in order to ensure reliable sampling data.

In addition to the three detailed transects, a series of Dutch cores was taken on a variety of slope angles and slope lengths, with different aspects and at different altitudes. These were recorded in the field for peat depth and humification. Each profile was drawn, photographed and its position noted on OS Pathfinder maps. By comparing the results of these, and transferring their positions onto geomorphological maps of the area (showing hydrology, palaeochannels and so on), key features such as hydrology, slope angle and slope length will be linked with peat depth and humification. In addition, digital terrain models of the current landscape topography were compared with the underlying sub-peat profile of the geology, inferred from the depth of coring, to ascertain whether current and / or past hydrological patterns have influenced the rate of peat growth. This will provide a complementary 'wider' picture of blanket peat spread compared to the more detailed analysis of blanket peat initiation from the three transects.

1.4 *Peat as an Environmental Proxy*

Ombrotrophic mires have been used to make inferences about past climate change for many years. Earlier work sought to identify only major shifts in effective climate wetness, but more recent work (Anderson 1998; Baker *et al* 1997; Barber *et al* 1994; Charman *et al* 1999) has provided data of high temporal precision which shows periods of change throughout the Holocene. The potential of ombrotrophic bogs as sources of reliable information is partly limited by difficulties of scale and the internal variability of the mire system, particularly as surface water on a convex area of raised mires and blanket mires is purely derived from precipitation, thus giving a proxy measure of past surface wetness (Charman *et al* 2000). However, to secure the reliability of this data, it is suggested here that records from both blanket mires (this PhD) and raised mires (previous palaeoenvironmental work) should be compared, highlighting regional trends in climate change, and samples from up and down slope of blanket mire will highlight records of internal variability. It is important to separate the climate signal within the record from factors such as mire expansion, local vegetation dynamics and micro-topography. This issue can only be resolved by replicating samples at different locations within sites at a variety of spatial scales (Charman *et al* 1999). A more detailed analysis of peat as an environmental proxy is explored in section 2.2.5.

Attention has thus been given to the design and implementation of field techniques and laboratory methods to minimise the potential for misunderstanding the data set and experimental error. The methodology adopted will allow a detailed study of an area where the temporal and spatial elements of blanket peat are thoroughly investigated. The physical and vegetational factors associated with blanket peat initiation on the site will also be considered, as well as the mechanisms behind the development and consequential spread of blanket peat in the area. This will involve:

1. High spatial and temporal resolution palynology, particularly at the blanket peat interface.
2. High spatial and temporal resolution humification tests to deduce possible episodes of climate change.
3. Establishment of the age of blanket peat inception and the rates of peat growth up and down slope at different altitudes, through a number of AMS radiocarbon dates.
4. Particle size analysis at the soil / peat interface to assess the impact of the underlying geology and subsoil in creating a waterlogged environment.
5. Dry bulk density every 1cm through the peat profiles to investigate the rate of peat growth up and down slope at a range of altitudes.
6. The consideration in isolation of geomorphology, topography and geology which may vary widely even within small areas, and the effect these may have had on blanket peat initiation: for instance, small scale variations in oxygen, temperature, water supply, nature of plant material, micro-organisms, pH and CO_2 levels.

In order to attempt to answer the question of when blanket peat was initiated in the south-west of Scotland and to establish the synchronicity of changes in climate and / or anthropogenic activity at the point of this change in the profile, it is crucial to obtain a reliable geochronology. Radiocarbon dating by accelerator mass spectrometry (AMS) is a common method for developing a chronology through peat sequences, and has been chosen for this study. The dates obtained throughout several profiles of blanket peat will also allow peat accumulation rates to be estimated and will allow inter-site as well as regional comparisons to be made.

1.5 Archaeology of the Lagafater Region

The archaeological evidence from Lagafater is dominated by the survival of Neolithic and Bronze Age remains. The area contains numerous Neolithic burial monuments, particularly the Clyde and Bargrennan chambered tombs and their associated cairns (Henshall 1963, 1972), the latter being more common in the study area (e.g. Cairn Kenny, at NX 174 752).

These monuments have affinities with areas across the Irish Sea (Cummings 2000) although the palynological evidence appears to suggest a continuity of agricultural practices with the earlier, Mesolithic period. Direct artefactual evidence for the Mesolithic is based on a narrow range of evidence across the region, but human activity throughout this period and the proceeding Neolithic is detected by relatively small scale changes in values of woodland taxa and the presence of several cereal grains (Tipping 1995, 1997). There are greater numbers of probable Bronze Age structures to the south of the study area. In particular, a number of hut-circles have been recorded in this area, suggestive of an organised, domestic and agricultural society, particularly with the recorded presence of early field systems (e.g. at Little Larg, NX 154 658) to the south of the coring sites. The archaeological evidence is discussed further in chapter 3.

1.6 *Factors Involved in the Formation of Blanket Peat: Previous Work*

When and why peat began to grow in each region across Scotland remains an unanswered question. The problem appears to be one of timing and the nature of the events preceding the change from soil to peat, and the exact processes and mechanics of this development. Many investigations have been concerned with the formation of the peat and not with the activities preserved in the record prior to peat growth (Korhola 1995). The intricate relationship between human activity and peat growth is also unclear: the effects of blanket peat growth and expansion of human activity and settlement is perhaps more complex than we have so far been able to elucidate. Many authors have drawn attention to the major changes that occurred in the archaeological record from the Early to Middle Bronze Age at around 3000 BP, in particular changes in settlement patterns (Baillie 1993, 1996; Burgess 1985, 1989; Piggott 1972). They have suggested that a prime cause for social and cultural upheaval during this period was changes in the natural environment, in particular a marked deterioration in climate, the formation of blanket peat, and a loss of cultivated land. An increase in heathland vegetation at this time has been recorded from many sites, particularly in the north of Scotland; e.g. Caithness (Peglar 1979) and Shetland (Bennett *et al* 1993). In some cases, blanket mire inception is also seen as a consequence of agricultural activity in a worsening climate: cultural change, climate change and blanket peat growth are therefore inter-linked. Climate change is often thought to lead to widespread blanket mire formation, causing land 'abandonment' in upland areas and leading to increased pressure on the remaining agricultural land, with consequent social upheaval. Alternatively, it was perhaps overuse of the land that tipped the balance and became the causal effect of peat growth. In the Scottish Southern Uplands, for example, work by Tipping (1994) has demonstrated that during the later Mediaeval period, wider economic and social factors may have played a greater role than climate in determining land abandonment, highlighting the inappropriateness of using models based on that period to predict prehistoric social responses to environmental change. Similarly, work at Lairg, Caithness (McCullagh & Tipping 1998), has suggested that prehistoric and historic cultivation may have *inhibited* blanket peat encroachment in this area.

Other work on blanket peat landscapes of north-west England and Scotland suggest that peat growth began in the early post-glacial period, and the rate of increase accelerated between c.5000-3000 cal. BP, typically associated with evidence for human activity, such as cereal pollen and charcoal (Tallis 1998) (section 2.2.6). Human impact or other individual causes of blanket peat initiation are simple explanations for changes in the landscape, but there are many other interacting factors and the problem of disentangling them can only be resolved by obtaining independent lines of evidence for each. For instance, those processes required for the decay of plant material alone, and therefore the ultimate creation of peat, include oxygen, temperature, water supply, the nature of plant material, micro-organisms, pH and CO_2 levels. These factors, however, are not independent of each other and are all a product of past and present environmental influences, including geomorphology, climate, geology and topography (Swift *et al* 1979). These should all be considered individually, particularly as the onset of peat may vary widely even within small areas.

A number of factors involved in the formation of peat have been accounted for within the literature, in particular climate, pedogenic processes and anthropogenic effects, but these have often been deduced following the analysis of single sites spread across Scotland: for example at Cross Lochs, Sutherland (Charman, 1992) and at Lairg, Caithness (McCullagh & Tipping 1998). A lack of standardised terminology for specific organic deposits, site heterogeneity, and uncertainty over the reliability of radiocarbon dates as well as the materials being dated, have all combined to suggest that there are few comparable details about the timing and causes of blanket peat inception and growth.

The synchronicity of blanket peat initiation and its spread across the area will, as a result of this study, be fully understood and placed not only within an environmental context but will also consider the local archaeological context and the relationship between the two. After obtaining samples from this part of the south-west of Scotland it is necessary to draw upon several other studies from across south-west Scotland and the central south-western belt (chapter 7) to see if the same variables of peat initiation apply. It is possible that land-use may have been more intense in other regions, and the response of the underlying geology to an increase in wetness may have been different, thus affecting the rates of peat initiation.

1.7 *The Thesis Aims*

The aim of this thesis is two-fold. Firstly, evidence for climate change and episodes of human activity from blanket peat records in the south-west of Scotland covering the last 5000 years are evaluated. Secondly, key factors responsible for the onset of peat accumulation at Lagafater, north of Stranraer, will be assessed and the impact that early human activity and climate change may have had on instigating and / or accelerating this process will be determined. Principally, what are the environmental factors and / or local hydrological mechanisms that determined peat initiation and its subsequent lateral spread.

The dating of peat deposits from the three different altitudes at strategically located topographical localities will allow determination of the thesis aims below:

- What factors led to the initiation of blanket peat (climate change, human impact or pedogenesis)?
- When did peat begin to grow in south-west Scotland?
- Whether the date of blanket peat initiation is synchronous up and down slope.
- Whether the date of blanket peat initiation is synchronous at different altitudes.
- What factors encouraged its spread (slope angle, slope length and aspect).
- At what date the spread of blanket peat began and effectively covered the area.
- What is the nature of human activity preserved in the peat record at the point of blanket peat initiation?
- What is the periodicity of climate change in south-west Scotland?
- The overall aim is to create a model of the interaction between potential factors involved in peat initiation, against which a series of questions based on observations can be derived in order to understand the nature and approximate timing of blanket peat initiation in any area. The problems inherent with the current models will be highlighted and new information and details generated will play a greater part in assessing the factors behind peat initiation. This will allow a greater understanding of the processes involved in peat growth over wider areas of differing topology and

land-use, making peatlands more understandable areas of land to manage today, and providing the archaeologist with information on how to assess past land-use and the environment.

The project was designed so that vegetational history from deposits only a few metres apart could be compared to determine whether or not a three-dimensional picture would emerge. Many publications consider peat initiation at the ‘macro-scale’, and dates are taken from only one or two sites. At the ‘micro-scale’, it is possible to identify detailed underlying landscape features such as depressions and mounds and therefore primary and secondary peats. Peat initiation will normally form within depressions first (primary sites) as these are micro-moisture receiving sites but secondary development occurs across the surrounding flatter, drier ground from the initiation foci (Hafsten & Solem 1976). Therefore, across a small area the date of inception may vary widely. Replica samples from these areas and samples up and down slope at close intervals (coring at 1 to 2 metres apart) will, however, give us a high resolution picture of these primary and secondary peat developments, helping us to understand the ‘macro-scale’ landscape development.

In order to answer these questions, it is necessary to look at peat development across different altitudes and across different slopes in order to map the sequence of peat establishment in the area. Have factors such as elevation, deforestation and nutrient leaching had an effect on the pattern of peat development in the south-west of Scotland? It has been recognised that the identification of ‘true’ blanket mire is sometimes difficult, particularly when individual samples from single areas are used, and that vegetation responses to surface wetness, for example, may reflect regional changes in climate and / or changes in physical hydrology caused by peat growth itself. For example, if peat growth is faster at the base of a slope than at the top, the gradient will become shallower over time and may lead to less runoff. The peat profile may show a change in vegetation (and hence humification values) indicating reduced surface wetness, but this may be completely independent of climate: by looking at transects up and down the slope, therefore, these two ‘causes’ may be separated.

Various hypotheses for the onset of blanket peat in Scotland have been put forward, in particular climate, pedology and human activity. It is suggested that all these factors play an important role in the onset of peat, but the timing of events is closely controlled by smaller-scale factors, such as localised agricultural activity and underlying geology.

Four hypotheses are proposed here:

1. Blanket peat initiation was a result of a natural pedogenic process and was inevitable across the study area.
2. Blanket peat initiation began as a result of external stress, e.g. climate change.
3. Blanket peat initiation was a result of human impact.
4. Blanket peat initiation has been time-transgressive with peat accumulation beginning in small isolated areas and progressively covering the landscape.

The causes of peat initiation across the site will be linked initially to localised patterns of human activity (deforestation and farming activity depleting the soil of its nutrients) where appropriate, and changes in pedology in small pockets of poorly draining substrate, while farming continues elsewhere in the area. The threshold into a peatland landscape is then crossed with an increase in more widespread wetter conditions. It is therefore important to understand the nature of vegetation change at this interface and the record of human activity and climate prior to peat initiation.

Wet shifts will also be identified from the blanket peat that will be associated with local changes in hydrology and water table. These may mask the climatic signal so data drawn from other raised mire sources in the south-west of Scotland will provide a detailed picture of climate change in the area. Given the hypotheses above, the timing of the trigger into a peat-covered landscape at the point of increasingly wetter conditions will be identified across the region, as well as identifying the impact that this had on human activity. In short, did human impact, climate or pedogenic processes accelerate or trigger the change to a peatland landscape in the south-west of Scotland?

1.8 *Arrangement of Thesis*

Chapter 1 presents a brief synopsis as to why the thesis was undertaken, highlighting previous views on the development and spread of blanket peat. It also presents an overview of the study area and the local archaeological record, which are key to the outcome of the thesis aims. The methodology adopted is also outlined and the thesis objectives clearly stated.

Chapter 2 provides detailed background information on the development of blanket peat, discusses the problems associated with its definition, and outlines our current understanding of the factors responsible for peat initiation. It also presents a summary of blanket peat initiation dates from across the British Isles, discusses the breadth of dates that are currently recorded, and demonstrates some of the current problems in understanding how to separate cause and effect.

Chapter 3 focuses on the palynological and environmental evidence from the south-west of Scotland. It presents a vegetational and archaeological history from across the region, particularly focussing on the Mesolithic, Neolithic and Bronze Age, in which the story of blanket peat initiation from Lagafater can be placed. The study site and the methods employed to obtain key environmental information are then outlined in Chapter 4.

Chapter 5 presents the results of the thesis beginning with the lithological and sedimentological history across all three altitudinal areas (sections 5.1–5.3). The pollen evidence is then presented through the basal sequences covering the transition from soil to blanket peat (sections 5.4-5.6). The longer palynological history from Lag 230m OD is then outlined, providing a complete record of environmental change (sections 5.7-5.9).

Chapter 6 places these results within the landscape setting, correlating the vegetational and lithological records across all nine sites to build a picture of environmental change. It also allows the initiation and development of blanket peat to be understood on the micro-scale, pin-pointing areas that have acted as foci for peat development and factors that were responsible for its initiation and subsequent lateral expansion.

Chapter 7 considers this information within a regional context, allowing wider, regional-scale patterns of climate and vegetation change to be identified. Similarly, the timing of blanket peat initiation and the pattern of peat development at Lagafater is considered in light of other known dates from across the United Kingdom and Ireland. Chapter 8 concludes by summarising the key findings of this study and suggests possible areas for further investigation.

Chapter 2 Background to Blanket Peat Initiation

2.1 *The Development, Classification, and Terminology of peats*

2.1.1 Blanket Bog Terminology

One of the major problems in the study of blanket mire systems has been to define them adequately (Moore 1973; Moore *et al* 1994). Blanket mires have been described as including elements of ombrotrophic, rheotrophic and minerotrophic mires, merging in a variety of ecotones (Gore 1983; Moore 1973; Moore *et al* 1984; Ratcliffe 1977; Solem 1986). Ombrotrophic blanket deposits occur in connection with rheotrophic sloping peats and difficulties arise when trying to define where one ends and the other begins, particularly as they occupy a variety of geomorphological positions. Several raised mire units may also be united by blanket systems and therefore it is difficult to separate the two without extensive fieldwork and investigation; for example at Coom Rigg Moss, Northumberland (Chapman 1964) and the Silver Flowe, Galloway, Scotland (Ratcliffe & Walker 1958). The complexity of this problem was underlined when Moore *et al* (1984) and Solem (1986) highlighted the fact that within a single profile where peat developed over a mineral soil, the peat initiation layers contain certain remnants of vegetation still in contact with the groundwater and must therefore be of minerotrophic type.

There is also a range of definitions for the term blanket peat, which highlight the lack of consensus with regard to a definition of this deposit. This factor makes it difficult when trying to work out when and why peat deposits began to accumulate across regions of Scotland where different workers have adopted different ideas. For example, Chambers (1981) states that the term blanket peat is more frequently used to encompass organic horizons of peaty gleys and podzols and includes deposits produced by vegetational communities other than those characteristic of strictly blanket bog. Similarly, Taylor & Smith (1980) have described profiles that have intervening layers of 'pedogenic peat' between layers of overlying 'blanket bog peat'. They also note that this pedogenic peat is not always a precursor to the development of blanket bog peat. The term blanket peat also conveys an image of a deposit that blankets an area and obscures the details of the underlying relief (Moore & Bellamy 1974; Tansley 1939; Taylor 1983). It is formed in discrete locations, later spreading and coalescing into a full cover (Hammond 1981). Burrows (1990) suggests that it can grow on any terrain regardless of slope, whilst Moore & Bellamy (1974) and Schouten (1984) suggest that it is restricted to slopes of up to 25°. Within Scotland, it has been suggested that there is a tendency for blanket peat to form where slopes lie at less than 15° as the ground moisture remains almost constantly in excess of that lost by evaporation (Ratcliffe 1964).

2.1.2 The Development of Ombrotrophic Bogs

A mire is a wetland ecosystem that supports 'peat-forming' vegetation. An ombrotrophic mire is so called as the wetland conditions and nutrient supply are derived solely from direct atmospheric precipitation (Lindsay 1995, 1996; Moore 1986). In Britain, such rain fed mires have traditionally been termed bogs (Lindsay 1996) and at present occupy 10.4% of Scotland's land surface (Taylor 1983). Ombrotrophic bogs represent one of the most acidic and nutrient-poor environments in the natural landscape but also contain a unique record of past environmental change and information spanning the Holocene and are particularly sensitive to climate-induced hydrological changes (Barber 1981).

2.1.3 The Development Sequence

Ombrotrophic mires can originate in shallow depressions, wide valleys, floodplains and watersheds (raised mires), where bodies of peat become isolated from, and independent of, the groundwater table. Research has been conducted into the mechanisms leading to ombrotrophy in British raised mires (see Hughes 2000; Hughes & Barber 2004; Whitehouse 2004), and the change from base rich groundwater fens to base poor meteoric mires has been well documented (e.g. Kuhry *et al* 1993).

In recent years, blanket mires have been subjected to rather less scientific scrutiny than most other mire types in Britain, with Holocene climatic signals being observed from within raised mires. Most existing studies have concentrated on vertical peat sequences from individual raised mires and have ignored the spatial aspect of peatland development (Bauer *et al* 2003).

Blanket mires are often the result of paludification, whereby peat formation is initiated on waterlogged, acid mineral substrates where drainage is impeded (e.g. podzols with an iron pan) or on impervious, acidic rocks where nutrients are readily lost through leaching (Anderson *et al* 2003; Rieley & Page 1990). The formation of peat, which has a low hydraulic conductivity, allows layer upon layer of partially decayed vegetation to build up (Brooks & Stoneman 1997). The base-deficient and waterlogged soil that develops provides ideal conditions in which *Sphagnum* can begin to grow and colonise the surface (Birks & Birks 1980; Lindsay 1988). For paludification to occur, it is often assumed that an external factor such as climate must change, but it may also be the result of autogenic change. Slow pedogenic changes over centuries may occur, altering the conditions within the soil profile, which in turn affect the hydrology, nutrient status, acidification and vegetation of the area (Taylor & Smith 1980). In this process, a thin organic soil horizon develops and leaching of iron and aluminium oxides may occur, producing an impermeable 'iron-pan' type horizon. There is good evidence for this type of peat development in parts of North America (e.g. Newfoundland - Hilbert *et al* 2000; Quebec – Payette 1984).

Ombrotrophic bogs are predominantly a mixture of partially decayed plants that have accumulated in a water-saturated environment, where the breakdown of vegetal material is reduced in anaerobic conditions and organic matter accumulates at a greater rate than it is decomposed, forming peat (Ward 2000). Their structure ranges from more or less decomposed plant remains to a fine amorphous, colloidal mass and the result is the building of layer upon layer of acidic plant matter. The basis for peat initiation is that organic productivity must exceed decay, factors that are external to the peatland system. The climate must be wet enough for plant growth and to allow waterlogging of the substrate for at least part of the year, so that the decay of material is inhibited. The temperature must also be low enough to prevent evaporation of surface water but high enough to allow the growth of plant material (Clymo 1984).

Ultimately, peat is a consequence of the intrinsic low decomposition rate of some of the plant species (e.g. *Eriophorum vaginatum* and *Sphagnum*) which colonise the mineral soil and function as cation exchanges (Andrus 1986), lowering the pH of the ecosystem and resulting in a species poor environment. Whilst this is not a direct factor of inception, these species play an important role in the development of peat. Biological processes of productivity and decay are central to peat formation and once these autogenic features are established, and no longer influenced by external factors, they can completely influence some aspects of the peat landform (Charman 2002).

As the decomposition of organic matter by micro-organisms is reduced under waterlogged conditions, the decay rate and also the accumulation rate are controlled by the position of the water table. This marks the division between the upper unsaturated active layer of the bog, the acrotelm, based on Ingram's (1978) terminology, and the lower, permanently saturated, anaerobic zone, the catotelm (Anderson 1998). If precipitation exceeds evapotranspiration, the water table remains in the upper layers of the peat where plant material has recently been deposited and water seeps away laterally (in the zone known as the acrotelm), where decay continues aerobically to a small distance below the water table. This is known as the 'active layer' with a high hydraulic conductivity. It includes the living surface of the vegetation and is affected by a fluctuating water table (Ingram 1982). Continuing aerobic decay lower in the profile uses the majority of the available oxygen found within the saturated layers and causes the peat to become anoxic, resulting in decay by anaerobic processes. Decay is over 100 times slower in this zone compared to the upper, aerated layers (Malmer 1992). Once in this zone (the catotelm), plant remains can survive exceptionally well and additional changes only occur from compression by the overlying peat moss or changes in the water table (Belyea & Clymo 2001).

The acrotelm / catotelm boundary also marks an abrupt change in the bulk density and permeability of the peat. It can be defined as the deepest point to which the water table descends in an annual cycle (Charman 2002; Clymo 1984, 1991). Seasonal variations of the water table are contained within the upper, acrotelm layers, perhaps within only a few centimetres of the mire surface (Burt *et al* 1997). The rate of peat transfer from acrotelm to catotelm therefore largely determines the net peat accumulation (Yu *et al* 2001). Changes in humification through the peat profile can be linked with past changes in the acrotelm relating to the average height of the water table, often fluctuating in summer conditions (Anderson 1998; Yu *et al* 2001). However, autogenic changes in the internal hydrology of the bog could possibly mask these climatic changes as mires only have a limited ability to store excess water in the aerated acrotelm, although this is only believed to affect mires once the equilibrium between bog hydrology and the prevailing climate has been altered (Stoneman 1993). Sub-fossil remains preserved in the peat body can also be used to infer former mire surface wetness given their sensitivity to specific moisture gradients.

Simulation models centred on this 'layering system' have been created in order to understand the processes of peat development modelling and accumulation rates (e.g. Clymo (1978 & 1984) peat growth model; Ingram (1982) hydrological model; Kirkby *et al* (1995) peat depth based model; Almquist-Jacobsen (1995) 'mixed' model; and more recently, Bauer (2004) and Yu *et al* (2001b) ecological modelling using cumulative peat mass and age / depth profiles). Traditionally, these models have been based on raised mires, which are possibly much simpler systems than blanket mires. Yu *et al* (2001b) reviewed several of these simulation and conceptual models and these are summarised in Table 2.1 below.

Model	**Basis**	**Basic formulation**	**Assumption**	**Consequence**	**Refs.**
Clymo Model	Dynamic balance of p and α determines peat accumulation	$dM / dt = p - \alpha M$	Constant proportional decay rate, $\alpha = \alpha_C$	$M_t = (p/\alpha)(1-\exp(\alpha_C T))$; asymptotic limit to p/α_C	Clymo (1978, 1984), Clymo *et a.l* (1998)
			Linear decreasing decay rate, $\alpha = \alpha_L (m_t/m_o)$	$M_t = (p/\alpha_L)\mathrm{In}(1+\alpha_L T)$; no limit	
			Non-linear decreasing decay rate, $\alpha = \alpha_Q (m_t/m_o)^2$	$M_t = (p/\alpha_Q)((1+2\alpha_Q T)^{\frac{1}{2}}-1)$; no limit	
Hydraulic / groundwater Model	Peat hydrology and hydraulic properties determine bog shape and size	$U/K = H^2/(2Lx-x^2)$	Elliptical cross-section, saturated catotelm, water balance determining the bog dimension	Dry climate results in broader / flatter bog; maximum bog height: $H_m = L(U/K)^{\frac{1}{2}}$	Ingram (1982)
Integrated Model	Both external and internal processes determine the peat shape, accretion and expansion	$L = (p/\alpha)(2K/U)^{\frac{1}{2}}$	As above	Lateral expansion is controlled by vertical growth; peat growth and expansion rates decrease over time under stable climate	Almquist -Jacobson & Foster (1995)
Modified hydraulic Model	Net rainfall and its variability determines peatland height	$H = L\{[R-\Delta R(1-r)]/K\}^{\frac{1}{2}}$, where $r = [(\pi p_a)/\alpha_a \Delta R)]^{2/3}$	Sinusoidal variation in net rainfall and water table; the acrotelm depth determined by moisture deficit	High net rainfall (moist climate) increases the bog height; high variability in effective moisture reduces the bog height	Kirkby *et al.* (1995)

Note; M, cumulated peat mass; m, mass of particular peat parcel; p, peat addition rate; α, proportional decay rate; α_C, α_L and α_Q, decay constant for constant, linear and quadratic decay models; T, time; U, net recharge percolating down to the water table (index of effective moisture); K, hydraulic conductivity (permeability); H, height of peat bog; L, radius of bog; x, distance from bog edge; R, average net rainfall (rainfall-evapotranspiration); ΔR, half-amplitude of variation in net rainfall; P_a, biomass addition rate to the acrotelm; α_a, acrotelm peat decay rate.

Table 2.1: Summary of conceptual models for raised peat bogs (Yu *et al* 2001b, 200)

Ombrotrophic mires are associated with a set of habitats and vegetation types which reflect the morphology of the terrain, are associated with the differential development of peat in relation to slope, and the development of pools, lakes and drainage systems that dissect the bog. Atlantic bog vegetation has been classified under different titles by many workers and the most important descriptions include those developed by McVean & Ratcliffe (1962), Ratcliffe (1964), Rodwell (1991), and Daniels (1978) who applied numerical analysis to floristic data from a wide range of mire sites. Detailed floristic accounts of ombrotrophic mires have allowed different forms of bogs to be distinguished and local variants to be recognised as a result of microclimate, topography, altitude, pH and other localised factors.

Figure 2.1 shows the distribution of typical blanket peat vegetation communities across the British Isles.

Figure 2.1: UK Map showing record of NVC communities M1, M17, M18, M19 and M20 in Great Britain (see section 2.1.4 for more details). Taken from JNCC International Designations; Queens Universiy Belfast Peatland Survey (1988); Rodwell (1995); SNH Uplands Database

It is necessary to generalise about the vegetation of blanket mires across the British Isles here, as local variations do exist (Ratcliffe 1977) and the present ecology of mire sites is not a reliable indicator of their history and dominant species (Barber 1993). There are over thirty different British ombrotrophic mire communities identified in the National Vegetation Classification (see Rodwell 1991) and a link between water supply, water chemistry and species composition of peat-forming vegetation has long been recognised (e.g. Coulson &

Butterfield 1978). The National Vegetation Classification (NVC) is determined by species that are absent rather than those that are present (Crawford 2000). See Table 2.2.

NVC Code	Community Description
Deep-peat communities	
M1	*Sphagnum auriculatum* bog-pool community
M2	*Sphagnum cuspidatum / recurvum* bog pool community
M3	*Eriphorum angustifolum* bog-pool community
M17	*Scripus – Eriophorum* bog
M18	*Eriophorum – Sphagnum papillosum* bog
M19	*Calluna – Eriophorum* bog
M20	*Eriophorum vaginatum* blanket and raised mire
M21	*Narthecium ossifragum-Sphagnum papillosum* valley mire
Shallow-peat communities	
M15	*Scripus – Erica* wet heath
M16	*Ericetum* wet heath

Table 2.2: Blanket Mire communities of the NVC associated with natural / semi-natural bog surfaces (Rodwell 1991).

2.1.4 Defining blanket peat initiation

Based on the discrepancies in the record and confusion over what terminology to adopt, the term 'blanket bog initiation' requires a more precise definition. It is used here to mean the first appearance of peat above the soil, where over 85% of the material is humified (decomposed) and contains less than 20% inorganic material (Clymo 1983, Heathwaite *et al* 1993). The term initiation is different from growth: this latter term describes the ensuing accumulation of blanket peat.

2.2 *Factors Responsible for Blanket Peat Initiation in the British Isles*

This section will explore the complexity of factors in the British Isles which are often implicated in the initiation of blanket peat and which guide the development of analysis in chapters 6 to 8.

2.2.1 Suggested pathways of blanket peat initiation

The critical threshold for peat initiation is for production of organic matter to exceed decay. Decay rate is primarily a function of moisture, temperature and water chemistry (Charman 2002, 73) but the controlling mechanisms behind these are complex and difficult to separate (Barber 1981; Frenzel 1983). Peatland development is often multi-directional and has been attributed to both autogenic and allogenic processes that operate and interact over the history of the landscape (Halsey et al 1998; Hu & Davis 1995). Blanket peat initiation across the British Isles has been regarded as the consequence of one, or a combination of, factors that have produced waterlogged conditions, including: climate change towards more humid and / or cooler conditions (Moore 1986; Tallis 1991; Zoltai & Vitt 1990); anthropogenic activity (Moore 1975; 1977); soil maturation (Smith 1972; Taylor & Smith 1980; Ugolini & Mann 1979); and the effect of geology and topography (Edwards & Hirons 1982).

Across the British Isles dates for peat initiation are varied and within small geographic areas there are differences in the timing of initiation (Chambers 1981; Price 1982). As a result of paludification in a limited number of foci (water collecting sites), the spread of peat across the landscape has been protracted with different suggested controlling factors (Dimbleby 1965; Tallis 1991).

Figure 2.2 summarises the interacting influences required for peat initiation from the literature reviewed later in this chapter. There are a number of factors that will increase the amount of surface water at the time of peat initiation and a change in any one of these will affect the sensitive hydrological balance of the system. These are placed around the outside of the diagram and are often cited as being the causes of peatland development. The autogenic processes that may affect the development of blanket peat are positioned within the darker grey circle and the allogenic processes are positioned in the grey circle; these are not independent of each other. The resultant internal changes (pedological and biotic) are positioned within these.

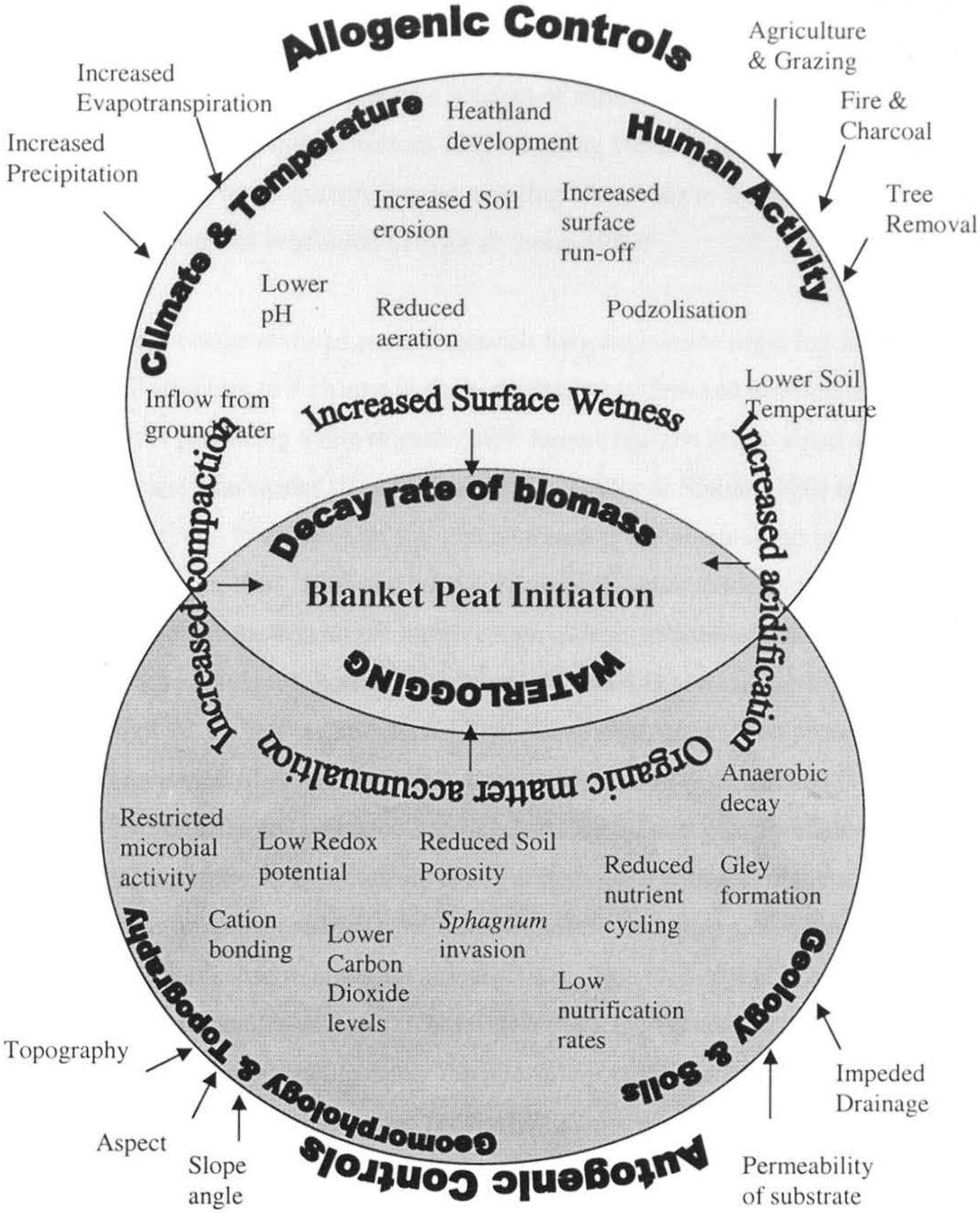


Figure 2.2: Conceptual model of the factors responsible for the initiation of blanket peat. Peat initiation is based at the centre of the model as a product of the surrounding interacting processes.

2.2.2 Pedogenic controls

Pedogenic processes result from the interaction of climate and vegetation acting on parent materials which may be modified by topography and human activity (Culletan & Gardener 1985). Blanket mire initiation may be a product of natural soil maturation on base poor soils in areas of high precipitation (Charman 1992; Bunting 1994) or may result in response to a loss of woodland cover or grazing impact, creating alterations to the soil hydrology, nutrient status, acidification and vegetation (Taylor & Smith 1980).

Freely draining, coarse-textured parent materials may experience rapid leaching following a change in soil structure or a change in the hydrological system and develop acidic, podzolised soils producing a thin organic 'mor' humus horizon above a pan with high levels of aluminium and iron oxides (Duchaufour 1982). Taylor & Smith (1980) term this 'pedogenic peat' and in many cases this can be found as the precursor to peat formation (e.g. Soulsby 1976; Tallis 1964, 1965 and 1975). Many soils show evidence of podzolisation, a process that involves the downward translocation of iron, aluminium and organic matter to form a Si-enriched eluvial E horizon overlying an illuvial B horizon, enriched in a combination of Al, Fe and organic matter (Birkeland 1999, 108). This process can occur rapidly, over a period of several hundred years (Anderson 1979). Mitchell (1972, 1976) and Moore (1975) consider podzolisation a prerequisite for blanket peat formation and Moore & Wilmott (1976) propose that pedogenic changes associated with soil maturation, namely the production of B horizons (podzols) and a consequent waterlogging of A horizons, have been responsible for blanket mire initiation at many sites. This type of soil is often associated with heathland and coniferous forest from which chelating agents and downward translocation of sesquioxides accelerate the podzolic process (Smith & Taylor 1989). Increasing acidity may also encourage further bog plants which have the potential for greater acidification and water retention (e.g. *Sphagnum*) (Foster 1984; Noble *et al* 1984) and a reduction in soil pH will affect the number of soil micro-organisms, reducing the rate of decomposition and accelerating peat development. Palaeoecological data from the Faroe Islands (Johansen 1975, 1982, 1985) and from Catta Ness, Shetland (Bennett *et al* 1992) have suggested that blanket peat initiation has been a consequence of increasing acidification of the soils. A more impermeable iron pan can also form within podzolised soils (Ball 1975), which increases water retention in the upper layers of the soil, although this process may take several thousands of years to form. This was highlighted at Lairg, Sutherland where stagnopodzol formation played a key role in the date of blanket peat formation

(McCullagh & Tipping 1998) and at sites across the west of Ireland (Doyle 1982; Lynch 1981; Mitchell 1972, 1976; O'Connell 1986). The role of human activity in producing a podzolic soil and accelerating peat accumulation has frequently been discussed (Chambers 1988; Moore 1988, 1993; Tallis 1998), although podzolisation alone may not have been solely responsible for creating an impermeable layer and triggering peat initiation as this layer is often formed on free-draining soils and is easily fractured (Birkeland 1999).

In poorly draining, fine-textured parent materials, nutrients are leached more slowly, often producing non-calcareous gleys where deformation of soil structure and constriction of pore space is liable to occur as the silt or clay fraction is redeposited (Davidson & Carter 2003; Taylor & Smith 1980). White (1987) demonstrated the effect of climate on a gleyed soil sequence in Ireland, where peaty gley soils on steep slopes were found under well-developed blanket peat (on well-drained parent material at altitudes over 300m) with thin iron pan horizons on intermediate slopes and podzols on the lower slopes. Hydromorphic soils (soils formed on impermeable parent materials) form as a result of surface saturation and remain waterlogged for long periods of time or as a result of a high water table and have been closely linked with extreme oceanic climates (Smith & Taylor 1989).

Conry (1972) and Duchaufour (1982) have demonstrated that there is a close relationship between vegetation and soil and, as already demonstrated, of soil on vegetation. The most important components of the plant litter include the nitrogen content and the water-soluble compounds present. For instance, plant litter composed of *Alnus*, *Fraxinus* and Poaceae with a C:N ratio of 25, decomposes quickly, frees a proportion of mineral nitrogen and is likely to lead to the formation of 'mull' (a soil rich in bases with little accumulation of organic matter). Litter from *Quercus* and Ericaceous plants however, with a C:N ratio of >45, decomposes slowly and forms 'humus' or 'mor' (an acidic, fibrous soil with slow decaying organic matter) from which nitrogen is not mineralised (Duchaufour 1982). Deeper rooted plants are gradually replaced by shallow rooting species, wet heath communities dominate and the biological populations of the soil become less active. Taylor & Smith (1980) describe this process as the 'primary stage of pedogenic peat'. Decomposition rates are therefore a factor of the underlying substrate as this will influence the plant species and their chemical composition, and the position of the water table is an indirect consequence (Coulson & Butterfield 1978).

Development of humus-iron podzols and gley horizons provide a basis for the development of peat. However, the geology and geomorphology together determine the topography, which must be suitable for paludification of water and restrict run-off. A combination of all these pathways is crucial in instigating peat initiation but soil and biotic factors are perhaps more important in areas less sensitive to changes in water balance as they require longer periods of time to develop.

2.2.3 Geomorphology & Topography

Peat initiation and subsequent growth have occurred at various times throughout the Holocene, depending at least in part on the topographic nature of the underlying substrate (Charman 2002; Edwards & Hirons 1982; Moore & Bellamy 1974). In section 2.2.1, the development sequence of blanket mire has been discussed with respect to the hydroseral sequence, with peat developing in deep 'foci' points. Moore & Bellamy's (1973) concept of peat development in primary, secondary and tertiary states highlights the need for an understanding of the topographical location from which samples are taken, as blanket peats are not, by definition, primary peats (those formed in basins under the influence of minerotrophic water).

Many studies of blanket peat initiation have found local topography to be a significant factor: in particular, the topographical and geomorphological variability of the landscape has resulted in major differences in the timing and spread of blanket peat initiation (e.g. Charman 1994; Foster & Fritz 1987; Tallis 1991). A review by Askew *et al* (1985) of soil development in upland Britain demonstrated a relationship between increasing acidity and soil wetness, the latter being controlled by the constant factors of topography and parent material. Early work by Tansley (1939) and Taylor (1975) set the limits for blanket peatland development on slopes of between 10-18°, but throughout Scotland (e.g. the north-west highlands) peat can be found on slopes of up to 35° (Lindsay 1995). Few studies, however, have included the effects of peatland developmental topography, the possibility that as blanket peat expands and increases in depth, local slope, aspect, hydrology and peat accumulation will also be affected (Hilbert *et al* 2000; Waddington & Roulette 1996).

Each individual blanket peat site will contain a continuum of individual profiles of different depths, reflecting variations in lithology, glacial and periglacial substrates (Smith & Taylor 1989). A variable degree of paludification and subsequent lateral spread is therefore to be expected across relatively small areas. Tallis' (1964) study of peat in the southern Pennines showed a transect down a hill side and suggested that peat began to form at different periods, highlighting a lack of synchronicity across the slope and with the current ground surface. Similarly, slope gradient will affect the timing and nature of peat accumulation and whether a site is moisture shedding or moisture receiving. On flat plateaux or concave receiving sites, changes in water table are direct and may form under the influence of climate alone. On sloping ground or convex sites, water is shed more rapidly and deterioration of the soil profile may occur prior to peat growth through deforestation, erosion and increased rainfall. In such situations, the angle of sloping ground will also affect the rate at which paludification will occur, with shallow slopes becoming waterlogged first (Charman 1992; Taylor & Smith 1980). On flat sites, lateral paludification caused by increasing precipitation may explain the absence of underlying soil profiles, and on many slopes, downwash and erosion may have removed evidence of earlier, thin soil horizons. The process of identifying older peat deposits and the nature of blanket peat spread requires the study of a number of profiles up and down slope, particularly as processes such as back-paludification, whereby peat spreads up-slope, have been recorded from several sites across Europe (e.g. Foster & Fritz 1987), and lateral paludification will have occurred on both micro- and macro-scales, within and between the main peat foci.

The geomorphological variability of pre-peat landscapes results in major differences in the time of peat initiation (Charman 2002, 77) but current peatland morphology may mask the shape of the underlying substrate. Raised bogs often demonstrate variations in age and depth from the centre of the mire outwards towards the edges (Warner *et al* 1991), whilst blanket bogs demonstrate different rates and directions of lateral expansion. For example, Foster & Fritz (1987) took several basal radiocarbon dates from a number of cores across a blanket mire in Sweden and found the expansion of peat to have occurred throughout the Holocene with peat becoming progressively younger further up slope. These results demonstrate paludification of a previously forested area through autogenically determined lateral spread of the peat.

Topography will also affect the flow of nutrients and vegetation distribution, as demonstrated by the early work of Pearsall (1950) in the North West Scottish Highlands, who described the various types of vegetation on both plateaux and valley bottoms, suggesting *Molinia – Myrica* communities are most likely to be found at slope bottoms. Similarly, as blanket peat accumulates, the surface terrain will also change as pockets of peat develop, forming uneven surface features and masking the shape of the underlying substrate, further affecting the hydrological network and the distribution of water throughout the system (Gorham 1956).

Several landscape models (Moore & Bellamy 1973; Smith & Taylor 1989; Taylor & Smith 1980) showing peat deposits, vertical profiles and hydrological conditions have tried to identify the altitudinal zonation of peat foci in British upland areas and explain the variation in peat initiation dates (often associated with climatic differences), first suggested by Durno & Romans (1969). Both models (Figures 2.3 and 2.4) show the development of peat from different positions along a topohydrological continuum. The simplistic, localised model presented by Smith & Taylor (1989), Figure 2.3, represents autogenic changes based on slope and substrate. The cross-sectional model proposed by Taylor & Smith (1980), Figure 2.4, covering the British Isles and Ireland, goes some way to exploring the allogenic changes experienced at various altitudes but presumes 'climatic' peat is only produced between 610m OD and 457m OD. These conceptual models remain general and do not take into consideration local impacts such as human activity, aspect, underlying substrate, peat depth and local climate regimes and the weighting of each of these factors is likely to vary over space and time.

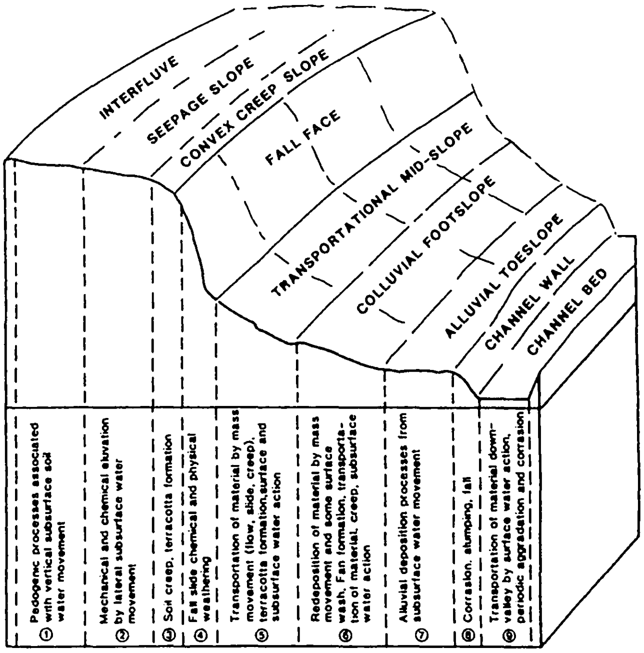


Figure 2.3: Landscape model relating soils and hydrological conditions (from Smith & Taylor 1989, 5)

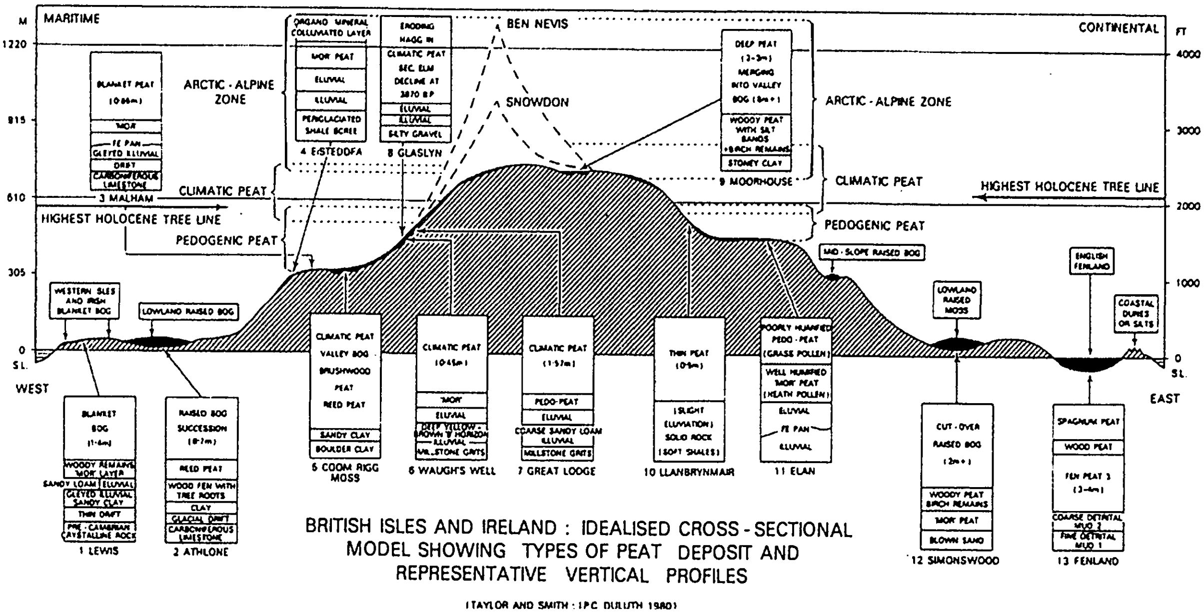


Figure 2.4: The British Isles and Ireland: an idealised cross sectional model showing types of peat deposit and representative vertical profiles (from Taylor & Smith 1980, 110)

It would appear that the various factors that promote peat growth are well understood, but the factors which directly trigger the process of initiation are more difficult to separate from those that merely perpetuate the system. For example, climate is an important element in peat formation but the impact of increased precipitation will be influenced by topography and soil porosity in determining the start and rate of peat growth. These complex factors will be considered in isolation for the initiation and spread of blanket peat at Lagafater, south-west Scotland.

2.2.4 Hydrological Variability

The process of paludification is a necessary precursor to the colonisation of wetland taxa, the preservation of remains through waterlogging and the development of peat (Smith & Taylor 1989). Water surplus is therefore a function of both precipitation and evapotranspiration which in turn is affected by solar radiation and temperature as well as wind speed, aspect and altitude. For blanket bogs, the main exchanges of water are with the atmosphere and are seasonally variable, with most recharge of the peatland taking place during winter (Charman 2002). The discharge of run-off water is closely associated with the water table and, as demonstrated by Evans *et al* (1999), discharge is greatest when the water table has risen to

5cm below the surface. As water input decreases, as may occur with reduced precipitation or surface gradient increase, the water table may fall into peat of lower hydraulic conductivity and increase the acrotelm thickness (Belyea & Malmer 2004). Reduction of the water table generally results in physical compaction and increased decomposition (Maltby 1997).

On flat terrain, blanket bogs may have ombrotrophic domes but lack the laggs typical of raised mires (Osvald 1949). The surface of the bog is often uneven in character, and consists of small hollows alternating with ridges and hummocks; these are, however, poorly defined compared to hummock / hollow sequences characteristic of other European bogs (Doyle 1997, 26). Blanket bogs are often drained by shallow surface runnels which feed into drainage channels that dissect the blanket peat to varying depths and along which micro-sites develop, receiving varying quantities of nutrients depending on the concentration and rate of surface water flow (Doyle 1997, 26; Moore *et al* 1994). Blanket bogs can also be drained by subterranean systems that are fed through vertical shafts called swallow holes (Doyle 1997, 26).

Landform position and water chemistry define the character of mires and are a direct consequence of hydrology (Ingram 1978; Ivanov 1981). Principal inputs into ombrotrophic mires are from precipitation, surface run-off from surrounding slopes, or from groundwater upwellings. Outflows from the system are predominantly from run-off (infiltration-excess overland flow or saturation-excess overland flow), seepage or from interception and evapotranspiration (Charman 2002), particularly around the margins of the peat mass or within the peat, as pipe flow or lateral seepage through the acrotelm (Holden & Burt 2003; Ingram 1983; Tallis 1998).

The relationship between water table depth, vegetation and hydraulic conductivity is important. Many studies have reported higher rates of groundwater flow in poorly decomposed litter near the peat surface and low hydraulic conductivity from peat layers below 40cm depth (e.g. Dasberg & Neuman 1977; Ingram 1967), and it has been assumed that lower peat layers are less important sources of discharge as a result of peat thickness (Holden 2003). Indeed, a number of traditional water-balance models exist based on groundwater flow through the acrotelm-catotelm, lateral seepage and water balance movements, particularly for raised mires (e.g. Ingram 1982, 1983; Kirkby *et al* 1995). These models lack representation of near-surface conditions, do not consider lateral and vertical differences in hydraulic conductivity, particularly within blanket mire regimes and do not consider the spatial structuring of hydraulic peat properties or infiltration (Baird 1995; MacAlister & Parkin 1999). Hydrological processes in blanket peats remain poorly understood. Recent research into run-off production in blanket peat-covered catchments (Holden 2003) has, however, demonstrated that approximately 81% of overland flow occurs at the peat surface, with 17.7% between the surface and 5cm depth, and throughflow below 10cm of peat is in fact an insignificant component of run-off production. However, there is a strong link between topography, preferential flow paths and production of run-off. On steeper slopes more flow seems to occur within the upper 10cm of peat rather than at the surface but on gentle slopes, overland flow at the surface appears to dominate (Holden & Burt 2003). As steeper slopes drain, return flow (water returning to the surface from within the peat) is produced on gentler slopes often causing saturation-excess overland flow. Surface cover, topography and preferential flow paths are important factors in controlling infiltration (macropore flow) and run-off production today (Holden & Burt 2003): these factors will therefore have also been important in the initiation of blanket peats and the relative rates of peat accumulation, and will be considered further in chapter 6.

The rate at which water moves through the peatland system is also a function of water pressure and the density / composition of the peat matrix as well as regional geology (Charman 2002). Dense peat with small pore spaces has low hydraulic conductivity and water movement is impeded. This is a result of the botanical composition of the bog and the rate of decomposition. Overall, *Sphagnum* peats (typically oceanic peats) have low permeability with more homogenous structure while peats composed of higher plants such as *Carex* and *Phragmites* are more permeable (Ingram 1983).

Identifying synchronous changes in hydrology across the mire is important for palaeoecological studies. There are two possible causes which could change the hydrology of the mire system: (a) regional climatic change and / or intensive anthropogenic activity; and at a smaller scale, (b) impeded or accelerated drainage due to morphological development. The lateral expansion of the mire will lead to changes in the surface gradient and affect surface run-off.

2.2.5 Climatic Controls

It has been shown that proxy climatic data can be inferred from late Holocene peat stratigraphy (Barber 1981; Blackford 1993, 2000; Buckland *et al* 1994, Chambers 1994, Charman 1994). The autochthonous nature of peat means that material is accumulated sequentially and contains a detailed record of local and regional vegetation change, climate change and a complex record of carbon accumulation (Chambers *et al* 2004).

Inferred changes in the hydrological status of peatlands have been used as a proxy indicator of climatic change throughout the Holocene for many years (Charman *et al* 2001), particularly in ombrotrophic mires. Early ideas of a variable climate over the last 12,000 years were based on pioneer stratigraphical peat studies in Scandinavia, where periods of 'continental' and 'oceanic' climates were identified and used to subdivide the post-glacial period in north-western Europe (Blytt 1776; Sernander 1908). For a more detailed review of this early work see Barber (1985) and Blackford (1993). Shortcomings in this scheme, however, were exposed by Smith & Pilcher (1973) and Barber (1978, 1981), and subsequently led to a call for its simplistic concepts to be abandoned. Many authors have more recently shown the close and more complex relationship between peat growth and climatic change (e.g. Aaby & Tauber 1975; Barber 1982; Blackford & Chambers 1991).

High precision proxy climatic records have been obtained from sensitive sites over the last 25 years across Britain and Europe. Peat based palaeoclimatic reconstructions from different mires, e.g. Bolton Fell Moss (Cumbria), Abbeyknockmoy Bog (Co. Galway, Ireland) and Svanemose (Jutland, Denmark), have shown spatial and temporal variability of climate change (Barber *et al* 1994), recording different dates for periods of wet and dry phases (see Table 3.1). Systematic methods of quantitative macro- and microfossil analysis and methods of peat humification (e.g. Anderson 1998; Anderson *et al* 1998; Blackford & Chambers 1991, 1993; Hughes *et al* 2000; Rowell & Turner 1985) have been used to reconstruct climatic changes across northern Britain at the site, inter-site and regional level (Chambers & Charman 2004, Langdon *et al* 2004). Through the application of refined techniques and correspondence analyses, more sophisticated indicators of mire wetness are being applied and more detailed and site based localised changes have been identified (Barber *at al* 1994, 2000; Barber 1995; Blackford 1993; Chambers *et al* 1997; Woodland *et al* 1998).

Early peat based palaeoenvironmental work was obtained from data collected from raised mires across north-west Europe (e.g. Aaby 1976; Aaby & Tauber 1975; Barber 1981; Barber *et al* 1994; Dupont 1985; Dupont & Brenninkneijer 1984; Haslam 1987; Stoneman 1993). Research involving the extraction of environmental data from blanket mires, however, has been slower to develop. Early work concentrated on sites in western Ireland (Pearsall &

Lind 1941; Godwin 1981) and in the northern Pennines (Pearsall 1941; Rowell & Turner 1986). Misconceived ideas concerning the uniform development and stratigraphy of blanket mires, their insensitivity to climate change and little knowledge of the range of macrofossils available for identification has meant that only since the 1980's have blanket mires been used in climatic reconstruction. For example, Blackford (1990), Blackford & Chambers (1991, 1993), Chambers (1984, 1991), Tallis (1995) and Chambers *et al* (1997) have shown climate change on a decade to century scale. Recent research using colorimetric changes in humification from blanket mires, measuring the concentration of humic acids and the extent to which peat has decomposed, has yielded valuable climatic data and has been used to identify changes across hydrologically unrelated sites implying a climatic cause. Raised mires and water-shedding parts of blanket mires are most suited for this method as these are the locations where changes in surface wetness will be most directly linked to changes in precipitation and evaporation (Blackford 1990; Haslam 1987).

There is much speculation regarding the causes of climatic variability, with evidence suggesting periodicities in the Earth's climate of the order 10^1 to 10^3 years (Chambers *et al* 1999). Recent research has suggested solar forcing (Blackford & Chambers 1995, van Geel *et al* 1996, 1998, 1999; Magny 1993; Stuiver *et al* 1998) and Ice rafted Debris (IRD) events in the North Atlantic (Anderson 1998) as possible causes. Changes in deep ocean circulation (Lamb *et al* 1995) and short term catastrophic events (e.g. volcanic events) are also considered important climate forcing mechanisms (Bradley & Jones 1993, Chambers *et al* 1999). The relative importance and interplay of these factors remains poorly understood (Rind & Overpeck 1993; Stuiver *et al* 1995). To establish the existence of solar driven (decadal and centennial) changes of climatic change, chronologies with greater precision are required (Blaauw *et al* 2004).

Within Britain and Ireland, blanket bogs typically occupy upland environments subjected to oceanic climates and inter-montane valleys along the Atlantic seaboard, and are notable features in western and northern areas (Doyle 1997, 25; Lindsay 1995, 103). Their distribution has also been influenced by Holocene sea-level rise, glacial history and the impact of human activity (Taylor 1983).

The relative importance of climate in controlling paludification rates is, however, unclear. Mäkilä (1997) and Anderson *et al* (2003) found little correlation between the intensity of lateral expansion and regional climate, but Korhola (1995) and Almquist-Jacobsen & Foster

(1995) found a correlation with wetter periods inferred from lake deposits and increased paludification. Separating the processes and effects of terrestrialisation, hydroseral succession and eventual paludification is also difficult with autogenic and regional climatic factors at work (Charman 2002).

A climate driven moisture signal will, however, be preserved in mires receiving moisture solely as rainfall and different bogs have shown different sensitivities to climate change (Barber *et al* 2000; Chiverrell 2001; Hendon *et al* 2001). In particular, those ombrotrophic mires that do not experience a summer water deficit may be more sensitive to recording palaeoclimatic changes (Mauquoy & Barber 2002).

2.2.6 Anthropogenic impacts

Evidence from pollen and charcoal sequences have led many authors to suggest that Mesolithic human activity occurred at the time of blanket peat initiation throughout Scotland (e.g. Bohncke 1988; Edwards 1996; Hirons & Edwards 1990; Newell 1988) and the British Isles (e.g. Moore 1975; Case *et al* 1969; Tallis 1991; Taylor & Smith 1980), where differences in topography and altitude alone cannot explain the range and dates of peat initiation. As a consequence of hydrological change through deforestation and early management of heathlands through burning (Bostock 1980), the accumulation of water is enhanced and soil degradation ensues. Experiments have shown that run-off increase by as much as 40% after clear felling of deciduous woodland and this can lead to the gleying and podzolisation of soils and the appearance of wet loving plant taxa such as *Filipendula* and *Caltha* (Simmons 1996, 114). At Lairg, Caithness, a change in the hydrological balance caused by deforestation in the later prehistoric era allowed stagnopodzol formation and the eventual onset of blanket peat (McCullagh & Tipping 1998). Similarly, the long term effect of burning is to reduce pore spaces in the surface layers of the soil, reducing permeability and lowering nutrient reserves (Mallik *et al* 1984).

Where former cultivated land lies beneath blanket peat, a causal relationship between prehistoric activity and peat initiation may exist. This has been demonstrated in Northern Ireland (Case *et al* 1969) and at Callanish, Isle of Lewis (Bohncke 1988; Johnson *et al* 2005). Grazing and trampling may also accelerate peat growth (Smith *et al* 1981), reducing infiltration by up to 80% and accelerating paludification (Smith & Taylor 1989).

Episodes of substantial forest clearance and blanket peat initiation have also been recorded throughout the Neolithic and Bronze Age periods and have been linked with an increase in clay movement downslope, soil erosion, and the depletion of more marginal soils associated with increased forest clearance (Keeley 1982; Limbrey 1975).

2.2.7 Anthropogenic Controls V Climate Controls

There is a lengthy history of debate as to the whether peat initiation was a natural phenomenon, occurring due to a strong oceanic climate, or whether it was due to human activity as outlined above, or how the two interacted.

Early work on blanket peat initiation often cited the climate as being the cause for this phenomenon (Godwin 1956, Moore 1968), believing early agricultural activity prior to c.6000 cal BP would have had little impact on the local hydrology and landscape, although this view has now been refuted (Simmons 1996, 2003). In the Pennines, northern England, for example, Conway (1954) dated peat growth to 7500 BP and 5000 BP during the 'Atlantic' period when conditions are thought to have been wetter and warmer than present. Similarly, Tansley (1939), Tallis (1964) and Turner *et al* (1973) considered blanket peat of the Pennines and Wicklow Mountains to have formed in the early part of the Holocene. Durno & Romans (1969) suggested that ombrogenous blanket peat in Scotland and northern England was climatically induced and Godwin (1975) noted that Irish blanket peat originated in the late Bronze Age during a period of climatic change. At several individual sites across the Pennines, peat initiation began in the early Holocene (Conway 1954; Hicks 1971; Simmons & Candill 1974; Tallis 1964) at the same time as peat began to develop in the Cairngorms, Scotland (Durno & McVean 1959). It was believed that this blanket peat formed under a regime of high precipitation / low evaporation ratio and was originally termed 'climatic peat' (Tansley 1939; Taylor & Smith 1972). Similarly, sites at Broad Amicombe Hole, Dorset (Maguire 1983) have been climatically induced where an increase in climatic wetness alone has been responsible for peat initiation, along with sites at Bolton Fell Moss, northern England; Mongan Bog, central Ireland; Abbeyknockmoy Bog, western Ireland (Barber *et al* 2003) and elsewhere in Europe at Sør Trondelag, central Norway (Solem 1986) and at Haramsøy, western Norway (Solem 1989).

The prevailing climatic conditions in the early Holocene have been argued to have been too dry for widespread peat development (Taylor 1975). Peat accumulation however, did begin at some sites early in the Holocene, often replacing organic-rich lacustrine sediments before c.9500 BP. Although little evidence for this now exists, this early infilling of basins may have provided the foci for later blanket peat development across the surrounding landscape. Typically, the Holocene is viewed as having several episodes of climatic warming and cooling that may have had a direct effect on peat initiation. A change to a wetter climate about 8000-7500 BP, for example, (Taylor 1975; Smith & Taylor 1989) has been seen as the trigger for more widespread peat initiation on flatter ground above 200m OD, but the majority of north-west European blanket bogs appear to have developed between 5000-4000 BP (Davis 1984). However, more recent studies have found this to be an over simplistic view and a number of interacting factors beginning as early as the Mesolithic period have contributed to the development of blanket peat (see this study). A marked change in climate during the Bronze Age is also documented and many authors have cited this as the reason for changes in the archaeological and environmental records (Burgess 1985; Frenzel 1966; van Geel *et al* 1996, 1998a, 1998b; Huang 2002; Pennington 1969).

Climate change has been seen as a cause of blanket peat initiation but the variety and number of reliably dated peat profiles and dates for the onset of blanket peat formation that now exist are at odds with a purely climatic explanation (Chambers 1981, 1983; Simmons 1969; Taylor 1988). Peat formation, for instance, began in the Southern Pennines by 7500 BP but only began in mid-Wales and western Ireland at c.4000 cal. BP, where a more oceanic climate existed (Tallis 1991). This diachronism however, may simply indicate that climatic changes impacted on different areas at different times but it is also possible that the causality of hydrological and vegetational changes become more complex, particularly during the mid to late Holocene, when humans were active in the landscape (Bunting 1994).

As further data from pollen diagrams and basal peat dates became available, anthropogenic impacts were implicated as the main trigger for peatland development, often being associated with the *Ulmus* decline in the early Neolithic (e.g. Moore 1973, 1975; Merryfield & Moore 1974). Pollen evidence from blanket bogs in upland Wales, for example, highlighted a series of woodland clearances with phases of re-growth and the eventual dominance of *Sphagnum* peat. Archaeological data supported the idea of human intervention and the clearance of the woodland, suggesting that their impact *caused* the development of peat (Charman 2002; Smith & Taylor 1989). Goddard (1971) examined the vegetation changes associated with blanket peat initiation in north-east Ireland and concluded that deforestation at c.3800 cal. BP, c.3200 cal. BP and c.2800 cal. BP caused severe soil degradation and led to the establishment of blanket bog conditions. Peat initiation has also occurred on abandoned cultivated surfaces (Case *et al* 1969; Mitchell 1972) and grazing pressure may have accelerated the growth of peat (Smith *et al* 1981). Various authors believe that as early as the Mesolithic, forested areas were cleared and the vegetation modified: evidence has been obtained from the Lake District (Pennington 1969, 1975; Walker 1966), Dartmoor (Simmons 1969; Caseldine & Maguire 1981, 1986; Caseldine & Hatton 1993), South Wales (Smith & Cloutman 1988; Chambers 1988), North Yorkshire (Smith & Taylor 1989; Simmons & Innes 1981, 1987; Simmons 1993, 1996), across the Pennines (Jacobi *et al* 1976; Williams 1985; Tallis & Switsur 1990; Tallis 1991; Moore 1982; Honeyman 1985), Caithness (Robinson 1987), Orkney (Bunting 1996; Blackford & Edwards 1996) and the Isle of Arran (Robinson 1983).

Throughout Northern Scotland and across upland areas, *Calluna* dominated heathland communities in association with high but decreasing values of hazel pollen, and increased pollen / spore values of open ground plants such as Poaceae and *Pteridium* increased after c.5000 cal. BP (e.g. Bennett *et al* 1990; Edwards & Moss 1993; Fossitt 1990). More recently, blanket peat initiation has been linked to lower altitudes where progressive soil deterioration through over grazing and felling may have been responsible (Smith & Taylor 1989; Moore 1993) and peat initiation began after a period of cultivation and subsequent abandonment. This has been seen at sites such as stone field walls, burial mounds and megaliths of typically Neolithic or Bronze Age (c 4900-2500 cal. BP): for example, in the Outer Hebrides (Flitcroft *et al* 2002; Mills *et al* 1994; Newell 1988), Shetland (Edwards & Whittington 1994; Whittington 1977; Whittle *et al* 1986) and northern and western Ireland (Caulfield 1978, 1983; O'Connell 1986; Pilcher & Smith 1979; Smith *et al* 1981). In Derbyshire, Hicks (1971) reported soil degeneration following Iron Age and Roman forest clearances and Crompton (1966) and Chambers (1980) have reported that the major expansion of blanket mire across upland south Wales occurred during the post-Roman and pre-Mediaeval era.

In the west of Ireland, blanket peat expansion has been closely linked with Neolithic activity. Caulfield (1978; 1983) detailed the spread of blanket peat during the Neolithic and Bronze Age at Belderg, north Mayo, and discovered pine stumps preserved within the peat, dating to 4220 BP, 3835 BP and 3200 BP respectively, indicative of peat development at different rates within a small geographic area.

The idea that human impact occurred briefly and was a one-off event has been refuted by several authors (e.g. Chambers 1981, 1982; Smith & Cloutman 1988; Tallis 1975). The combined effects of grazing, regular burning and deforestation at different intensities have all been cited as resulting in mire initiation both in the British Isles and elsewhere: e.g. western Norway (Solem 1989; Kaland 1979, 1986) and in the Krkonoše Mountains, Czech Republic (Speranza *et al* 2000). In other areas, the timing of blanket peat initiation has been variable, spreading from 8000 to 4000 BP, and periods of forest growth were noted after the development of peat (Smith & Cloutman 1988). Many of the basal peats, particularly from sites across Wales at Waun-Fignen-Felen and Trum Felen, contained large quantities of charcoal, and peat growth was seen as resulting from the use of fire to clear areas of woodland which continued for some time as an on-going process (e.g. Bostock 1980; Smith & Cloutman 1988). The addition of charcoal to a soil effectively reduces the porosity by addition of carbon particles to the minerogenic component and the soil becomes impermeable, reducing by up to 74% the infiltration of water into the soil (Mallik *et al* 1984). Increased fire frequency appears to have contributed to the initiation of the Aukhorn Peat Mounds in Caithness (Robinson 1986) and the initiation of blanket peat at Letterfrack, Connemara, Ireland (O'Connell 1990) and on Dartmoor (Caseldine & Hatton 1993). Charman (1992), who examined the basal peats from four sites at Cross Lochs, Sutherland, however, was unable to demonstrate any single factor that was responsible for peat initiation but the presence of charred remains suggested anthropogenic burning of the birch woodland was ultimately an influencing force. Charcoal remains are frequent from the base of blanket peat profiles and whilst they may represent early human activity associated with a lowering of the tree line, coeval with peat initiation, their presence may also represent a residual build up from the degradation of surrounding peat and can have widely different sources (Clark 1988; Edwards 1990; Smith & Taylor 1989).

The change in the hydrological balance as a consequence of deforestation or the gradual reduction in woodland would have been great: reduced interception of rainwater, increased run-off downslope, loss of fertility by leaching, structural deterioration following acidification, and impedance of drainage by podzolisation and surface gleying. This situation may have been worsened by reduced infiltration capacity of the soil following compaction by grazing animals and fine charcoal particulates after fire (Tallis 1998). This situation was identified at Lairg, Sutherland, where soil disturbance eventually led to the initiation of blanket peat after 2000 cal BC following intensive cultivation, but in fact semi-permanently delayed the process through continued activity (McCullagh & Tipping 1998, 155). Smith & Taylor (1969) have also suggested that blanket peat development in northern Cardiganshire, Wales, on the slopes marginal to the moorland areas, was delayed as a result of human exploitation. The development of a grazed sward immediately following deforestation in the Neolithic promoted the development of a mull or intermediate humus and the process of podzolisation was delayed.

The Moore (1975, 1993) hydrological model (Figure 2.5) is based on the interaction of predominantly human activity leading to waterlogging and the creation of a mire ecosystem and peat formation, which assumes the removal of forest cover or shrub dominated vegetation and a progressive change. These findings are based on pollen evidence from beneath blanket peat at several sites across Wales, e.g. Carneddau Hengwm, North Wales (Moore 1973). The initial peat forming vegetation from other sites however, suggest that woodland cover was not initially present, e.g. at Kentra Moss, north-west Scotland (Ellis & Tallis 2000) where high values of *Potentilla* and *Poaceae* are present, and on the Isle of Lewis, Outer Hebrides (Newell 1988). Evidence in the pollen record, however, suggests that some human activity by burning or grazing may have hastened the transition from a minerotrophic to an ombrotrophic bog in an otherwise climatic situation.

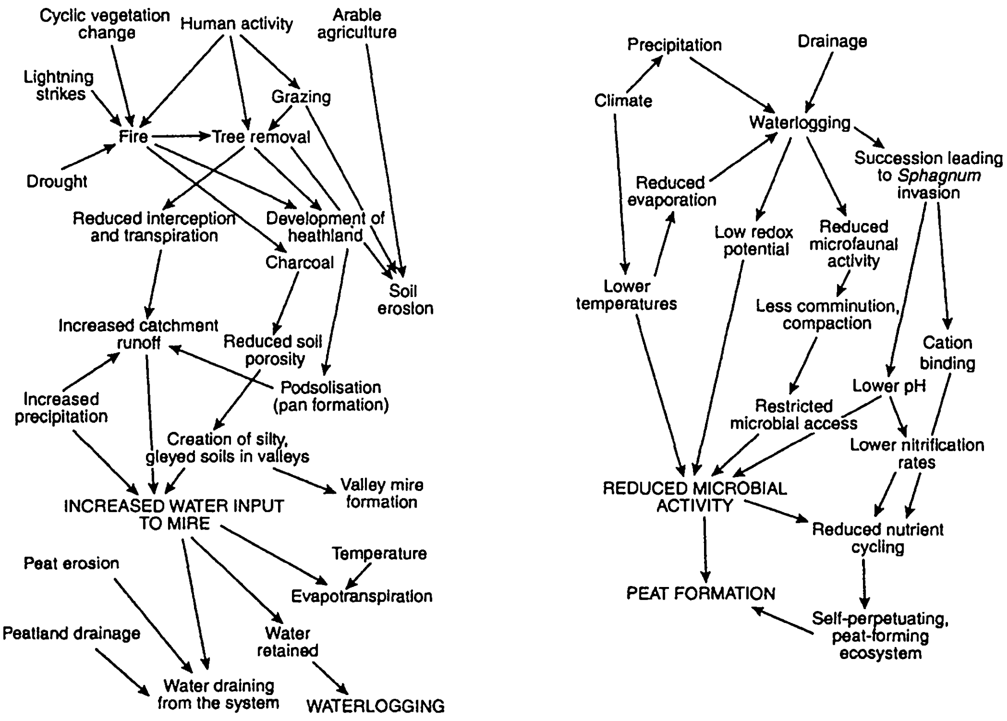


Figure 2.5: (a) Factors responsible for waterlogging in mires, with particular reference to anthropogenic activity and (b) consequences of waterlogging on peat formation. Redrawn from Moore (1993).

2.2.8 Regional Synthesis

It is difficult to identify the cause and effects of blanket peat initiation from single sites. To assess the primary *cause* for initiation it is necessary to correlate regional evidence to identify broad spatial and temporal patterns that may highlight the impact of climatic change. The secondary *effect* of human activity in response to this change may then have accelerated the process of peat development in more localised areas and an association between the two impacts can be discerned. Tallis (1991) grouped together a number of sites from northern England and summarised their basal peat ages. He found that a wetter climate c. 7500 – 7000 BP was important in early peat initiation. In more oceanic regions of the British Isles, where the climatic limits of blanket peat are approached, their initiation becomes more dependent on other factors such as human activity (Moore *et al* 1984). O'Connell (1990) proposed for Ireland that a clustering of dates for the initiation of blanket peat implies control factors such as climate or the expansion of farming but a spread of dates may suggest that more local factors such as hydrology and edaphic factors are involved. Several authors have postulated that following clearance of vegetation and / or high grazing pressure, a deteriorating climate and the acidification of surface mineral soil horizons ultimately led to peat initiation (Keating & Dickinson 1979; Lynch 1981; Cruickshank & Cruickshank 1981), and climatic change alone might not have been sufficient to destabilise the forest cover or prevailing vegetation but fire, grazing of animals and felling was ultimately responsible (Moore 1973, 1975, 1993).

Given the other factors of climate and natural soil deterioration at a time of increased human activity, separating natural and human causes becomes more difficult and a multi-causal explanation must be most appropriate (Moore 1993). Regional, topographic and altitudinal meta-chroneity is to be expected which will reflect the different intensities of anthropogenic activity and will also reflect the nature of peat spread across the landscape. As demonstrated by Smith & Taylor (1989), Chapman (1964) and Smith & Cloutman (1988), fine interval sampling across undulating topography has shown that deeper, older sediment records within late glacial basins are in contrast to blanket peats taken from sites on slopes with shallower peats and those at the base of slopes. Ombrotrophic peat appears to form at key 'centres', and following the hydroseral succession, then extends over the landscape, often following a shift in local hydrological conditions. The pre-peat record at each of these points is different, representing peat development at different stages of the blanketing process and lateral spread of peat. Blanket peat initiation should therefore be considered with respect to slope, aspect and morphology of the ground over which it has formed (Moore 1993) (and these aspects are considered at Lagafater, south-west Scotland.)

2.3 Defining the ages of Scottish blanket peat inception

2.3.1 The radiocarbon dating of peat initiation

It is difficult to precisely compare dates for the initiation of blanket peat across the British Isles (see section 2. 3.2). Edwards & Hirons (1982) warn against comparing apparent ages of basal peat deposits in order to make inferences about blanket peat initiation, as the nature of the sediment dated is not always noted and it is not clear what has been sampled. Tallis (1998, 1991) discusses this problem and suggests wherever possible dates from basal ombrogenous peat should be used rather than from underlying highly humified mor humus or wood peat. Similarly, Caseldine & Maguire (1986), Chambers (1981), Pilcher & Smith (1979) and Solem (1986) agree that the soil / peat transition provides the basis for dating initiation, although Matthews (1993) highlights the problems of residence time in organic matter within organic soils. Maguire (1983) and Taylor & Smith (1980) suggest that this boundary is easy to identify where peat changes from a 'non discrete' form to a 'discrete' one and Chambers (1981) and Smith & Taylor (1989) suggest the point of initiation is where peat-forming flora succeeds the pre-peat mineral soil.

It is difficult to distinguish between the basal peat layer and an underlying humic soil horizon by eye alone but a combination of topographical studies, pollen analyses, humification and measurement of organic content (here over 85%), should indicate the change into true ombrotrophic conditions and the nature of peat growth. This methodology has been employed in this study. Moore *et al* (1984) also suggest examining a wide range of dates from one area to search for a clustering of dates from topographically comparable sites in order to determine the roles of various factors that are implicated in peat initiation.

Radiocarbon dating of different blanket peat fractions is also problematic (see also section 4.6.4). Fine particles of plant material (e.g. *Sphagnum* or other moss leaves) have been used as they are 'fixed' within the profile and their lack of roots means they cannot translocate old carbon (Charman 2002). However, well-decomposed blanket peat contains few macrofossils and errors may be experienced from depositional processes. Similarly, ^{14}C of plant material dates the age of the plant and not necessarily the date it became included within the blanket peat. Traditionally, fulvic acids and humic acids have been dated from bulk peat samples. Fulvic acid typically produces age estimates younger than the horizon of accumulation being dated, as they are highly mobile and can be leached easily (Dresser 1970; Shore *et al* 1995). Humin and humic acid fractions are also problematic as downward penetration of roots, particularly *Eriphorum* spp., introduces humin and humic acids that are younger than the horizon being dated (Pilcher 1991). Differences in radiocarbon dates from chronologically sequenced samples have been experienced from May Moss, north-east England (Chiverrell 2001). The differences were encountered between ^{14}C dates from bulk samples and *Sphagnum* remains and were explained through site heterogeneity.

Investigations into the different pre-treatments of blanket peat samples (for example, sieving to remove larger roots and acid washing to remove carbonates) do not appear to have a consistent relationship on ^{14}C ages (Shore *et al* 1995) but accumulation rates will affect dating. When accumulation rates are slow, more years will be represented per cm sample and it becomes more important to extract a thin sample; this is often difficult given the fibrous nature of blanket peat (Hanna 1993; Tipping 1994). A sequence of high precision radiocarbon dates throughout the peat profile, coupled with measurements of dry bulk density and humification, will therefore allow age-depth to be determined and assess more accurately the accumulation rate of the mire.

Kilian *et al*'s (1995) high resolution Accelerator Mass Spectrometer (AMS) ^{14}C dates of plant macrofossils from raised bog deposits at Engbertsdiijksveen, Netherlands, highlighted several sources of ^{14}C variation for mire deposits, in particular a 'reservoir effect' which can make bulk samples appear older by some 100-250 years. This is created by old carbon dioxide emitted from within the peat (at depth) and being fixed by plants growing on the surface. These problems are exacerbated further by errors introduced by the effects of calibrating the age estimates to produce comparable calendar years (Blackford 2000). Kilian *et al* (1995) therefore proposed 'wiggle matching' for estimates of peat age using high precision radiocarbon dates (one SD $< \pm 30$ years) through peat sequences. The results are then cross-matched (a non-linear relationship) with the decadal ^{14}C curve obtained from tree-ring sequences to obtain a precise age estimate. Other more accurate means of correlating peat sequences is through the identification of fixed points where tephra is identified (Blackford *et al* 1992; Dugmore 1989; Dugmore *et al* 1995; Pilcher & Hall 1996). These geochemically distinct isochrones provide accurate and precise dating horizons and have been found preserved within blanket peat across the British Isles (Hall & Pilcher 2002; see also section 4.6.6).

To summarise, when making inferences from radiocarbon dates with regards to peat initiation, the following must be taken into account:

- A precise definition of the term 'blanket peat initiation' must be made before comparing dates from across the site. Here it is a transition to peat containing over 85% organic matter.
- The nature of the sub-peat topography must be determined in order to ensure accurate sampling of true blanket peat.
- Several sites from within one area must be investigated in order to understand the nature and timing of the spread of local blanket peat. A series of radiocarbon dates per site are needed to encompass any variations.
- High precision radiocarbon dates should be obtained and these should be used in conjunction with 'wiggle matching' and / or the identification of tephra layers to improve precise age estimates.

2.3.2 Dating British Blanket Peat Initiation

Moore (1975) found a correlation between the peat-soil interface and the *Ulmus* decline shown in pollen diagrams from British peat profiles at c. 5000 cal. BP (the traditional Atlantic/Sub-Boreal transition) and believed this was a reliable guide to dating the initiation of peat, although the possibility of two *Ulmus* declines and the time transgressive nature of some of the boundaries has also been noted (Smith & Pilcher 1973). For example, at Rishworth Moor, Yorkshire, Bartley (1964) found a basal *Ulmus* decline which he later dated at c.6600-5900 cal. BP. The assumption that this was a synchronous event across Britain, however, was disputed by Smith & Taylor (1973), Taylor (1980) and Chambers (1981) as more dates became available. The subsequent spread of dates for peat initiation at both a regional, intra-regional and topographical scale has now supported the view of an asynchronous *Ulmus* decline.

Prior to the advent of multiple radiocarbon dated sequences, key pollen zones were used to pinpoint the timing of peat initiation. For example, blanket peat in the Beinn Eighe region of western Scotland (Durno & McVean 1959) and Bigholm Burn (Moar 1969) was believed to have developed prior to the *Alnus* rise, dated at c.6440-6180 cal. BP at Loch Maree (Birks

1975) and post-dating c.7700-7150 cal. BP at Loch Clair to the south-east (Pennington *et al* 1972). Similarly, pine stumps preserved within blanket peat that are located at or near the mineral soil / peat interface have been used to date peat initiation. Birks (1975) found analogous dates for pine stumps in blanket peats across Scotland (7471 to 7165 BP) and linked the subsequent spread of blanket peat to an increasingly wetter climate.

Many studies have been interested in the growth rates and development of peat and the age of initiation has been dated approximately through isolated radiocarbon dates or pollen-related stratigraphic correlations. The timing of this complex phenomenon is therefore little understood both at a local and national level, particularly across Scotland. An article by Tallis (1991), concerned with the expansion of moorland, cited no Scottish examples, and it is only in the last decade that our interests have turned in particular to the northern and central regions of Scotland and to the more exposed islands off the west coast (e.g. Bunting 1996, Charman 1992).

As this chapter has demonstrated, a mix of climatic, pedogenic, hydrological and anthropogenic processes have led to peat initiation which ultimately has covered large areas of the Scottish landscape. The available dates for assessing peat spread are difficult to evaluate as a result of a lack of sub-peat surveys to assess the topographic origins of the peat (Edwards & Hirons 1982; Tipping 1995), confusion over dating material (no standard for measuring 'true' blanket peat), and a series of single site dates.

Table 2.3 summarises the published dates for blanket peat initiation across the British Isles and Ireland. All of these dates are based on radiocarbon determinations and are taken from basal ombrogenous peat, rather then underlying minerotrophic deposits, mor or wood peat. The total time span for blanket peat spread across the British Isles and Ireland is from 9900 BP to 800 BP. A survey of the dates for blanket peat initiation in Ireland showed dates covering the period between 4500-1000 BP (Edwards 1985; Lynch 1981). Surveys of blanket peat around the Round Loch of Glenhead (Jones 1987) suggested basal peats began accumulating at 9000 BP in the west of Scotland but lateral expansion did not begin until after 5000 BP and is a mid to late Holocene phenomenon. To date, there has been no collation of dates for Scotland although a wide spread from individual sites is indicated in Table 2.3.

Peat formation was in progress much earlier in the Southern Pennines than in other upland areas of England and Wales (Tallis 1991) with the exception of some sites in Cumbria (e.g. Walton Moss). In the Southern Pennines (e.g. Robinsons Moss, Featherbed Moss and Tintwistle High Moss) discrete episodes of peat initiation can be recognised, when peat extended to lower altitudes; c. 7500-6000, 5500-4500 and 4000-3600 cal. BP (Tallis 1998). Figure 2.6 shows the cumulative plot of 190 radiocarbon dates from basal blanket peats in the British Isles (Tallis 1998). Although it is not clear what material has been used to date the basal blanket peat, this diagram suggests that widespread peat initiation occurred between 5100-3100 BP across Britain, with 51% of the dates from Scotland.

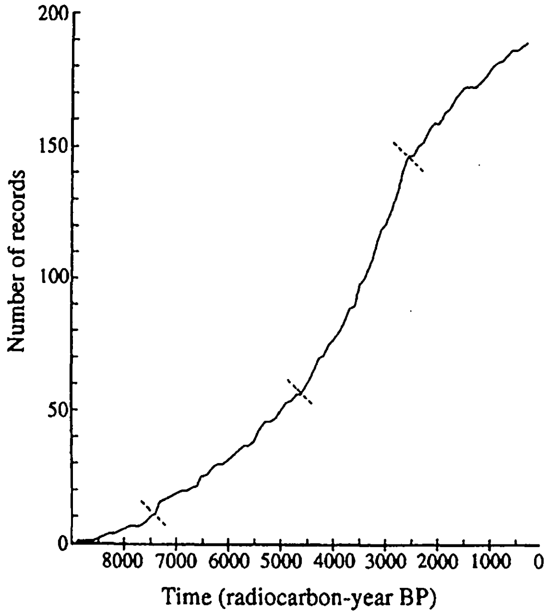


Figure 2.6: Cumulative plot of 190 published radiocarbon dates from basal blanket peats (from Tallis 1998, 86)

Tallis (1991) argued that the earlier dates for peat initiation in the Southern Pennines could not be explained by altitudinal or topographical variation but were more likely to relate to patterns of human activity and forest clearance. For example, a number of radiocarbon dates exist from the Berwyn Mountains (Bostock 1980) but these are significantly later then those from the Southern Pennines. Peat developed locally on the higher ranges of the Berwyn Mountains between 4200 and 6500 BP but lateral expansion to the lower slopes occurred only after 2500 BP to 1000 BP, perhaps as a result of the presence of tree cover and scrub regeneration over a longer period of time, acting to prevent the peat from spreading. Similarly, Chambers (1981) obtained radiocarbon dates from the mineral soil / peat transition from sites in the South of Wales (e.g. Cefn Gwernffwrd) with a range from 3465-1435 BP. Dates obtained from sites in the Black Mountains, Wales however, extend back as far as

7600 BP with impermeable humus or mor creating waterlogged conditions (Smith & Cloutman 1988). From this array of dates it would be unwise to conclude that there have been specific periods of blanket peat initiation acting synchronously across the British Isles but that they began to form at different times according to climatic and local site conditions.

The earliest blanket peat formation study in Scotland, carried out by Durno & Romans (1969), argued for climatic and altitudinal controls on blanket peat formation, based on a series of sites across Great Britain. Their site comparisons, however, were based on a system of tentative pollen-stratigraphic correlations that have since been questioned (Lowe & Tipping 1994). In the south-west of Scotland, work by Jones (1987), in the catchment of the Round Loch of Glenhead, concluded that paludification occurred during the early Holocene (by 9400 BP). Tipping's work (1995) at Carn Dubh, Perthshire found that peat formation was synchronous throughout the area at an early date of c. 9700-9500 BP.

Elsewhere, dates for the initiation of blanket peat in Scotland vary widely. On the Isle of Lewis and the Uists, Outer Hebrides, blanket peat growth is recorded from the early Holocene when woodland and peat communities co-existed for several millennia until 5200-4000 BP when woodland declined and blanket peat expanded. Peat initiation has been attributed to a cool, wet climate and acidic bedrock and soils, but its later expansion may have been influenced by human activity (Fossitt 1996). Dates for initiation at Callanish for two adjacent profiles varied greatly across a small geographical area (e.g. c.8330-7930 cal BP and c.5660-5320 cal. BP) (Bohncke 1988).

Charman's (1992) work based at Cross Lochs, Sutherland, involved the construction of a chronology using a series of radiocarbon dates within a small area. This work indicated that basin fen began to accumulate in depressions at lower altitudes and in the valley at 9170 BP and 8835 BP respectively. Accumulation at the two sites at higher altitudes (on the summits) occurred almost synchronously at c.6600 cal.BP. Charman (1992) concluded that early human activity in the early-mid Holocene (from c.8000 cal. BP) may have led to paludification through the burning of *Betula* woodland. However, the assumption that this early burning phase was anthropogenically induced is not certain and there is little palynological evidence to suggest human activity in the area. The Lairg report, Sutherland (Tipping & McCullagh 1998), also suggested that cultivation during the prehistoric and early historic period in fact inhibited blanket peat encroachment and it was only following land abandonment that blanket peat really began to expand.

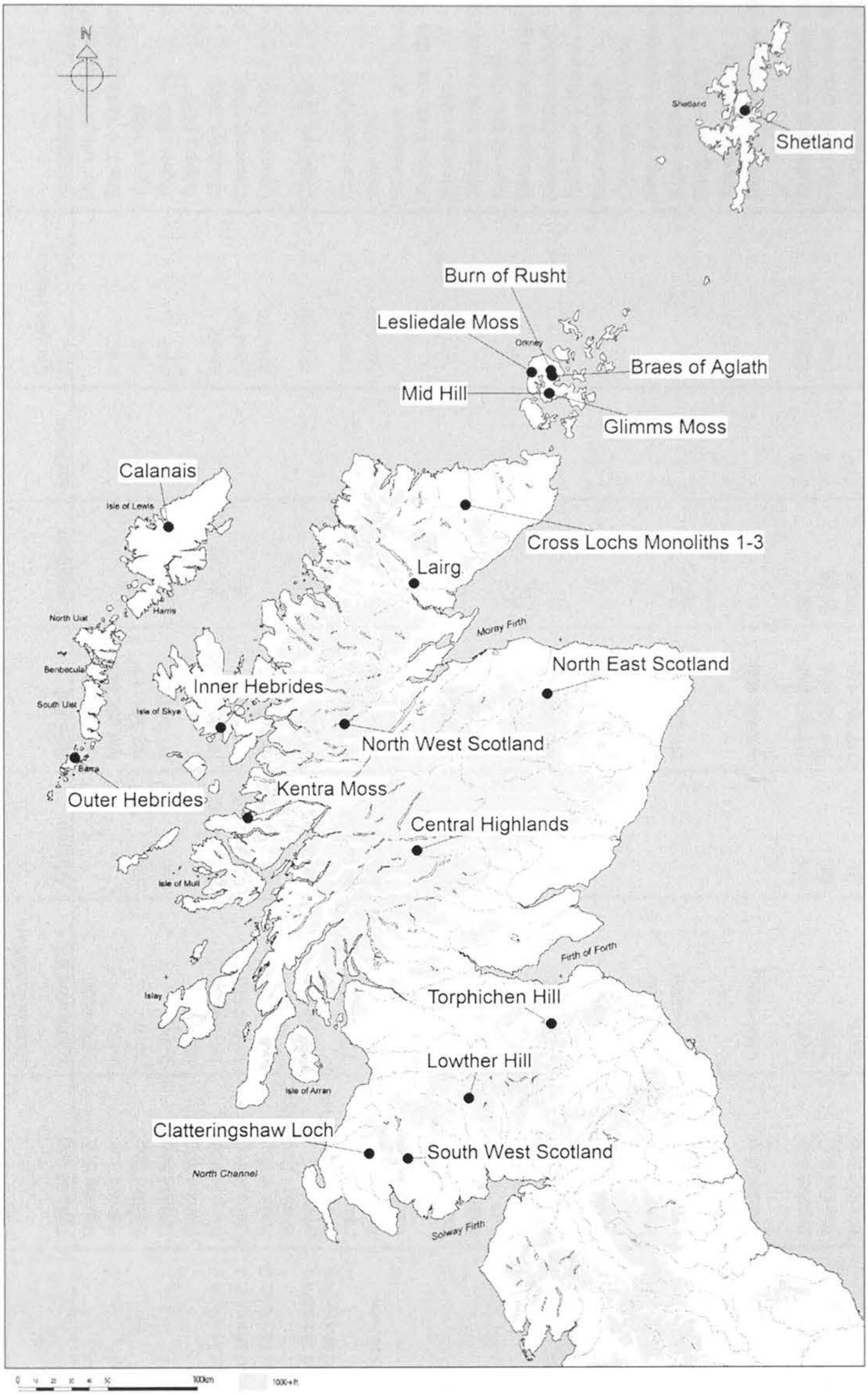


Figure 2.7: Locations of basal dates for blanket peat in Scotland

SCOTLAND	Type of bog	Date of Initiation Calibrated BP	Altitude	Grid Ref	Longitude	Latitude	Sample Depth (m)	Reference
Lairg, Sutherland Site AG3	Blanket Bog	8390-8050		NC 583 018				McCullagh R,Tipping R 1998
Kentra Moss, north Argyll	Blanket Bog	4430		NM 655 695			2.40	Ellis C & Tallis JH 2000
Lowther Hill	Blanket Bog	4010	595	NS 885113			0.54	Taylor 1983
Torphichen Hill	Blanket Bog	1700	395	NT 346532			0.35	Taylor 1983
Carn Dubh, Perthshire	Blanket Bog	9200						Tipping 1995
Cross Lochs, Sutherland Monolith 2	Blanket Bog	5470-4820	Summit 169	NC 8746			51-52	Charman 1992
Cross Lochs, Sutherland Monolith 3	Blanket Bog	7740-7570	Summit 169	NC 8746			206-207	Charman 1992
Cross Lochs, Sutherland Monolith 3	Blanket Bog	8290-8000	Summit 169	NC 8746			209-210	Charman 1992
Cross Lochs, Sutherland Monolith 1	Blanket Bog / Fen peat	10570-10190	Slope 145	NC 8746			137-138	Charman 1992
Cross Lochs, Sutherland Monolith 4	Blanket Bog / Fen peat	10300-9500	Base 118	NC 8746			170-171	Charman 1992
Clatteringshaws Loch, Galloway	Blanket Bog	8050-7300	210	NX 545 775			145-190	Birks 1975
Shetland	Blanket Bog	4800-3100		HU 415 675				Whittington 1977; Spence 1979
								Hulme & Shirrifs 1994
Callanish, Isle of Lewis	Blanket Bog	4810-7270		NB 215 335				Bohncke 1988
Outer Hebrides	Blanket Bog	5200-2600		NF 695 035				Wilkins 1984; Newell 1988
								Bennett et al 1990
								Mills et al 1994; Fossitt 1996
Inner Hebrides	Blanket Bog	4000-1600		NG 505 205				Birks & Williams 1983
								Robinson & Dickson 1988
Northeast Scotland	Blanket Bog	6200-3500		NJ 325 395				Robinson 1987
								Charman 1992,1994
Northwest Scotland	Blanket Bog	5000-4000		NH 195 225				Birks 1975; Pennington 1975
Central Highlands	Blanket Bog	5900-4200		NN 599 512				Dubois & Fergussen 1985
								Bridge et al 1990
								Tipping et al 1993
Southwest Scotland	Blanket Bog	4800-1600		NX 329 802				Birks 1975; Boatman 1983
Mid Hill, Orkney	Blanket Bog	3422	120	HY 335 085	59.1	3.15	1.29	Keatinge & Dickinson 1979
Burn of Rusht, Orkney	Blanket Bog	3355	90	HY 345 215	59.08	3.12	1.48	Keatinge & Dickinson 1979
Braes of Aglath, Orkney	Blanket Bog	2919	90	HY 355 185	59.06	3.07	1.37	Keatinge & Dickinson 1979
Glimms Moss, Orkney	Blanket Bog	3400-3000		HY 339 086				Keatinge & Dickinson 1979
Lesliedale Moss, Orkney	Blanket Bog	3800		HY 239 206				Davidson et al 1976

Table 2.3: Blanket Peat Initiation Dates from Sites across the British Isles (dates in cal. BP)

WALES	Type of bog	Date of Initiation Calibrated BP	Altitude	Grid Ref	Longitude	Latitude	Sample Depth	Reference
Brecon Beacons, S Wales	Blanket Bog	5290-4830	715	SO 043196	51.8	3.45	1.01	Chambers 1981, 1982, 1983
Cefn Fford, S Wales	Blanket Bog	4160-3700	600	SN 906032	51.6	3.6	0.25	Chambers 1981, 1982
Cefn Gwernffrwd, S Wales	Blanket Bog	3930-3560	400	SN 738494	52.1	3.9	0.69	Chambers 1981
Cefn Gwernffrwd, S Wales Site A	Blanket Bog	3600-3800	490	SN 738494		1.4		Smith & Green 1995
Cefn Gwernffrwd, S Wales Site B	Blanket Bog	3800-4100	490	SN 738494		0.95		Smith & Green 1995
Coed Taf, S Wales	Blanket Bog	1510-1460	400	SN 988108	51.7	3.45	0.29	Chambers 1981, 1983
Glaslyn, Wales	Blanket Bog	4430-4150	480	SN 828932	52.45	3.55	1.19	Taylor 1973
Berwyn Mountains, N Wales	Blanket Bog	1595	821		52.80	3.65	1.43	Pearson 1979
Banc Nant Rhys, Wales	Blanket Bog	4430-4150	543	SN 825792			1.85	Taylor 1983
Carnedd Wen, Wales	Blanket Bog	4100-3830	520	SH 924098			1.00	Taylor 1983
Y Godor II	Blanket Bog	6500	650				3.40	Bostock 1980
Trum Felen 2	Blanket Bog	5300	695				3.65	Bostock 1980
Trum Felen 4	Blanket Bog	5000	695				3.30	Bostock 1980
Trum Felen 7	Blanket Bog	5000	695				3.40	Bostock 1980
Ceulan Meyheryn 1	Blanket Bog	5000	775				2.65	Bostock 1980
Ceulan Meyheryn 5	Blanket Bog	4200	775				2.60	Bostock 1980
Ceulan Meyheryn 3	Blanket Bog	2100	775				1.80	Bostock 1980
Trum Felen 1	Blanket Bog	4200	695				2.95	Bostock 1980
Y Godor I	Blanket Bog	4200	655				2.60	Bostock 1980
Y Godor I	Blanket Bog	2500	655				2.20	Bostock 1980
Bronkin Harry	Blanket Bog	2400	655				1.50	Bostock 1980
Carnedd y Ci	Blanket Bog	2000	610				1.50	Bostock 1980
Y Godor I	Blanket Bog	2000	655				1.40	Bostock 1980
Moel Sych	Blanket Bog	1800	820				1.00	Bostock 1980
Trum Felen II	Blanket Bog	1000	550				0.40	Bostock 1980
Waun-Fignen-Felen B125N	Blanket Bog	7610	480	SS 825179			0.44	Smith & Cloutman 1988
Waun-Fignen-Felen EE17E	Blanket Bog	7020	480	SS 825179			0.68	Smith & Cloutman 1988
Waun-Fignen-Felen B46-5N	Blanket Bog	5670	480	SS 825179			1.80	Smith & Cloutman 1988
Waun-Fignen-Felen NP	Blanket Bog	5100	500	SS 825179			0.36	Smith & Cloutman 1988
Waun-Fignen-Felen SW	Blanket Bog	4250	530	SS 825179			0.48	Smith & Cloutman 1988

IRELAND	Type of bog	Date of Initiation Calibrated BP	Altitude	Grid Ref	Longitude	Latitude	Sample Depth	Reference
Ballynagilly, Tyrone, N Ireland	Blanket Bog	1735	200		54.6	6.8	0.24	Pilcher & Smith 1979
Ballynagilly, Tyrone, N Ireland	Blanket Bog	2525	200		54.6	6.8	0.24	Pilcher & Smith 1979
Ballypatrick Forest, Antrim, N Ireland	Blanket Bog	3680	220		55.15	6.1	1.99	Smith et al 1970
Glens Bridge Antrim, N Ireland	Blanket Bog	3610	255		55.2	6.25	2.01	Smith et al 1970
Altnahinch, Antrim, N Ireland	Blanket Bog	2725	275		55.05	6.2	0.54	Smith et al 1971
Beaghs Forest, Antrim, N Ireland	Blanket Bog	2520	310		55.1	6.15	0.43	Smith et al 1971
Beaghmore, Tyrone, Ireland	Blanket Bog	2230	200		54.6	6.85	1.5	Pilcher 1969
Beaghs Sand Quarry, Antrim, N Ireland	Blanket Bog	3705	305		55.13	6.07	1.57	Smith et al 1971
Gruig Top, Antrim, N Ireland	Blanket Bog	3335	290		55.2	6.05	0.81	Smith et al 1971
Loughermore, Londonderry, N Ireland	Blanket Bog	2900	180		54.96	7.08	0.47	Smith et al 1981
Pubble, Londonderry, N Ireland	Blanket Bog	2775	180		54.96	7.08	0.47	Smith et al 1981
Butter Mnt, Co. Down	Blanket Bog	3270	490		54.10	6.02	1.24	Holland 1975
Skerry Hill, Ulster, N Ireland	Blanket Bog	3720-3460	415	D 143207			1.45	Taylor 1983
Cadogan Bog, SW Ireland	Blanket Bog	6500	69					Mighall TM et al 2004
Slieve Croob	Blanket Bog	4215	462		54.20	5.98	2.58	Holland 1975
Maughansilly I, SW Ireland	Blanket Bog	3265	213		51.80	9.00	0.23	Lynch 1981
Dromatouk I, SW Ireland	Blanket Bog	2020	107		51.80	9.20	0.48	Lynch 1981
Cashelkeelty III, SW Ireland	Blanket Bog	1060	110		51.65	9.75	0.11	Lynch 1981
Dromteewakeen I, SW Ireland	Blanket Bog	987	101		51.90	9.80	0.46	Lynch 1981
Cullenagh I, SW Ireland	Blanket Bog	800	101		51.65	9.75	0.07	Lynch 1981
Lough Doo, Co. Mayo	Blanket Bog	3500						O'Connell et al 1987
Carrownaglogh, Co. Mayo	Blanket Bog	3600						O'Connell 1986
Corslieve, Co. Mayo	Blanket Bog	4860						Browne 1986
Bellanaboy, Co. Mayo	Blanket Bog	7110						Hakansson 1974
Bellanaboy, Co. Mayo	Blanket Bog	4340						Hakansson 1974
Belderg, Co. Mayo	Blanket Bog	4000						Caulfield 1978
Behy / Glenulra, Co. Mayo	Blanket Bog	4500						Caulfield 1978
NC 1, Claggan Mt, Co. Mayo	Blanket Bog	4470						Foss & Doyle 1990
NC 11, Claggan Mnt, Co. Mayo	Blanket Bog	3100						Foss & Doyle 1990

Ireland	Type of bog	Date of Initiation Calibrated BP	Altitude	Grid Ref	Longitude	Latitude	Sample Depth	Reference
Letterfreck II, Co. Galway	Blanket Bog	<6000						O'Connell 1988
L.Namackanbeg, Co. Galway	Blanket Bog	3400						O'Connell 1988
Union Wood Lake, Co. Sligo	Blanket Bog	4400						Dodson & Bradshaw, 1987
Glenveagh, Co. Donegal	Blanket Bog	4000						Telford 1977
West Donegal	Blanket Bog	8200-7200						Fossitt 1994
West Donegal	Blanket Bog	5000-4500						Fossitt 1994
ENGLAND								
Broad Amicombe Hole, Dartmoor	Blanket Bog	4350	605		50.65	4.01	1.13	Maguire DJ 1983
Broad Amicombe Hole, Dartmoor	Blanket Bog	3570	600		50.65	4.01	0.89	Maguire DJ 1983
Broad Amicombe Hole, Dartmoor	Blanket Bog	2810	582		50.65	4.01	0.82	Maguire DJ 1983
Broad Amicombe Hole, Dartmoor	Blanket Bog	3440	595		50.65	4.01	0.82	Maguire DJ 1983
Black Ridge Brook, Dartmoor	Blanket Bog	7700-6300	440	SX 585 845				Caseldine & Maguire 1986, Caseldine & Hatton 1993 Hatton 1991
Pinswell, Dartmoor	Blanket Bog	7000	461					Caseldine & Hatton 1993
Snaefell, Isle of Man	Blanket Bog	2865	442	SC 395885	53.96	4.75		Russell 1978
Fleet Moss, W Yorkshire Pennines	Blanket Bog	9550-9445	565	SD 860836			3.60	Honeyman A 1985
Penhill, W Yorkshire Pennines	Blanket Bog	5660-5460	549	SE 038858			1.80	Honeyman A 1985
Fountains Fell, W Yorkshire Pennines	Blanket Bog	5940-5580	623	SD 871708			1.42	Smith RT 1970
Rishworth Moor, Yorkshire	Blanket Bog	6600-5900	410	SE 005 175	53.55	2.00	1.85	Bartley 1975
Skell Gill I, Nidderdale	Blanket Bog	4500-3600	290	SE 177693	54.00	1.75	1.39	Tinsley 1975
Thunacar Knott, Lake District	Blanket Bog	4680	700	NY 275 085	54.30	3.03	1.00	Pennington 1975
Milltyr Gill, Pennines	Blanket Bog	2600	490	SJ 020306			1.00	Taylor 1983
Whirley Gill, W Yorkshire Pennines	Blanket Bog	10250-9770	488	SD 970940			3.50	Honeyman A 1985
Hail Storm Hill, W Yorkshire Pennines	Blanket Bog	6750-6490	460	SD 832189			1.55	Taylor 1983
Low Stony Bank, W Yorkshire Pennines	Blanket Bog	1730-1410	400	SD 918650			0.90	Smith RT 1970
Skell Moor I, W Yorkshire Pennines	Blanket Bog	4600-3950	320	SE 172696			0.25	Tinsley 1975
North Gill Wood, Pennines	Blanket Bog	1180-760	267	SE 167726			1.90	Tinsley 1975
Widdybank Fell, North Pennines	Blanket Bog	3370	520	NY 825 305			0.64	Turner et al 1973

ENGLAND	Type of bog	Date of Initiation Calibrated BP	Altitude	Grid Ref	Longitude	Latitude	Sample Depth	Reference
Robinsons Moss, S Pennines	Blanket Bog	9100	495				4.10	Tallis & Switsur 1990
Robinsons Moss, S Pennines	Blanket Bog	7800	495				3.35	Tallis 1991
Soyland Moor, S Pennines	Blanket Bog	8800	385	SD 985195			6.65	Williams 1985
Alport Moor, S Pennines	Blanket Bog	8100	540	SK112 929			3.20	Tallis 1991, 1994
Bleaklow. S Pennines	Blanket Bog	7200	622	SK 105965			3.55	Conway 1954
Ringinglow C, S Pennines	Blanket Bog	7000	410	SK 285835			6.10	Conway 1954
Kinder KV1, S Pennines	Blanket Bog	7000	625	SK 085885			2.95	Conway 1954
Kinder K1, S Pennines	Blanket Bog	6300	625				2.20	Conway 1954
Featherbed moss FW3, S Pennines	Blanket Bog	6800	510	SK 085 925			2.70	Tallis 1991
Featherbed moss, S Pennines	Blanket Bog	6500	490				2.60	Tallis & Switsur 1973
Featherbed moss FW4, S Pennines	Blanket Bog	6200	485				2.50	Tallis 1991
Featherbed Top, S Pennines	Blanket Bog	5500	540				1.50	Tallis 1985
Featherbed Moss East, S Pennines	Blanket Bog	4570	470				0.50	Tallis & Switsur 1983
Salvin Ridge, S Pennines	Blanket Bog	6300	525				2.20	Tallis 1985
Tintwistle High Moor AT7, S Pennines	Blanket Bog	6000	467	SK 025 994			2.57	Tallis 1991
Tintwistle High Moor AT8, S Pennines	Blanket Bog	5500	465				2.30	Tallis 1991
Tintwistle High Moor AT9, S Pennines	Blanket Bog	5400	435				1.50	Tallis 1991
Tintwistle Knarr, S Pennines	Blanket Bog	4475	460	SK 035995			0.70	Tallis & Switsur 1990
Leash Fen, S Pennines	Blanket Bog	5500	290	SK 295735			5.80	Hicks 1971
Lady Clough Moor, S Pennines	Blanket Bog	5410	480	SK 105925			1.20	Tallis & Switsur 1983
Laund Clough, S Pennines	Blanket Bog	5110	455	SK 165995			1.50	Tallis & Switsur 1983
Coldharbour Moor, S Pennines	Blanket Bog	4670	435	SK 075935			0.90	Tallis & Switsur 1983
OTHER COUNTRIES								
Glendhu Basin New? Zealand	Blanket Bog	7000	460					McGlone & Wilmshurst 1999
Central Alberta, western Canada	Blanket Bog, Basin Mires	7020						
Salthammar Drumlin, Nord-Trondelag Norway	Blanket Mire	8460	490				97-102	Solem T 1991
Momyr S Drumlin, Nord-Trondelag Norway	Blanket Mire	7800	279				87-90	Solem T 1986
Momyr N Drumlin, Nord-Trondelag Norway	Blanket Mire	7400	266				50-52.5	Solem T 1986

Chapter 3 The Environmental & Archaeological Record of South-West Scotland

3.1 *The environmental and archaeological record from the south-west of Scotland: the Lateglacial and Mesolithic*

This chapter explores the evidence for the Holocene vegetational and climatic history of the south-west of Scotland obtained from different proxy data sets, and considers the impact of human activity on landscape change during the Holocene. South-west Scotland here comprises an area bounded by the headwaters of the Tweed to the east and by the Clyde Basin to the north, and the study area includes Kintyre and Arran to the west (see Figure 3.1). This will place the vegetational history, archaeological record and blanket peat development at Lagafater in a Scottish, regional context.

1	Loch Dee, south west scotland
2	Cooran Lane, Galloway
3	Loch Dungeon Peat, Galloway
4	Clatteringshaws Loch, Galloway
5	Rotten Bottom, Southern Uplands
6	Catharine Hill
7	Burnfoothill Moss, Kirkpatrick Fleming
8	Picts Knowe
9	Snibe Bog
10	Nick of Curleywee
11	Little Lochans
12	Culhorn Mains
13	Moss of Cree
14	Bigholm Burn
15	Racks Moss
16	Brighouse Bay
17	The Round Loch of Glenhead
18	Aros Moss
19	Machrie Moor, Arran
20	Bloak Moss
21	Airds Moss
22	Linwood Moss
23	Wilderness Plantation
24	Dubh Lochan
25	Shewalton Moss
26	Carsegowan Moss
27	Ellergower Moss

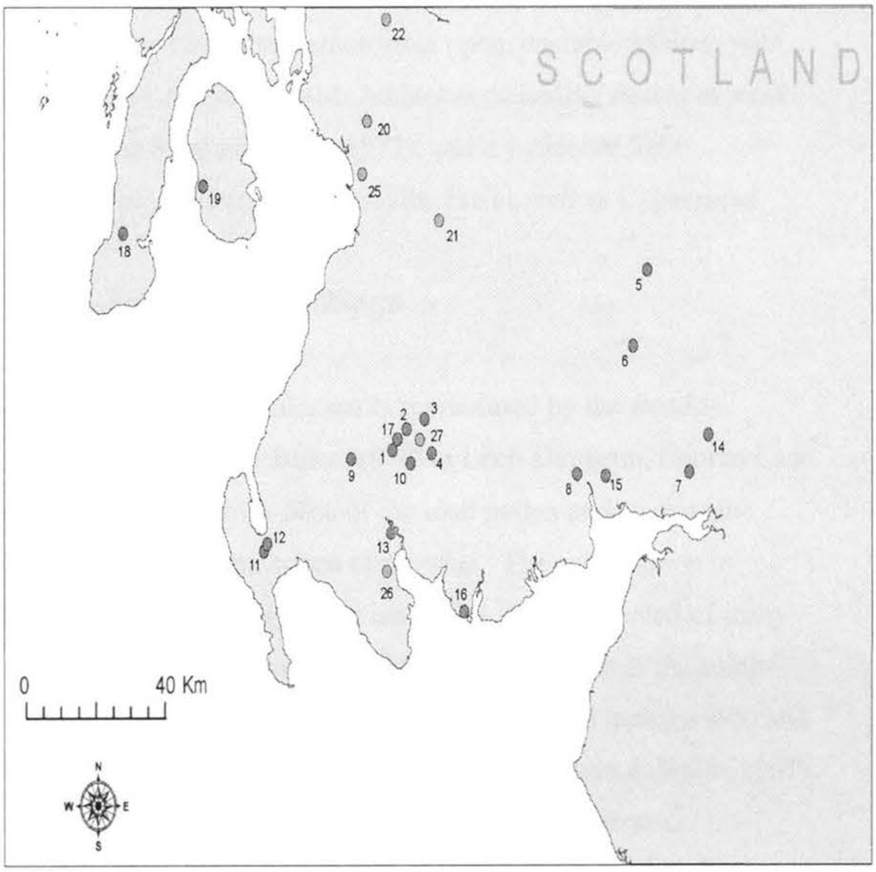


Figure 3.1: Location of palynological sites from south west Scotland

3.1.1 Early Holocene climatic changes in Scotland

The beginning of the Holocene period is marked by a rapid climatic amelioration c.11800 cal. BP, marking the end of the Devensian period. The northward movement of the oceanic polar jet streams brought an abrupt end to the Loch Lomond cold stage with warm surface waters once again becoming established around Western Europe (Ruddiman & McIntyre 1981).

3.1.2 *Empetrum-Salix-Juniperus* Assemblage

Few pollen diagrams from the south-west of Scotland exhibit an early Holocene vegetation assemblage and no ^{14}C dates appear to exist for the timing of early plant colonisation. Evidence has been obtained from zone LD-1a to 1d from Loch Dungeon, Kirkcudbrightshire (Birks 1972), zone CL-1 from Cooran Lane (Birks 1975), and zones I, II and III identified by Moar (1969) at Little Lochans and Culhorn Mains, and at Aros Moss (Nichols 1967). An open landscape existed, composed chiefly of Poaceae, Cyperaceae, *Rumex* and dwarf shrubs such as *Empetrum*. Several pollen diagrams also demonstrate open, unstable habitats with fluctuating values of *Betula, Salix* and *Juniperus*, with *Juniperus* preceding *Betula* in most pollen stratigraphies from south-west Scotland (Birks 1972), and a variety of light-demanding herbs such as *Ranunculus, Artemesia,* Carophyllaceae as well as Cyperaceae.

3.1.3 *Betula-Corylus-Myrica-Juniperus* Assemblage

The establishment of woodland species in the Holocene is represented by the *Betula-Corylus-Myrica* assemblage zone as defined by Birks (1972) at Loch Dungeon, Cooran Lane and Snibe Bog, where these species exceed over 50% of the total pollen and suggest the climate had improved sufficiently for the colonisation of *Corylus*. The colonisation of *Betula* across the British Isles and its time transgressive nature (as with the spread of many woodland taxa) is well recorded (Birks 1989; Tipping 1994). Its appearance in the south-west of Scotland has been dated to c.10400 cal. BP at Burnfoothill Moss (Tipping 1995) and between c.11650-10350 cal. BP at Brighthouse Bay, Kirkcudbright (Godwin & Willis 1961). This assemblage is also accompanied by relatively low proportions of *Empetrum*, Cyperaceae and *Filipendula*. *Juniperus* levels appear to be significant at low altitude sites such as Little Lochans (Moar 1969) but less so at higher altitude sites. The upper boundary of this early phase is generally placed where *Betula* pollen values fall. This period also marks the transition at Cooran Lane (Birks 1975) to ombrotrophic conditions from zone CL-2 to zone CL-3.

A key feature in many pollen diagrams during this period is the increase in *Corylus avellana* in the south-west of Scotland. However, defining its limit and the date of its first appearance is difficult as many diagrams show numerous fluctuations in values (Birks 1989) and depths and subsequent ages of material sampled. The *Corylus* rise in the south-west of Scotland is broadly dated to c.9500 cal. BP (Tipping 1999) and appears strongly synchronous across securely dated palynological sites across Scotland as it out-competed Betula. *Corylus* formed a mixed woodland with *Betula* in south-west Scotland, and whilst some *Pinus* grains are represented at Nick of Curlywee and Bigholm Burn (Moar 1969) coincident with this phase, further north throughout the Grampians, Wester Ross and western Sutherland (Bennett 1984; Birks 1989) the spread of *Pinus* had a much greater impact, replacing the early birch-hazel woodland. The colonisation of *Corylus* is often seen as representing migration from a source west of Scotland (Birks 1989; Edwards 1990, 1994; Tipping 1994), and the possibility that its appearance is closely related to fire frequency and early anthropogenic activity has also been postulated (Smith 1970) but remains a topic of some debate. For further reviews of the spread of *Corylus* in the south west see Boyd & Dickson (1986).

3.1.4 *Ulmus-Quercus* Assemblage

Ulmus was the next tree species to colonise the region although it is only represented by low pollen values (Ramsay & Dickson 1996 144). At approximately the same time, *Quercus* arrived (Birks 1972; Moar 1969; Tipping 1995) where the sequence has been dated to c. 8050 cal. BP at Burnfoothill Moss (Tipping 1999) and between c.8600-8050 cal. BP at Cooran Lane (Birks 1972). Sites in the south-west of Scotland were typical of more widespread oak-hazel-elm woods identified by Bennett (1989) and Tipping (1994).

The end of this zone is also distinguished by the presence of *Pinus* along with *Salix,* and the decline of *Betula.* There is also a substantial rise in *Alnus* across the south-west of Scotland at this time, followed by a decline to low values before the main regional expansion of this species, particularly at Aros Moss and Racks Moss near Dumfries (Nichols, 1967), on Jura (Durno 1968), on Machrie Moor, Arran (Robinson & Dickson 1988), and across the Galloway Hills (Birks 1972). This is thought to have been a localised response either to an increase in the water table brought about by a rising sea level (Nichols 1967), increasing oceanic conditions (Birks 1972) or the influence of early Mesolithic populations (Smith 1984). There is much debate surrounding the asynchronous spread and varied timing of *Alnus* across Scotland with various hypotheses such as anthropogenic activity, disturbance through fire and geomorphological processes, a lack of suitable habitats and its thermoclimatic demand (Bennett & Birks 1990; Chambers & Elliot 1989; Huntley & Birks 1983; Tallantire 1992). However, it is possible *Alnus* was present in Scotland as early as c.10000 cal. BP and increased in the period following this as more suitable habitats and changing local conditions ensued (Bennett & Birks 1990). In south-west Scotland, the appearance of *Alnus* appears to coincide with the occurrence of macrofossil charcoal in the peat profile, suggesting there may have been burning of existing vegetation from as early as c.8600-8050 cal. BP at Cooran Lane (Birks 1975), affecting the spread of this species. Similar early dates for possible anthropogenic activity have been recorded from Arran (Robinson 1983; Affleck *et al* 1988).

Pinus was generally uncommon in the south-west of Scotland during the early Holocene period, probably restricted to the drier margins of peat bogs and upland areas from c.8250 cal. BP where the soil was too acid to support other competitive species, e.g. in the uplands of Galloway (Birks 1972; Bennett 1984; Jones *et al* 1989). A post-glacial maximum for *Pinus* values is recorded at Aros Moss (Nichols 1967) at the end of Birks' traditional *Ulmus-Quercus* assemblage zone (Birks 1975), and at Brighouse Bay, south of the Galloway Hills, it was locally present between c8400-8250 cal. BP (Wells *et al* 1999). At Cooran Lane, a pine stump was radiocarbon dated to c.8480-8010 cal. BP (Birks 1975) and high levels of *Pinus sylvestris* pollen were recorded at Pict's Knowe between 7880 and 6400 ^{14}C BP (Milburn & Tipping 1999a). Pine probably grew as scattered individuals or in small groups across the landscape of the south-west. The timing of their colonisation is problematic as a result of sedimentation rates and the abundance of *Pinus* pollen, and the reasons for its decline and then sudden appearance across western Scotland is a contentious issue, further discussed by Tipping (1989), Bennett (1984), Blackford *et al* (1992) and Bridge *et al* (1990). Birks (1975), however, refers to its disappearance by c.7000 cal. BP at sites in the Galloway Hills as largely a result of increased wetness and bog growth, although he does not go on to explain further declines at c.4000 cal. BP. Values of *Pinus* pollen from Pict's Knowe sharply declined between c.6410 and 6190 ^{14}C BP possibly as a result of an increase in groundwater tables (Milburn & Tipping 1999). With the exception of Clatteringshaws Loch at c.5750-

5310 cal. BP, *Pinus* played no major role in the woodland landscape of Dumfries and Galloway until the last two centuries when it has been extensively planted.

3.1.5 Changing climate in the Mesolithic period

The scarcity and ephemeral nature of many Mesolithic archaeological remains has meant a reliance on the palynological record to determine anthropogenic alterations to the local vegetation (Tipping 2004). Characteristically, the expansion of *Corylus* and *Alnus* has been paralleled with fragmentary evidence of early human activity (Bennett & Birks 1990; Mellars 1976; Smith 1984; Simmons 1993, 1996; Tallis 1991), although this has often been based on small-scale changes within the pollen record over relatively short time-scales, with clear regional differences (as outlined above). More recently, Tipping (2004) has argued that none of these 'disturbance phases' or charcoal inclusions are demonstrably anthropogenic in origin and perhaps climate change and autogenic processes are more responsible for vegetation change at the start of the Mesolithic. Evidence from the Greenland ice core, GISP2, suggests that a short-lived fall in temperature and increased atmospheric circulation, lasting between 200-400 years, occurred at c.8400-8000 cal. BP (Alley *et al* 1997), comparable with the Younger Dryas deterioration (Tipping 2004) and referred to as the early to mid-Holocene transition (EMHT) (Stager & Mayewski 1997). Throughout the British Isles, an increase in oceanic conditions is characterised by rising water tables and the more widespread appearance of ombrotrophic plant communities. For example, early wet phases and changes in vegetation are recorded from the north of England at Walton Moss (Hughes *et al* 2000) and Bolton Fell Moss (Barber *et al* 2003) at c.7400-7800 cal. BP, and the expansion of blanket peat is recorded in Finland (Korhola 1994, 1995). Similarly, this event coincides with disturbances to woodland species and changes in fire frequency records (Simmons 1996; Tipping & Milburn 2000). Pollen diagrams also show an increase in wetland habitats and a marked increase in herbaceous pollen (Bell & Walker, 1992; Mannion, 1991). Elsewhere in northern England, Tallis (1991) believes that, between c.9000 and 7500 cal. BP, two main episodes of blanket peat formation occurred across the Pennines (e.g. blanket peat initiation is dated to c.8100 cal. BP on Alport Moor). Between c.7950-8050 cal. BP at Kirkpatrick Fleming (Burnfoothill Moss) in south-west Scotland, a wet phase is recorded which appears to have reduced *Betula* and *Salix* values (Tipping 1995) and marks a change from fen peat to raised moss.

In recent years it has been suggested that the climatic record of Scotland (and northern Europe) is cyclical. Periods of higher effective precipitation, 'wet phases' have been detected in changes in bog vegetation and humification values from several mires across the UK. These wet shifts are summarised in Table 3.1 and spectral analysis of several mires has identified a cyclicity in the proxy climate record of 210 years (Chambers *et al* 1997), 206 years (Dupont 1986) and 260 years found by Aaby (1976) from raised mires in Denmark. These changes may relate to the collapse of the Laurentide ice sheet and the influx of freshwater which disrupted the North Atlantic Ocean circulation (Broecker 1994; Lowe & Walker 1997). It is has been suggested that these wetter phases may in fact be related to the periodic behaviour of the North Atlantic oscillation, which is the only periodic atmospheric teleconnection to match the stable isotope record from the Greenland Ice Core (GISP2) (White *et al* 1996), and is known as the thermohaline circulation system (Tipping & Tisdall 2004). Similarly, sun-spot activity may be responsible for periodic changes in climate and Bond *et al* (1997) identified periodicities of around 1400-1500 years throughout the Holocene.

3.1.6 *Alnus* expansion

The rise of *Alnus* (alder) in the south-west of Scotland occurs at varying dates across the region: between c.7700 and 7200 cal. BP at Burntfoothill Moss (Tipping 1995); between c.8100-7700 cal. BP at Scaleby Moss (Godwin *et al* 1957); at c.7500 cal. BP on Machrie Moor, Arran (Robinson 1981, 1983); at c.7590 ^{14}C BP at Pict's Knowe (Milburn & Tipping 1999a); at c.7320 ^{14}C BP at Catharine Hill (Milburn & Tipping 1999b); and dated to c.8590-8370 cal. BP at Brighouse Bay (Wells & Mighall 1999). These changes mark the beginning of the *Alnus-Ulmus* zone of Birks (1972), recognised at Loch Dungeon and Cooran Lane, at Moar's (1969) zone FIV at Nick of Curlywee, and at Racks Moss (Nichols 1967). This zone also contains high values of *Corylus* / *Myrica* and *Calluna* and decreased values of non-local open habitat herbs. This period probably reflects the onset of peat growth at Clatteringshaws Loch (Birks 1975). Elsewhere in western Scotland the *Alnus* rise has been dated to c.6500 cal. BP at Auld Wives Lifts (Dickson 1981, 15) and c.6700 cal. BP at Dubh Lochan (Ramsay & Dickson 1996, 144). The asynchronous spread of *Alnus* and its site specific nature have been discussed earlier in this chapter. Smith (1984) & Edwards' (1990) study of several Scottish sites implicated fire in the *Alnus* rise and demonstrated a correspondence between charcoal and *Alnus* pollen curves. The number of charcoal fragments recorded at Rotten Bottom between c.7000 and 6400 cal. BP, for instance, are consistently high (Tipping &

Milburn 2000). On Machrie Moor, the rise in *Coryloid* pollen along with *Plantago lanceolata*, *Ranunculaceae*, Peteridium and *Urtica* pollen suggest regular coppicing or pollarding of trees (Robinson & Dickson 1988). At Loch Dungeon and Loch Doon (Edwards 1989), the presence of *Plantago lanceolata* is accompanied by a rise in Graminoid and Cyperaceous pollen at the LD4/LD5 boundary (Boatman 1983). It can also be seen at l.p.a.z.C at Burnfoothill Moss, thought to relate to Mesolithic activity (Tipping 1999b), and where two possible early anthropogenic woodland disturbances have been dated at 5850-5750 cal BC and 5540-5400 cal BC (c.7750-c.7400 cal. BP). At Brighouse Bay however, pollen analytical evidence for Mesolithic activity is unclear and the rise in *Alnus* is more likely to have been a response to a rise in sea level and increased wet conditions (Wells & Mighall 1999).

3.1.7 *Alnus-Ulmus* Assemblage

By c.6000 cal. BP, woodlands were at their maximum extent with all of the major tree species present. These were dominated by *Quercus*, *Ulmus* and *Corylus* with *Betula* as a subsidiary tree (Tipping 1994, 30), although variation was dependent on edaphic and altitudinal constraints. *Tilia* was relatively common from c.6000 cal. BP in parts of southern Scotland and Cumbria (Tipping 1997). *Populus* and *Fraxinus* are recorded from sites in the south-west (although in low proportions) and at the Nick of Curlywee (Moar 1969). Altitudinal differences are also recorded for the spread of certain species: the higher altitude woods of the Campsie Fells (Dickson, 1981; Eydt 1958) and the Nick of Curlywee (Moar 1969) show low values of *Quercus* and *Ulmus* with woodland dominated by *Betula*, *Alnus* and *Corylus*. Above c.300m OD in the Dumfries and Galloway region, the major woodlands comprised *Corylus* and *Betula* (Tipping 1999), and a predominance of open ground species at higher altitudes suggest largely treeless, montane habitats in the early Holocene (Birks 1972). Airds Moss in the Ayrshire Hills (Durno, 1956) shows a similar picture and open areas of moorland were also present in some upland areas (Eydt 1958).

By the close of the *Alnus-Ulmus* period, dated to c.6200-5550 cal. BP at Clatteringshaws Loch, which marks the fall in *Ulmus* pollen, *Pinus* values fluctuated across the south-west. For example, there was a notable absence of *Pinus* at Racks Moss, but increased values were recorded at Clatteringshaws Loch (up to 60% AP) and dated to c.5750-5310 cal. BP. Similarly, at Burnfoothill Moss, a reduction in total charcoal fragments after c.5400 cal. BP, identified by Tipping (1995), coincides with a shift to a wetter peat surface as previously discussed. The apparent mid-Holocene fall in charcoal values is diachronous across the lowlands of south west Scotland (Tipping & Milburn 2000; Cayless & Tipping 2000), particularly at Catharine Hill, Burnfoothill Moss and Pict's Knowe, but this does not seem to have extended to upland sites (e.g. Rotten Bottom). The reasoning behind such a fall in charcoal values is still unclear but may reflect natural climatic change causing a reduction in fire regime or perhaps a change in anthropogenic activity and the spatial patterning of land use (Tipping & Millburn 2000).

3.1.8 Mesolithic Activity in south-west Scotland

Throughout Dumfriesshire and Kirkcudbrightshire, evidence for Mesolithic communities is unclear and remains ambiguous (Gregory 1998). Many of the events recorded in the pollen diagrams may simply represent natural disturbances and, as Tipping (2004) has demonstrated, may simply be the result of climate change. Direct evidence for Mesolithic activity has, however, been based on a number of archaeological sites in the south-west, often with the discovery of imported flint and chert artefacts concentrated around river valleys and coastal areas. There have been concentrations around Loch Doon and Loch Grannoch and a number of sites have been discovered around the Nith estuary (Gregory 1998). Early ^{14}C dates have been obtained from Redkirk Point with the excavation of an exposed hearth providing early radiocarbon dates of c.7160-6740 cal. BP and c.7200-6550 cal. BP (Masters 1981).

The discovery of Mesolithic artefacts on raised beaches, particularly to the south of the river Stinchar, suggest post marine-transgression activity (Jardine 1980). In particular, the area immediately adjacent to the standing stones at Garleffin to the north west of the study area (NX 087817) has produced a large number of late Mesolithic artefacts thought to be indicative of a temporary settlement. Similarly, excavations at Smittons, Water of Ken by Affleck (1986), uncovered flint and chert artefacts and a number of fire spots were dated to between c.7420 cal. BP and c.6000 cal. BP. A series of stakeholes associated with lithics and pits was also discovered at Starr, Loch Doon, thought to represent some kind of temporary shelter (Affleck 1985). A 'proxy' date for early human activity has also been established inland from the area around Loch Dee where a single Mesolithic flint discovered within a stratigraphic layer used for pollen analyses has been dated to c. 6280-5990 cal.BP (Edwards *et al* 1991), and on the Isle of Arran where a Mesolithic narrow blade assemblage was discovered (Affleck *et al* 1989). The scale of this early human movement across the south west of Scotland has been discussed by Edwards *et al* (1983) who suggested travel between the Solway coast and the Ayrshire coast via the river systems of the Dee and Doon and the Fleet and Doon, spanning a period between the 7th and 5th millennium BC.

Changes in ocean current dynamics at the end of the Mesolithic may have impacted on the coastal geography of the area, particularly along the Solway coast (as discussed by Dawson *et al* 1999, Jardine 1980, Wells 1999), and may have impacted on the availability of marine food sources and ultimately on population dynamics, with a shift from marine to terrestrial foodstuffs along the Scottish west coast (Bonsall *et al* 2002; Richards 2004; Schulting 1998; Tipping & Tisdall 2004). It has been suggested that this was in response to abrupt climate change at c.6000 cal. BP and by the availability of alternative agricultural resources (Bonsall *et al* 2002; Tipping & Tisdall 2004).

3.1.9 Climatic deterioration at the Mesolithic / Neolithic Transition

Evidence from Bolton Fell Moss (Barber *et al* 1994), Walton Moss (Hughes *et al* 2000) and Burntfoothill Moss (Tipping 1995, 1999a) indicate that climatic dryness was widespread between c.7000 and 5800 cal. BP followed by an abrupt shift to wetter conditions at c.5900 cal. BP. A shift to wetter conditions is seen stratigraphically around c.5600-5500 cal. BP at Stanshiel Rig, south-west Scotland: the humification record shows a shift with increases in % light transmission up to 40%, and percentages of *Alnus* pollen rise to >60% TLP as an *Alnus* carr becomes established (Cayless & Tipping 2002). Elsewhere in the south-west, a pronounced shift to wetter conditions is recorded at Rotten Bottom after c.6500 cal. BP (Tipping 1999) and at Pict's Knowe from c.6040-5710 cal. BP (Milburn & Tipping 1999). This is reinforced from other sites in the north of England (e.g. Bolton Fell Moss) and elsewhere in Scotland such as Talla Moss in upper Moffatdale (Chambers *et al* 1997). The magnitude of this climatic deterioration is not clear across Scotland, although some may argue that its impacts were further reaching than a change in mire surface vegetation as it occurs at the traditional boundary between the Mesolithic and the Neolithic (Richards & Hedges 1999; Tipping & Tisdall 2004). After this period of increased precipitation, mire records from the south-west of Scotland suggest a generally dry and warm climate persisted for some time, interspersed with minor wet phases (e.g. Milburn & Tipping 1999; Barber *et al* 2003).

3.2 *The environmental and archaeological record from the south-west of Scotland: the Neolithic*

3.2.1 The *Ulmus* Decline

The beginning of Neolithic agriculture heralds the first conclusive indication of human impact on vegetation in the region. It is perhaps unlikely that changes in climate and vegetation alone determined the introduction of livestock and agricultural techniques, but these may have provided the right conditions and landscape setting for farming to be the preferred option (Bonsall *et al* 2002; Tipping & Tisdall 2004). The beginning of this period is generally held to broadly coincide with the *Ulmus* decline in most pollen diagrams. Recent studies have suggested that low intensity forest exploitation with small-scale cereal cultivation may have occurred earlier than previously thought, with low impact tree clearance of short duration visible only in high resolution pollen diagrams (Edwards 1996, 2004). Innes *et al* (2003) recognise pre-*Ulmus* decline cereal cultivation at Ballachrink, Isle of Mann and date *Triticum*-type cereal grains to c.6940-c.6630 cal. BP, suggesting that a model of low intensity farming with short-lived forest exploitation is perhaps more accurate for the transition from Mesolithic to Neolithic agricultural activity. Similarly in Ireland, cereal pollen pre *Ulmus* decline has been recorded from Cashelkeelty I in Co. Kerry dated to c.6900-c.6410 cal. BP (Edwards et al 1985), at Ballynagilly dated to c.5750 cal. BP (Pilcher & Smith 1979) and at Weir's Lough at c.5620 cal. BP (Edwards & Hirons 1984).

The more traditional 'landnam' clearance of woodland, heralded as the beginning of the Neolithic and coincident with the decline in *Ulmus*, does show variations in timing between dated sequences (Ramsay & Dickson 1996), but the mean date for the *Ulmus* decline in Scotland, based on 38 radiocarbon dates, is c.5020 cal. BP (Parker *et al* 2002). There is considerable debate over the cause of this event as it occurs within a period of increased mire wetness, but current thought suggests disease, possibly aided by human activity and / or climate change (for summaries of this argument see Roberts 1998; Tipping 1994; Peglar & Birks 1993; Parker *et al* 2002; Tipping & Tisdall 2004). The decline in *Ulmus* pollen also marks the opening of Birks' (1972) *Alnus-Quercus-Plantago lanceolata* zone seen at Snibe Bog, Machrie Moor, Arran, and at Loch Dungeon. Birks (1972) goes on to recognise eleven pollen assemblage 'zonules' based on changes in dry land trees and shrubs, but elsewhere this zone is distinguished by a rise in *Poaceae* and *Pteridium* levels (e.g. Claish Moss; Aros

Moss and Racks Moss) and little change in other tree species. At Rotten Bottom, a surprising increase in *Calluna vulgaris* is recorded at c.5600 cal. BP. Whilst this post-dates the local spread of blanket peat in this area, it is possible that woodland loss and increasingly dry conditions at this high altitude site (620m OD) permitted the development of heath (Tipping 1999c) and encouraged the spread of blanket peat. Few sites from the south-west display such early heathland development, perhaps as a consequence of localised spatial or altitudinal contrasts in climate.

The *Ulmus* decline recorded from a number of pollen diagrams from the south west of Scotland is not always associated with other palynological evidence for human activity. For example, at Loch Dungeon (Birks 1972) there is no evidence for increased inwash of mineral matter and no rise in associated Poaceae or weed species at this time and a similar picture has been found further west at Gartlea Bog (Ramsay 1995, 147). The first Neolithic woodland clearances, leading to an increase in open and disturbed ground taxa, - such as *Plantago lanceolata* at Snibe Bog (zonule 2), Aros Moss (Nichols 1967), Torrs Warren, Luce Sands (Durno 1996) where early cereal grains were recovered, Auld Wives Lifts (Dickson1981, 15) and Bloak Moss (Turner 1975) - are seen as being small and only temporary at many locations (Tipping 1994). Nichols (1967) recognises at least two phases of anthropogenic activity at Aros Moss during the Neolithic, and Wells & Mighall (1999) identified two declines in *Ulmus* pollen, the first occurring at c.5500 cal. BP and followed by a second dated to c.5900-5590 cal. BP. The fall in charcoal levels recorded from several pollen diagrams across Scotland during this period (e.g. Pict's Knowe (Milburn & Tipping 1999a) and Catharine Hill (Milburn & Tipping 1999b)) also suggest that fire was not being used as a land management tool during the *Ulmus* decline.

3.2.2 Neolithic Woodland Regeneration

A period of later Neolithic woodland regeneration is recorded in several Scottish pollen diagrams. Görransson (1994) believes this recovery of woodland species does not suggest abandonment of farmland but a return to forest farming and a change in resource exploitation. This woodland regeneration may also coincide with a shift to wetter conditions until c.4400 cal. BP (Tipping & Tisdall 2004). At some locations, where woodland does recover after clearance (Eydt 1958; Nichols 1967), there is a matched increase in open ground taxa such as *Calluna* and *Empetrum* but the re-establishment of woodland is often short lived, as seen at Brighouse Bay (Wells & Mighall 1999), Auld Wives Lifts (Dickson, 1981), Airds Moss (Durno, 1956), Bigholm Burn and Nick of Curlywee (Moar 1969), and Snibe Bog (Birks 1972). Tipping (1999b) suggests that there is no synchronicity for this phase of woodland regeneration across the south-west of Scotland and there are no consistent patterns between lowland and upland sites. Conversely, the archaeological evidence suggests farming moved into more upland sites after c.4500 cal. BP and Burgess (1984, 1985) suggests this occurred during a period of ameliorating climatic conditions with widespread movement to more marginal land. The palaeoclimatic and palynological evidence however, (as outlined below and in Tipping 1994), suggests that upland settlement expansion occurred during deteriorating climatic conditions.

Evidence from Burnfoothill Moss (Tipping 1995) suggests that the expansion of *Calluna* and other Ericaceae inferred from palynological changes at c.4700-4800 cal. BP was the result of a slightly drier phase, interrupted by a wet phase at c.4300 cal. BP. This wet phase is recorded from sites across the British Isles (see Table 3.2) and is discussed later in this chapter (section 3.3.3).

3.2.3 Neolithic Archaeology at Lagafater, south-west Scotland

The landscape surrounding the study area is predominantly a Neolithic and Bronze Age landscape with the majority of structural and artefactual remains belonging to these two periods. Monuments which are important from an early date include the Clyde and Bargrennan chambered tombs and their associated cairns (*cf.* Henshall 1963, 1972), the latter being more common in the study area (e.g. Cairn Kenny, at NX 174 752 to the east of the coring sites, and Auld Wife's Cairn, at NX 135 649 to the south) and found exclusively in the uplands of Galloway. These chambered tombs consist of a round cairn covering a passage, using long orthostatic slabs which end at a rectangular shaped tomb (Gregory 1998; Murray 1992). It is believed that these structures were precursors of the long cairns in the region and may have been in use over an extended period. For example, at Lochhill, south-west of Dumfries, a mature timber plank was dated to c.5955-c.5720 cal. BP and was believed to have been associated with a rectangular timber mortuary structure (Masters 1973). These structures are often found on knolls and ridges, giving them a prominent position over the landscape, and are distributed over a 60km belt from Loch Ryan in the west to the Water of Deugh in the east, suggesting contemporaneity of use. Although they lack 'functional' space, the uniform design and landscape position suggests social contact, a unique upland identity and the maintenance of an information network (Murray 1992).

Cummings (2002) has explored the landscape settings of these chambered tombs across the south-west of Scotland and demonstrates the problematic nature of their classification and typology, primarily based on a lack of artefactual remains. The distinctive difference between the lowland locations of the Clyde monuments with views of the sea and the upland locations of the Bargrennan monuments away from the coast with isolated views over the local landscape argues for an earlier date for the Clyde monuments, as the importance of the coastal resource follows directly from the Mesolithic tradition (Murray 1992, Cummings 2002, 142). However, the two distinctively different localities of these monuments may also suggest contemporary exploitation of different resources as part of a seasonal, nomadic lifestyle, visiting the inland areas during the summer and living along the coast in the winter. It is possible that people were moving around the landscape at different times of year, exploiting the naturally rich coastal resources during the winter, with movement inland during the summer perhaps with small groups of domesticated animals when plants and food were more available as part of a seasonal round. This latter idea predominates if we support the view of continuity from the Mesolithic into the Neolithic, and is supported by the palynological evidence for low intensity forest exploitation with small-scale pre-*Ulmus* cereal cultivation during the transition from Mesolithic to Neolithic agricultural activity.

The Clyde monuments have affinities with the court tombs of Ireland (Childe 1940; Piggott 1954; de Valera 1960) and in form, the Bargrennan chambered tombs are similar to the Irish passage graves. More recently; Sheridan (2000, 2003) has argued for movement between these two areas and with southern Brittany. In west Scotland, pottery found in simple passage tombs has been identified as being of late Castellic style, commonly found in passage tombs in the Morbihan, southern Brittany, between c.6250 and c.5850 cal. BP (Cassen 2000, 2001), although this evidence is based on a single site at Achnacreebeag, some way from this study site. Porcellanite axeheads, however, and partly worked raw materials, have been documented throughout south-west Scotland, their source being in County Antrim, north-east Ireland. Antrim flint artefacts have also been discovered (Saville 1999) along with pottery fragments whose design links north-east Ireland with south-west Scotland (e.g. Beacharra II carinated bowls) (see Sheridan 1995 for details). Sheridan (1986) and Cooney (2000) have suggested there may be two distinct trade networks in the Neolithic, the first with north-east Ireland and the second with Cumbria, as many of the axes in Dumfries and Galloway originate in Cumbria. These scattered finds may also suggest a tentative link between sites across the west coast and the Hebrides as fragments of Grooved

Ware with affinities to the Outer Hebrides and across Scotland have been found at Machrie Moor (Cowie & Macsween 2000). Many of the Clyde monuments throughout the area also have views of the Isle of Man and Cummings (2002) has suggested that the idea of monumentality was brought about through contact with this small island. Figure 3.2 (Cummings 2002) suggests that the Neolithic architecture of south-west Scotland was based on a number of styles that were found throughout the Irish Sea area.

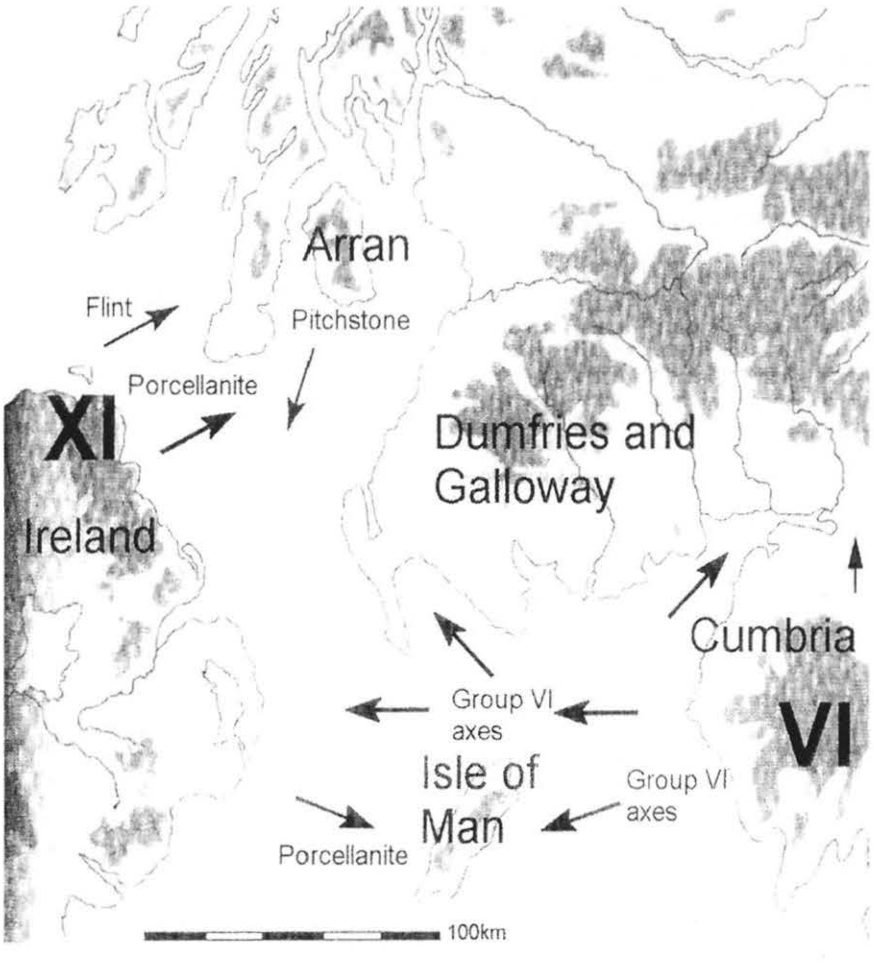


Figure 3.2: The movement of material culture in the northern Irish Sea (Cummings 2002)

Apart from the possible links with southern Brittany, Cumbria and Ireland, the lack of Mesolithic precedents for funerary traditions involving monument construction or the use of pottery suggests the Neolithic period in the south-west marked a period of incoming settlers, whose social, intellectual and ideological beliefs developed at a time when changes in the environment and a greater understanding of subsistence meant they were no longer wholly dependent on wild or semi-domesticated resources. Their activities gave rise to an expansion in plants with gathering potential around woodland and field margins created by farmers (Monk 2000), which could have been exploited by the native hunter-gatherer inhabitants. The scarcity of Neolithic settlement evidence has been linked to peripatetic or semi-mobile farming communities (Thomas 1991; Edmonds 1998) which perhaps, as upland woodlands decreased (Birks 1972), meant increased opportunity for specialist, nomadic, pastoral farming activity (Tipping & Tisdall 2004).

More commonly found in the Lagafater region are simple round cairns but it is unclear what age and purpose is represented by these (although Marklach cairn, NX 175 729 to the east of the coring sites, has been given a tentative Neolithic date (RCAHMS 1991)). Within the study area, however, evidence for prehistoric land use has survived the effects of peat growth and afforestation at these altitudes. Cairn Kenny is surrounded by deep peat, but at 500m to 2km distance, a number of hut-circles, buried walls, small cairns and enclosures have been recorded (see Figure 3.3) as dating to the Bronze Age, but with the small burial cairns offering the best prospect of a Neolithic origin (e.g. Marklach Cairn NX 175 729) suggesting a long continuity of local occupation. Murray (1992) suggests that, if as a minimum, half a dozen family units were farming within a 2km radius of each Bargrennan cairn, the population over the whole area would have reached several hundreds, although there is no architectural evidence at Lagafater to support this view.

Across the south-west of Scotland the palynological record suggests some continuity between the Mesolithic and Neolithic periods (e.g. Tipping 2004) whilst the artefactual evidence suggests new incomers (Cummings 2002). It is possible that greater numbers of people from elsewhere began to spread through the south-west of Scotland bringing new material culture but it is perhaps unreliable to assume they were also sedentary (Thomas 1996). The lack of domestic architecture for the Neolithic period is apparent across the south-west of Scotland and it is possible that at Lagafater, the blanket peat has now effectively concealed any domestic evidence. Thomas (1996) suggest that Neolithic settlement is likely to have been regionally variable in form and ephemeral in character with different seasonal cycles influencing the activities and locations of these communities, an idea supported by the palynological evidence. Across the south-west of Scotland there are only a few examples of Neolithic structures. For example, a long history of occupation is recorded at Pict's Knowe in Dumfries from an enclosure on an isolated island, with the earliest occupation evidence dating to the Neolithic. Similarly, several postholes and ditches containing early Neolithic pottery assemblages have been recorded from Hollywood, north of Dumfries; and at Holm, a kilometre away, a series of burnt ring-ditches and associated postholes have also been excavated (Thomas 2000). These ephemeral structural remains, however, highlight the scarcity and paucity of Neolithic archaeological remains across much of Scotland. Although direct evidence for Neolithic occupation within the Lagafater region is unclear, the palynological evidence supports the longevity of agricultural practises during this period (see also chapter 7).

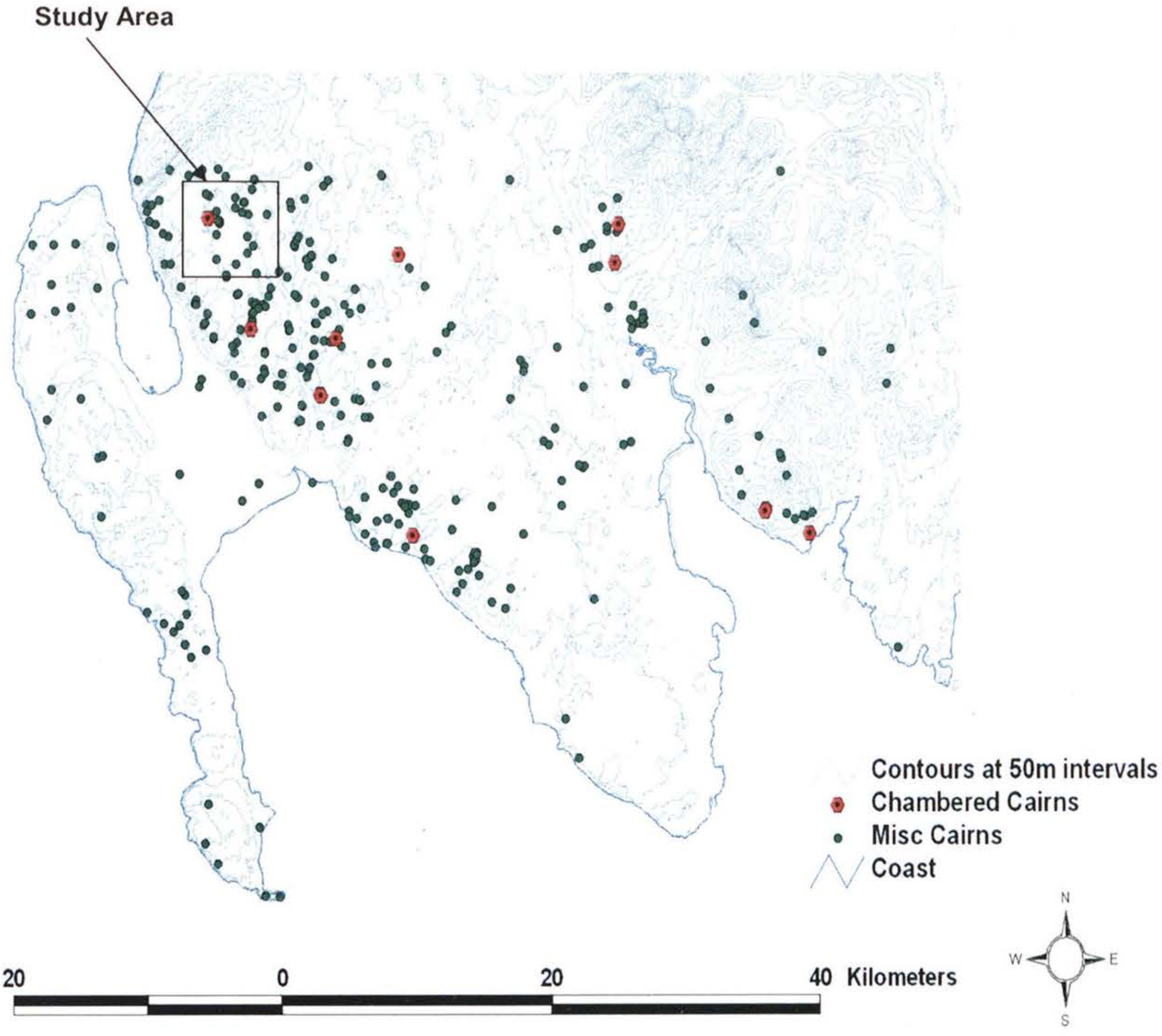


Fig 3.3 Distribution of chambered cairns across the south west of Scotland (source: Canmore, RCAHMS)

3.3 *The environmental and archaeological record from the south-west of Scotland: the Bronze Age*

3.3.1 Bronze Age decline in arboreal pollen

Many pollen sites show their first major vegetation change (with the clearance of forest and appearance of cereals) in the Bronze Age. A marked decline in tree pollen frequencies is a common phenomenon across the British Isles (Edwards 1999), arguably a continuation from the Neolithic period (Turner 1969). Agricultural activity is distinctive during this period (Tipping 1997), between about c.4000 and c.2800 cal. BP, and is mirrored at sites in Cumbria (Dickinson 1975; Hodgkinson *et al* 2000; Pennington 1970; Wimble *et al* 2000). In the Border region Bronze Age impacts have also been recorded (Davies & Turner 1979; Tipping 1992) and on the Isle of Man (Chiverrell *et al* 2004). Deforestation began early in the Oban area of west Scotland (Gallanach Beg, Lochan a'Bhuilg Bhith) at c.5500-5000 cal. BP, compared to a later date of c.3600 cal. BP along the coastal fringes of the west coast (e.g. Lochavullin) (Macklin *et al* 2000). Tipping (1994, 31) also suggests that south of the Forth-Clyde line there was a major increase in clearance activity around c.4000-3800 cal. BP, but the picture in central Scotland shows little major change until later in the Bronze Age. The frequency, extent and spatial impact of anthropogenic activity throughout this period appears to have been varied, with continuous occupation but with often small-scale clearances followed by periods of recovery (Tipping 1999). Airds Moss for example, shows a significant change around c.3000 BP with an expansion in cleared land (Durno 1956), and Linwood Moss Cottage shows peaks in herbaceous species and decreases in woodland from c.3640-3380 cal. BP (Boyd 1986). Bloak Moss (Turner 1965), Walls Hill (Ramsay 1996), Gartlea Bog (Ramsay 1995), Lochend Loch Bog (Ramsay 1995) and Lyles Hill (Austin-Smith 1998) all indicate a series of small and short-lived woodland clearances, probably for grazing purposes.

The pollen stratigraphy in 'zonule' 5 at Snibe bog and Loch Dungeon (Birks 1972), zone LRDIb from Loch Dee (Edwards *et al* 1991), zone CM-6 at Claish Moss (Moore 1977), zone C1 at Aros Moss (Nichols 1967), zone BHb1 from Burnswark Hill (Jobey 1978) and zone MM6a and MM6b at Machrie Moor, Arran (Robinson & Dickson 1988) all show a decline in tree pollen spectra, particularly *Quercus*, *Ulmus*, and *Alnus,* and an increase in non-arboreal pollen (NAP) such as Poaceae, *Plantago lanceolata*, Cyperaceae, Ericaceae, *Pteridium* spores and *Rumex Acetosa*. The first indications of cereal-type pollen are also recorded at Aros Moss, although small counts suggest no extensive agricultural activity occurred during the Bronze Age, and on Machrie Moor and from Loch Dee. The combination of cereal pollen (cf. *Hordeum*) along with pollen of Chenopodiaceae, Caryophyllaceae and Umbelliferae suggest mixed farming was practised, and a cyclical process of forest clearance may have taken place with periods of arable farming, pastoral activity and then land abandonment with subsequent forest regeneration (Robinson & Dickson 1988). Tipping (1994, 31) suggests that for clearings to have remained open for time periods extending over 100 years, settlement must have been long-term with repeated clearance episodes, whilst other authors (e.g. Ramsay 1996, 62; Turner 1965, 253) propose that communities were still practising a nomadic way of life and once they had exhausted the land, they moved elsewhere. The archaeology of the Lagafater region supports the former view (see section 3.3.2).

This period is also marked by an increase in the number of inorganic bands within peat stratigraphies and the presence of charcoal fragments. This is particularly marked at Loch Dee (Edwards *et al* 1991) and at Burnswark Hill (Jobey 1978). A charcoal layer at the former site was dated to c.2850-2490 cal. BP and would place the activity at the Bronze / Iron Age boundary (Ritchie & Ritchie 1981); a similarly dated period of soil instability is recorded at Brighouse Bay (Wells & Mighall 1999). Following these changes, open *Calluna* and Coryloid wet heath vegetation appear to have become more established, particularly at Loch Dungeon alongside a rise in *Plantago lanceolata* and *Rumex* a*cetosa* type pollen values (Birks 1972). It is during the Bronze Age in particular that widespread soil deterioration, podzolisation and blanket peat formation occurred at Tormore on Arran (at c.3200 cal. BP) (Robinson 1983; Robinson & Dickson 1988).

3.3.2 Bronze Age Archaeology at Lagafater, south-west Scotland

The study area includes a number of probable Bronze Age structures. In particular, hut-circle sites have been found in relative abundance and 90% of the known hut-circle sites in the study area were first recorded during walkover survey by the Royal Commission on Ancient and Historical Monuments of Scotland (RCAHMS) (see Figure 3.4; Cowley 2000). The majority of hut-circles are found in what are currently agriculturally marginal areas, typically in unimproved land above the 100m OD contour line. It is necessary when analysing the distribution of hut-circle sites to consider a balance of factors in which survivability and detection rate are considered (Stevenson 1975). While hut-circle sites are much more likely to survive in marginal, unfarmed land at higher altitudes, they are consequently much less likely to be discovered on lower altitude arable land except by concerted systematic survey, probably guided by aerial photographic evidence. Of the 60 hut-circle sites located in the study area, 80% are located above the 100m contour.

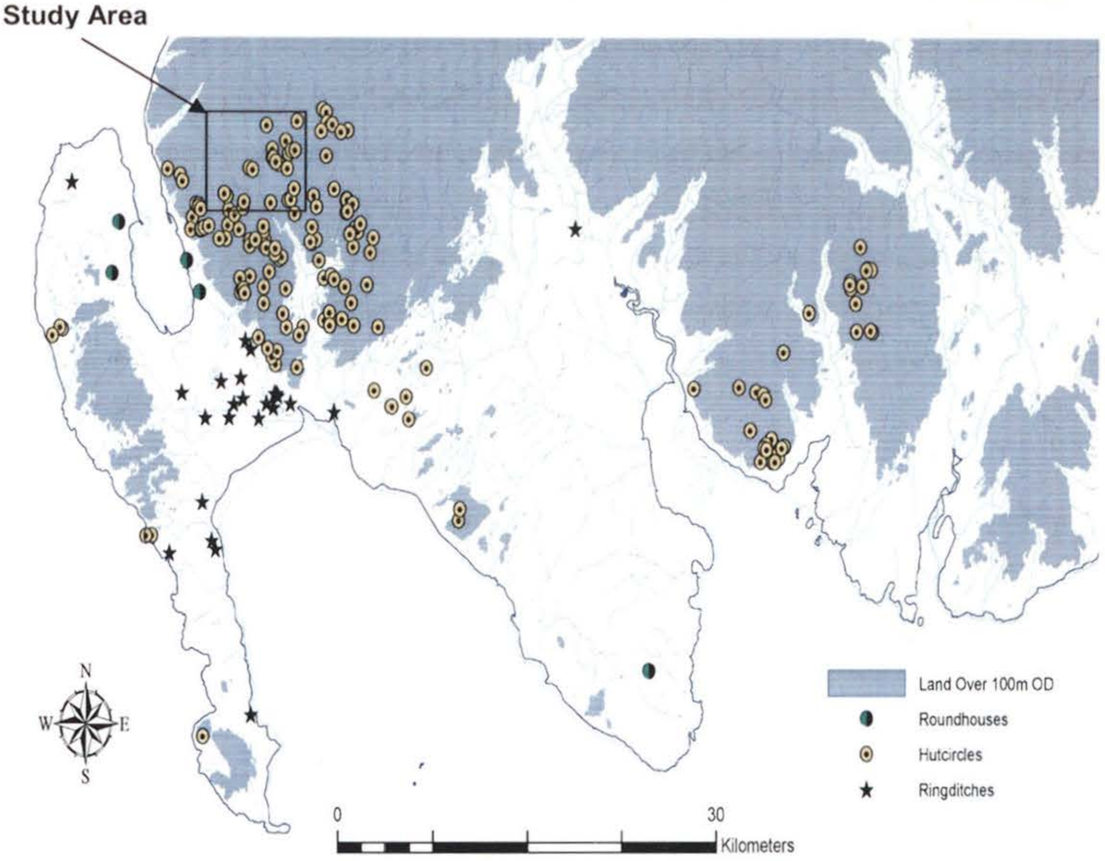


Figure 3.4: Distribution of hut circles and archaeological sites across the south west of Scotland (source: Canmore, RCAHMS)

The circular roundhouse structure as a form of settlement can be demonstrated to have currency throughout a large chronological span, from the Bronze Age through to the early historic periods, and there is little to guide classification with regard to chronological periods without excavation. There is also the possibility of the misidentification of small round-barrows. It seems likely, however, that many of the examples found in association with cairnfields, field banks and burnt mounds mainly to the south of the coring site (e.g. at Miltonise (NX 195 740), Altibrair (NX 141 696, Glenwhilly (NX 159 722) and Craigbirnoch (NX 160 860), are predominantly of Bronze Age date (Gregory 2002,68). The chronological specification of 'cairnfields' need not be tightly defined, since these are often interpreted as areas of small-scale agricultural clearance and so without distinct chronological boundaries.

Hut-circles grouped into unenclosed settlements were common in the later second and earlier first millennium BC in upland Scotland (Barber 1997; Fairhurst and Taylor 1971; Jobey 1980; Rideout 1996) and later can also be found apparently post-dating the abandonment of fortifications at many sites in southern and eastern Scotland (Armit 1999; Cowley 1998; Harding (ed.) 1982; RCAHMS 1997). It may also be likely that unenclosed settlements were occupied at the same time as later prehistoric fortified and defended settlement types. The over-representation of hut-circle settlement groups in upland unimproved lands, therefore, is an artefact of differential survival rates, and it is entirely plausible that unenclosed hut-circle settlements were equally common throughout the later second and first millennia BC in both upland and lowland zones (Harding 2000); indeed, preliminary indications from cropmark sites in the Luce area suggest that this was the case (such as at Fox Plantation, MacGregor 1996, 1997).

The hut-circles in the study area generally measure between 5m and 12m across, with an average diameter of 8-9m (Cowley 2000). They typically comprise a low perimeter bank, sometimes revetted into a hill slope and occasionally (more commonly in the west of the region) with porch or enhanced entrance features, such as the 'baffle walls' at sites like Little Larg (NX16NE 82), Little Laight (NX07SE 44), Several Burn (NX06NE 4) and Dalhabboch (NX16NW 88). Generally, the upland examples are of a type widespread throughout Scotland and northern England, the common double-walled variant of which is often referred to as the 'Dalrulzion' type (Thorneycroft 1933). Almost invariably, the entrances to hut-circles are placed in the SE quadrant (facing E, SE or S), a feature that has been taken to indicate ritual aspects. The frequency with which hut-circles are located on S and SW facing slopes has also been noted, indicating attempts to maximise the available light and warmth from the sun (Yates 1984, 223). The uniformity of this arrangement might suggest a broad contemporaneity within the currency of these ritual and practical concerns, so that notable exceptions such as hut-circle 1 within the complex at Cairnmon Fell (NX04NW 1) may indicate longevity of settlement at that site, outliving the general concern with entrance orientation in these structures. Similarly, it might be reasonable to suggest that the larger, more developed sites like the massively built roundhouse at Cairnerzean (NX16NW 70), with its 3m thick wall might date to the earlier Iron Age, after the commencement of the main phase of monumental roundhouse construction (Hingley 1992).

The archaeological landscape during the Bronze Age is suggestive of an organised, sedentary, domestic and agricultural society, particularly with the recorded presence of early field systems associated with possible cereal agriculture (Carter *et al* 1997). Examples of narrow rig-and-furrow field systems can be seen at Little Larg (NX 154 658) to the south of the coring sites. The characteristic cairnfields and groups of cairns may represent the locations of single burials but more likely relate to land clearance. Burnt mounds are suggestive of domestic use, although their relationship to settlements and exact function are unclear (Tipping 1999). Burnt mounds found in association with Bronze Age settlements have been recorded to the south of the coring sites, at Mardhu (NX 189 745), Glenwhilly (NX 159 713), Dirniemow (NX 181 715) and Pularyan (NX 139 685).

Of particular relevance to this study are the hut-circle sites and field systems at Barnvannoch (NX17SW 19), Stab Hill hut-circle (NX 146 719), Knockglass Rees hut circle and field system (NX 148 716) and Glenwhilly hut circle, clearance cairns and field system (NX 163 724). (See also Fig 3.4). These Bronze Age sites lie within 2-3 km of the coring site (Lag 230m OD) and highlight the colonisation of land not previously used before and an attempt to farm when conditions were perhaps unfavourable. These sites suggest that upland moor or grassland areas were used for resources such as timber and stone for building materials, other raw materials, and possibly upland seasonal grazing.

A marked decrease in human activity at the end of the Bronze Age and in the early Iron Age has been recorded from Machrie Moor, Arran (Robinson & Dickson 1988) and from Aros Moss (zone C3) where *Ulmus*, *Quercus* and *Fraxinus* values rise (Nichols 1967). Numerous reasons have been cited for this apparent abandonment of activity: it has been hypothesised that deterioration in the climate (Lamb 1977; Piggott 1972) may have resulted in increased ombrotrophic conditions, podzolisation and the spread of heath (Moore 1975).

3.3.3 Climatic Deteriorations during the Bronze Age

By 6000 cal. BP, the interglacial cycle had been fully initiated (Stager & Magewski 1997) and a general deterioration in the climate occurred (Bell & Walker 1992). Evidence from peat stratigraphy suggests however, that the last 5000 years were typified by a series of relatively short-lived climatic changes with periods of slightly drier and wetter conditions (Hughes 1997). Overall, increased storminess and precipitation levels prevailed during the late Holocene with several more frequent 'wet phases' identified in many proxy records. Dubois and Ferguson (1985) indicate that such a phase existed between c.4200 to 3900 cal. BP, coinciding with the demise of pine woodlands on bog surfaces, an idea also supported by Gear & Huntley (1991) who believed a change in atmospheric circulation was responsible for increased precipitation. There is evidence to support the idea that blanket bog spread considerably throughout the north of England and across the Pennines at c.4000 BP (Pennington 1974; Tallis 1991), and wet shifts have been recorded at Burntfoothill Moss between c.4400-4000 cal. BP and persisting until after c.3000 cal. BP (Tipping 1999), at Bolton Fell Moss, Cumbria from c.4020-4620 cal. BP, and at several sites across Ireland e.g. Abbeyknockmoy at c.4000 cal. BP (Barber *et al* 2003). Anderson *et al* (1998) inferred major transitions in climate between c.3900-3500 cal. BP from sites across Scotland, implying that this was a regional, synchronous event.

After c.3000 cal. BP, some sites, including Bolton Fell Moss, show a recovery to drier conditions but this is replaced by further climatic deterioration, particularly at the period beginning c. 2800-2500 cal. BP where records suggest more frequent cooler and wetter phases with accelerated peat development, and temperatures approximately 2°C lower than they had been 500 years before (Taylor 1980; Lamb 1977). Across Europe, major climatic change at c.2650 cal. BP is recorded: e.g. van Geel *et al* (1996) records climatic deterioration from sites in the Netherlands, and Table 3.1 shows a clustering of similar dates around this time from sites across Scotland, in particular Temple Hill Moss (Langdon *et al* 2003) and Kentra Moss (Ellis & Tallis 2000). Few sites from south-west Scotland appear to have recorded major changes in humification records or vegetation change at this time, perhaps as a result of natural lags in response time within the peat system. After this time, a number of frequent and discrete wet shifts have been recorded across Scotland, particularly at c.2250, 1750, 1400 and 1000 cal. BP (e.g. Barber *et al* 2003; Charman *et al* 1999).

3.4 The environmental record from the south-west of Scotland: the Iron Age & Roman Iron Ages

3.4.1 Iron Age and Roman Iron Ages

For most areas within central and south-west Scotland, large-scale clearance occurred during the late pre-Roman Iron Age, particularly between c.2500-2000 cal. BP (Ramsay & Dickson 1996; Tipping 1999). Intensification of agriculture and settlement during the late pre.

Roman Iron Age is believed to have been widespread across much of southern Scotland (Mercer & Tipping 1994) and exceeds in scale later historic clearance episodes (Dumayne 1993; Dumayne & Barber 1994; Tipping 1995, 1997). Sites at Walls Hill (Ramsey 1996), Cranley Moss (Dumayne 1993), Peelhill (Durno 1965), Lochend Loch Bog (Ramsey 1996), Letham Moss (Dumayne 1993), Lenzie Moss (Ramsay 1996), Burnfoothill Moss (Tipping 1995a) and Gartlea Bog (Ramsay 1996) all show clearance episodes during this period. An intensification of grazing is suggested at Brighouse Bay by a rise in *Plantago lanceolata* at the end of zone BB/POL/6, and the occurrence of cereal grains suggest pastoral agriculture was also being practised (Wells & Mighall 1999). Large-scale permanent woodland clearance also begins in the Iron Age at Ellergower and Carsegowan Mosses in the south-west and is followed by a second clearance phase during the Roman occupation (Dumayne 1992, 1993; Barber *et al* 1993).

Most clearance episodes appear to have been for pastoral activity, e.g. at Over Rig (Tipping 1997). Numerous records of cereal pollen have been recorded and Boyd (1986, 77) believes that arable agriculture may be under-represented and patterns may show some local variation. In Ramsay's study (1995), some areas appeared to have undergone a series of discrete clearings, whilst other sites do not show any evidence that clearance occurred until much later on, e.g. at c.1620-1250 cal. BP at Bloaks Moss (Turner 1965). It is therefore likely that the Iron Age and into the Roman Iron Age consisted of a landscape that was a mosaic of forested and cleared areas (Boyd 1985; Edwards & Ralston 2003).

Some areas remained cleared throughout the later Iron Age and into the Roman period, such as Fannyside Muir and Letham Moss (Dumayne 1993), whilst woodland regenerated elsewhere: e.g. Burnfoothill Moss (dated to c.1650 cal. BP) (Tipping 1999a); Walls Hill Bog (Ramsey 1996); and Black Loch (Whittington *et al* 1991). It has been suggested that vegetation change in different areas of northern England and southern Scotland reflects the differing relationship between native populations and the newly arrived Roman presence (Boyd 1984; Tipping 1994; Whittington & Edwards 1994) with the establishment of the Antonine Wall across the Forth-Clyde isthmus by AD 142 (Edwards & Ralston 2003). However, the extent of the natural forest cover, the date of extensive clearances, and the impact of a Roman presence in southern Scotland has been a subject of long debate (e.g. Dickson 1992; Dumayne 1993; Hanson 1996). Dumfries and Galloway remained little affected by the presence of a Roman army elsewhere in southern Scotland and there is increasing palynological evidence to suggest a largely cleared landscape existed prior to any short term demands made by a Roman presence, attesting to the long term expansion of settlement and agriculture in the local area (Edwards & Ralston 2003).

3.5 The environmental record from the south-west of Scotland: the post-Roman era

3.5.1 Post-Roman Period

Over the final 2000 years in what seems to be a general cooling period, two specific periods of climatic change stand out, 'The Mediaeval Warm Period' and 'The Little Ice Age'. The former occurred between the 11th and 13th centuries AD, marked by a period of warmer and drier conditions with summer temperatures up to 16.5°c, and the latter occurred following this. A major wet shift is recorded for the period between c.850-450 cal. BP, in particular at Burntfoothill Moss (Tipping 1999), Talla Moss (Chambers *et al* 1997), Coom Rig Moss, Northumberland, and at Bolton Fell Moss (Barber *et al* 2003). Palaeoenvironmental and historical data indicate that the 'Little Ice Age' began abruptly in the 15th century and ended even more abruptly in the 18th century, and was characterised by colder, wetter winters with temperatures 1-3°c cooler than today (Bradley & Jones 1993). The effect of this was to encourage the re-advancement of mountain glaciers, flooding around the Atlantic coasts and vegetational changes (Bell & Walker 1992).

Few pollen diagrams from the south-west of Scotland have considered the palynological evidence for the post-Roman and Mediaeval periods. Clearance was generally maintained for several centuries after the Roman period - e.g. at Bloak Moss, Ayrshire (Turner 1970), at Burnfoothill Moss (Tipping 1999b), at Rotten Bottom (Tipping 1999c) and from the Galloway Hills (Birks 1972) - and resumed again from c.1150 BP in many areas, e.g. at Gartlea Bog (Ramsay 1995) and Black Loch (Whittington *et al* 1991), and later at c.750-550 BP (Ramsey & Dickson 1996). At Machrie Moor, Arran it would appear that agriculture continued throughout the Dark Ages between 1550-1150 cal. BP, with the continued presence of *Plantago lanceolata*, *Ranunculaceae*, *Rumex*, *Urtica* and Pteridium spores but that it was severely limited by peat growth.

SITE	Post Med.	Little Ice Age	Med.	Warm Period	Early Med.		Early Historic		L. Iron Age		L. Iron Age	E. Iron Age	L. Bronze Age	EBA / L. Neo	Early Neo	Meso.	Meso.
ENGLAND																	
Bolton Fell Moss (1)	210	500			1000	1300					2200	2900	3600	4350			
Bolton Fell Moss (2)			630		1000		1400				2200	2350	3020	4020	5250		7500
												2440	3200	4280	5420		7800
												2580	3600	4420	5700		
												2900	3750	4620	6200		
Walton Moss (3)	100						1450		1750		2320-2040	3170-2860	3500	4410-3990	5300-5900		7800
	350																
Walton Moss (4)	240-150	500-400	680	840	1120		1550-1400		1730			2630-2590					
												2900-2830					
Border Mires (5)	180	550		850	1030		1400		1740	1980	2130	2540					
												2710					
Wood Moss, Derbyshire (6)						1270				1910							
Harolds Bog, North East England (6)					1150	1310	1390										
Foulshaw Moss (7)						1350						2900	3400	4300			
Heslington Moss (7)												2900	3400	3800			
White Moss North (7)			600		1050				1700		2250	2900					
White Moss South (7)				800				1500			2250		3500				
White Moss, S.Cheshire (8)														4750-4570			
May Moss, North York Moors (9)	250-150	550-330	600-500		1280-970	1400-1300		1690-1410									
Coom Rigg Moss, Northumb (10)		450	600	850	1000	1350		1550			2150	2900-2700	3500				
Coom Rigg Moss, Northumb (11)	180-150	550-480		840-690	1030-890	1400-1280			1740-1590		2130-2080	2710-2570					
												2470					
IRELAND																	
Mongan Bog, Ireland (2)		450	600	850					1600		2250	2350	3200				
									1800			2450					
												2750					
Abbeyknockmoy, Ireland (2)	210		700		1050		1400		1750		2200	2750	3500	4000			
														4250			
Fallahogy Bog, Northern Ireland (12)	300-100				1250-1010												
Latterfrack, W.Ireland (6)	290-230	540-410				1310	1390										

Table 3.1: Wet phases inferred from palaeoclimatic evidence from sites across the British Isles & Europe. Dates in Cal. BP

SITE	Post Med.	Little Ice Age	Med.	Warm Period	Early Med.		Early Historic		L. Iron Age		L. Iron Age	E. Iron Age	L.Bronze Age	EBA / L. Neo	Early Neo	Meso.	Meso.
WALES																	
Migneint, N.Wales (6)						1330	1400										
Migneint, North Wales (13)												3000-2100					
Brecon Beacons (6)		490							1855								
SCOTLAND																	
Talla Moss, Borders, Scotland (14)		540			1095				1700	1930	2265	2600	3455				
Sutherland (15)			600					1400-1600		2000	2200-2300						
Traligill Basin, Sutherland UAM1 (16)							1470		1840	2010	2280	2540					
										2090		2810					
Traligill Basin, Sutherland UAM2 (16)									1870	2020	2240						
										2090	2310						
Temple Hill Moss (17)						1250						2800-2450	3450-3400	4650	5950-5300	6650	
Kentra Moss, Argyll, Scotland (18)	325		600	875	1150		1400				2150	2550	3250				
Moine Mhor, Scotland (12)	280-140			960-750													
Bell's Flow, nr Gretna Scotland (19)		430					1390-1440	1500-1530									
								1590-1610									
Raeburn Flow, Gretna Scotland (19)		540	580-680		1110-1140		1390	1500-1570	1760-1790		2140	2740-2810	3340	3830			
Felecia Moss, Borders, Scotland (11)	150	550-480		840-690	1030-890	1400-1280			1740-1590	1980-1870	2110	2660					
												2480					
												2360					
Cross Lochs, Sutherland (20)												2890-2750					
Kilpatrick Flemming (21)		400			1200					2050				4000	5250		
Eilean Subhainn Bog, W. Ross (22)					1000							2690	3460		5260	6220	7500
Glen Torridon Bog, n.w Scotland (22				900								2400	3170	3850	4950		
Glen Carron Bog, n. w Scotland (22)				870										4400	5130		
														3830			
Rannoch Moor, Western Scotland (23)													3300	4250-3870		6250-5800	7500
Beinn Dearg, Wester Ross LDM (22)					1000								3000	3900-3500		6500-6000	
Beinn Dearg, Wester Ross MFD (22)					1000								3000	3900-3500		6500-6000	
Beinn Dearg, Wester Ross GBT (22)					1000								3000	3900-3500		6500-6000	
Beinn Dearg, Wester RossDMR (22)					1000								3000	3900-3500		6500-6000	
Ellergower Moss (30)	175			830					1800		2220		3390	4120-4415			
Carsegowan Moss (30)		410				1430		1635		2030	2150	2680					

SITE	Post Med.	Little Ice Age	Med.	Warm Period	Early Med.		Early Historic		L. Iron Age		L. Iron Age	E. Iron Age	L. Bronze Age	EBA / L. Neo	Early Neo	Meso.	Meso.
OTHER COUNTRIES																	
NW Europe (23)					1150				1850			2550		4200			
												3050					
Engbertsdijksveen, Netherlands (24)												2850		3750	5450	6800	
												3020		4350	5850	7150	
												2750-2450			6450		
Meerstalblok, Netherlands (25)																	
Isosuo, Tremanskarr Kantosuo (26)														4300			8000
N & C Norway (20 bogs) (27)		420	720	850	1140		1400		1680	1930	2230	3120	3370	3780	5350		
														4280			
														4690			
Bourtangerveen (28)										1950			3300-3650	4450	5300		
Etang de la Gruere, Switzerland (28)																	
Draved Mose, Denmark (29)		450	660	860				1500	1700		2250	3000	3400	4000	4850		
														4300	5050		
														4600	5400		

References

(1) Barber 1981, 1994 (2) Barber et al 2003 (3) Hughes et al 2000 (4) Barber 1991 (5) Mauquoy & Barber 1999b (6) Blackford & Chambers 1991, 1995 (7) Wimble 1986

(8) Lageard,G.A et al 1999 (9) Chiverrell RC 2001 (10) Charman et al 1999 (11) Mauquoy D & Barber K (1999a) (12) Barber et al 2003 (13) Ellis & Tallis (2001)

(14)Chambers et al 1997 (15) Anderson et al 1999 (16) Charman et al 2001 (17) Langdon PG et al (2003) (18) Ellis & Tallis 2000 (19) Mauquoy D & Barber K (2002)

(20) Charman 1990 (21) Tipping 1995 (22) Anderson 1998, Anderson et al 1998 (23) Bridge et al 1990 (24) Van Geel 1978, 1996 (25) Blaauw M et al 2004

(26) Korhola 1995 (27) Nilssen & Vorren 1991 (28) Dupont 1986 (29) Aaby 1976 (30) Stoneman 1993

Chapter 4 The Study Area & Methodology

4.1 *The Study Area*

The study area is a large blanket peat complex located approximately 12 miles north-east of Stranraer in the parish of Newton Stewart (NX 138 755). The site was chosen following extensive exploration of the south-west of Scotland as it contains a largely undisturbed tract of 'active' blanket bog spanning an area *circa* 10km^2 and is positioned some distance from the nearest forestry plantation (see Figure 4.1). The area is bordered to the east by the main water of Luce and to the west by Glen App, and at its higher altitudes (420m OD) it is possible to see the tip of the North of Ireland. An area of blanket peat was sought which would provide a sub-peat topography with which to test the theories of blanket peat initiation and which covered a large enough topographical area to understand those processes operating at higher and lower altitudes.

The study site, known locally as the Berneraird / Lagafater moorland, falls under the Glen App – Galloway Moors SPA (Special Protection Area) which encompasses a larger upland area extending north from Castle Kennedy in Dumfries and Galloway to Ballantrae in South Ayrshire. The study area has a subdued, rolling topography at altitudes in the range of 200-450m above sea level and the blanket peat appears to extend from 230m OD to 450m OD. This area once formed a continuous moorland landscape but is now fragmented by afforestation planted in the 1960's, particularly at Peat hill, lying one kilometre east of the higher altitude site and the plantation at Dupin Hill to the west, which lies approximately one and a half kilometres from the mid altitude site. The upland location of these plantations has influenced the dominance of Sitka Spruce (Forestry Commission 1999).

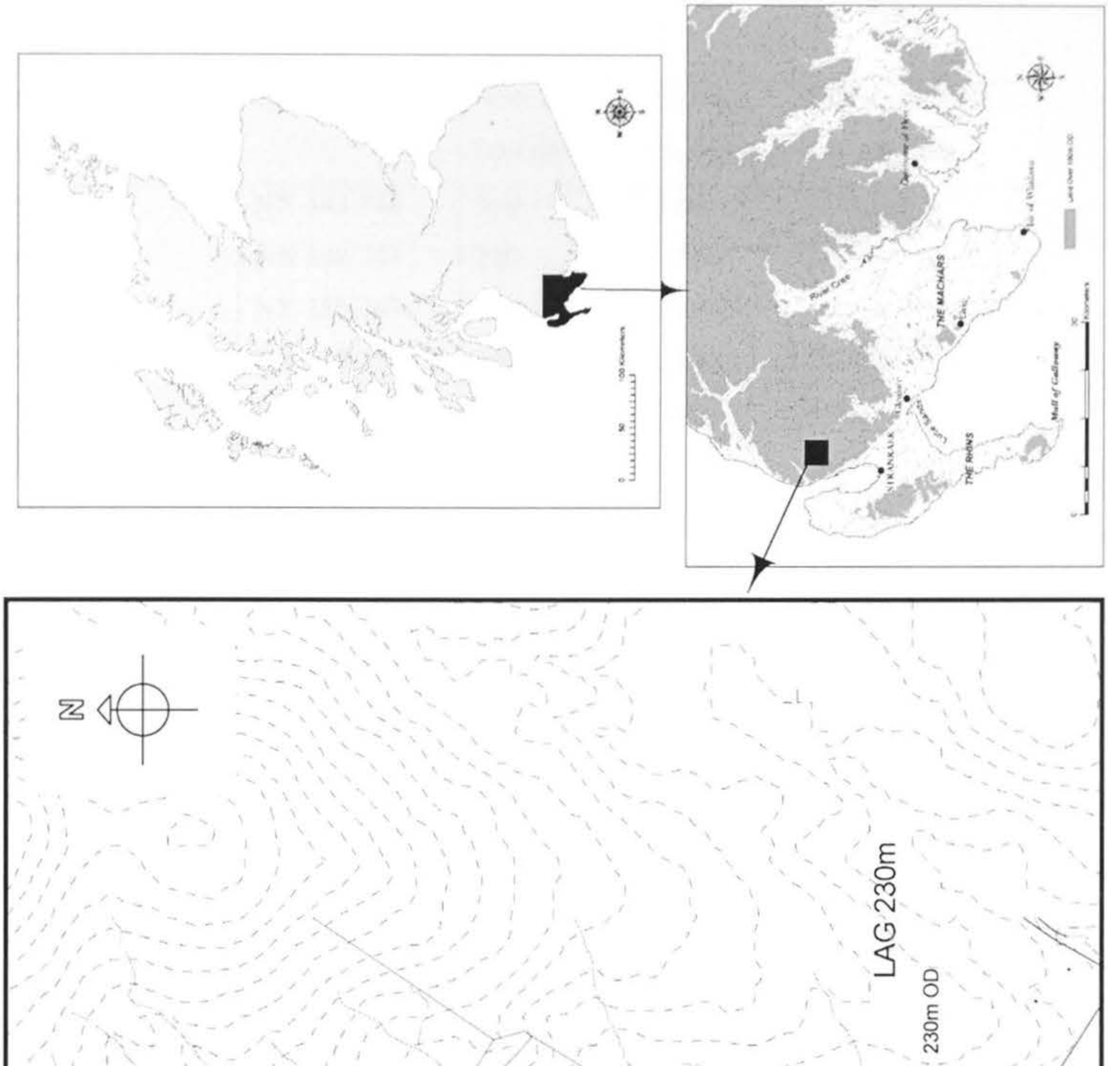


Figure 4.1: Location of the study area in south west Scotland. The location of the three coring sites at Lagafater (Lag 230, 300 & 400m OD).

Site	Grid ref.	Altitude (m OD)	Av. Peat Depth (m)	Catchment area km² (approx)
230m BOS	NX 143 748	210	2.00m	1.50km^2
230m MOS	NX 148 747	220	1.00m	1.50km^2
230m TOS	NX 150 747	230	2.00m	1.50km^2
300m BOS	NX 139 754	230	1.50m	2.00km^2
300m MOS	NX 133 754	300	1.00m	2.00km^2
300m TOS	NX 127 755	320	1.30m	2.00km^2
400m BOS	NX 140 771	320	1.55m	2.00km^2
400m MOS	NX 136 772	370	1.20m	2.00km^2
400m TOS	NX 134 776	410	1.50m	2.00km^2

Table 4.1: Lagafater site details

The climate of the region is typically oceanic with mean annual rainfall exceeding 2000mm with over 200 rain days a year particularly on higher ground (Met office data, 2004). A high incidence of cloud and relative humidity is experienced across the Lagafater region with a mean January temperature of 6.7°C and a mean July temperature of 19°C (Birks 1996). During the winter Dumfries and Galloway remains relatively mild with <25 days of snow falling between December and April (Met office data, 2004).

4.2 Geology and soil formation

The solid geology of the area is comprised mainly of Ordovician Ashgill and Caradoc series, and Silurian Llandovery and Wenlock series (greywackes and shales) with pockets of Carboniferous basalt and spilite and coal measures (IGS 1979). The Lagafater estate lies over the Ordovician series with the Silurian Llandovery sediments beginning slightly north of Glen Luce. Both series run east to south-west in the direction of the southern upland fault (Ballantyne *et al* 1997). Bands of chert have also been discovered in the Ordovician and lower Silurian sediments and are believed to have been an important source for stone tool manufacture (Wickham-Jones & Collins 1978).

Evidence for previous glacial activity during the Dimlington Stadial and Loch Lomond Stadial in particular (c. 11000-10300 ^{14}C BP) is particularly clear at Dalnigap, close to the study site (NX 135 715), where there are a series of drumlins, rock outcrops and small kettle holes, typifying the drumlin fields found in the western lowlands (Kerr 1982). The region was covered by the southern upland ice sheet from the Loch Doon-Merrick massif to the Lowther Hills (Sutherland 1984). ^{14}C dating of early peat deposits from Redkirk Point (c. 12300 ^{14}C BP) and Bigholm Burn (c. 11800 ^{14}C BP), suggest deglaciation was complete by 13000 ^{14}C BP (Nichols 1967).

The study area is dominated by blanket peat, with some peaty gleyed soils and peaty podzols derived from greywackes and shales at the lower altitudes and around the periphery of the coring area, particularly towards the valley floor and the Black Glen Burn and Main Water of Luce (see Figure 4.1). The development of these soils and the influence of the underlying geology are particularly relevant to the study as the presence of a soil horizon was noted beneath several of the peat sections prior to blanket peat initiation. The ability to recognise palaeosols has been discussed by several authors (e.g. Birkeland 1999; Catt 1990) but the presence of root traces and possible soil horizons (in particular C and E horizons) suggest that these may represent a previously vegetated ancient land surface (Rettallack 1980, 1990). All the soils in the study area consist of poorly sorted quartz and feldspar set in a matrix of clay composed of chloritic or micaceous material (Brown & Heslop 1979) and shales composed of mica and chlorite (Bain et al 1995). These soils form the Ettrick Association that is common across the Southern Uplands (Soil survey of Scotland 1984).

Several diagenetic changes are likely to have occurred to these buried soil horizons including compaction, cementation and dissolution but they will nevertheless have been derived from the underlying parent material which will have played a role in the rate of paludification prior to the onset of blanket peat. Bain *et al* (1995) consider the rate of weathering in soils developed on greywackes and shales across the south-west of Scotland and suggest the mineralogy of the basal horizons reflects the mineralogy of the parent material. The study suggests a marked decrease in the amount of chlorite and mica initially, with a resultant increase of more resistant quartz and alkali feldspar. This process will often lead to the formation of vermiculite (a 2:1 layer clay mineral), which frequently contains hydroxyaluminium material in the interlayer space (adsorbed from soil solution). Similarly, these soils contain low rates of base cations indicating these soils are, and have been, susceptible to acidic inputs (Bain *et al* 1995).

4.3 Vegetation

The area is almost totally devoid of native trees and blanket bog communities are widespread. The surface vegetation is dominated by *Calluna vulgaris*, *Rhytidiadelphus triquestrus*, *Amphidium mougeotti* and *Festuca ovina.* At 230m OD and towards the base of slopes, agricultural intensification has resulted in the creation of semi-improved grassland towards the Water of Luce, and an abundance of *Juncus* spp and *Erica cinerea* predominates over *Calluna vulgaris.* Across the area, in the wetter hollows, *Sphagnum palustre*, *Sphagnum cuspidatum* and *Sphagnum magellanicum* can be found along with *Eriphorum vaginatum* and *Potentilla*, particularly at higher altitudes. On the more hummocky ground *Erica tetralix*, Poaceae, and *Polytrichum commune* are evident. At 400m OD *Breutelia chrysocoma*, *Pseadosderopodium perum*, *Rhizomrum punctatum*, *Rhytidiadephus squarrosus* and *Cratoneuron commutatum* are also recorded.

Most of the area is covered in degraded heather moorland with areas of rough, agriculturally unimproved grassland at the lower altitudes. Over 90% of the agricultural land in the area is pasture or rough grazing for sheep, and a number of former early eighteenth century enclosures and field boundaries can be seen, particularly below 300m OD.

4.4 Hydrology & Topography

Each individual blanket peat site is an area that will contain a continuum of individual profiles of different peat depths, reflecting variations in lithology and glacial and periglacial substrates (Smith & Taylor 1989) as outlined in section 2.2. The process of identifying older peat deposits and the nature of blanket peat spread requires the study of a number of profiles up and down slope. This is because processes such as back-paludification, whereby peat spreads up-slope, have been recorded from several sites across Europe (e.g. Foster & Fritz 1987), and lateral paludification will have occurred on both micro- and macro-scales, within and between the main peat foci. The geomorphological variability of pre-peat landscapes results in major differences in the time of peat initiation (Charman 2002, 77) but current peatland morphology may mask the shape of the underlying substrate. Consideration was therefore given to the surface and sub-surface geomorphology and topography of each site location and samples were retrieved from closely identical situations (moisture receiving / shedding sites etc.) for accurate comparability.

Contour survey maps, focused upon the three individual slope surroundings, were produced. Using *Penmap* for *Windows* running on a pen based *Compaq Concerto* portable computer linked to a *Leica TC1010 Total Station* it was possible to produce an accurate digital image of the topography of the adjacent landscape, highlighting more specific morphological features relating to the hydrological and topographic history of the area. The heights and distances across each slope were also recorded. Figure 4.2 shows the location of the survey areas and Figure 4.3 (a, b and c) shows a high resolution computer-generated model of the three altitudinal areas. Unfortunately, it was not possible to display the contour data recorded at site Lag 300m OD as a result of problems with the data points. The original transect locations however, were geo-referenced and placed over the 1:25,000 OS map (Figure 4.3 (b)). The wider implications of this are discussed in Chapter 5.

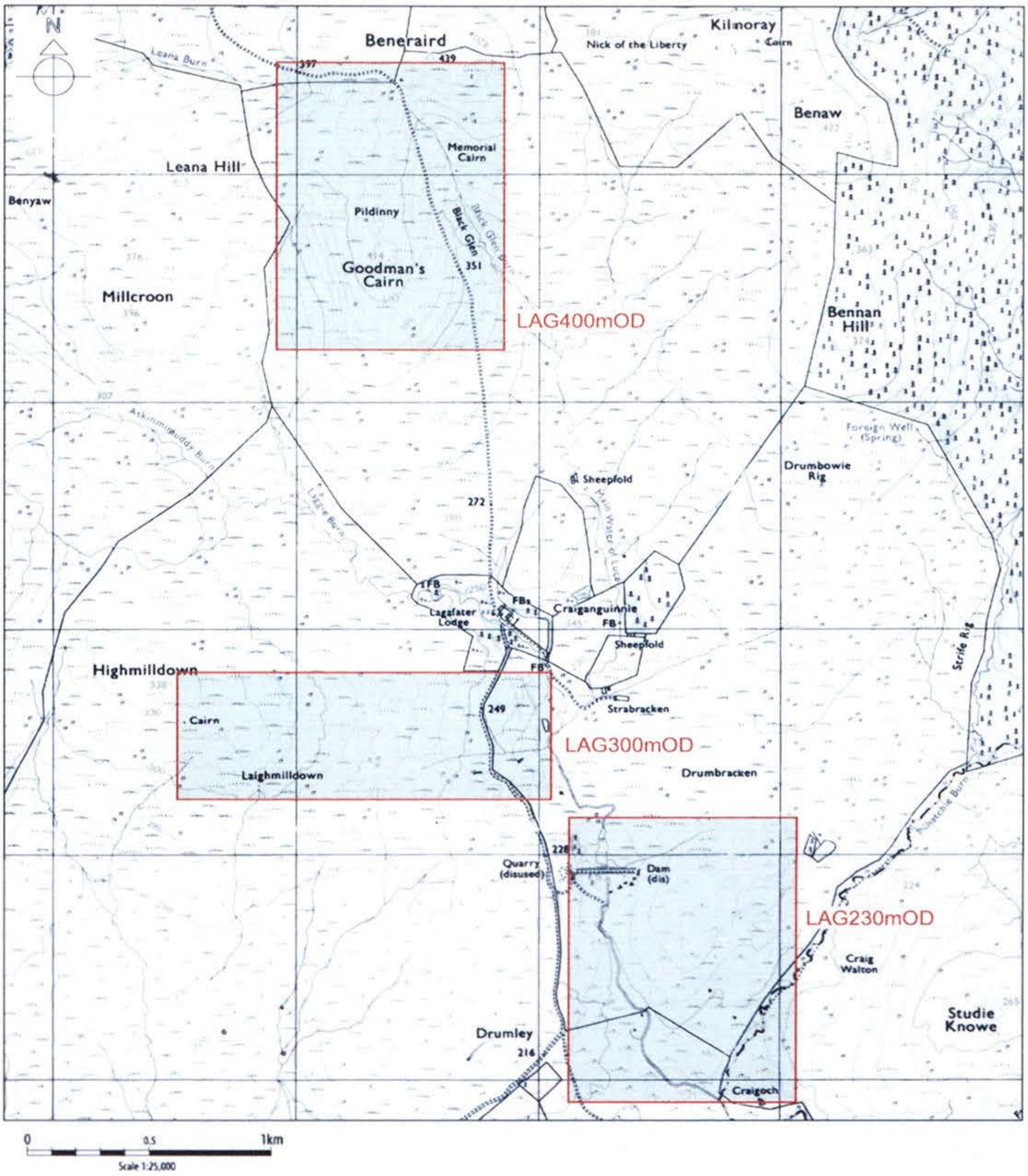


Figure 4.2 Location of the digital terrain models at the three altitudinal areas.

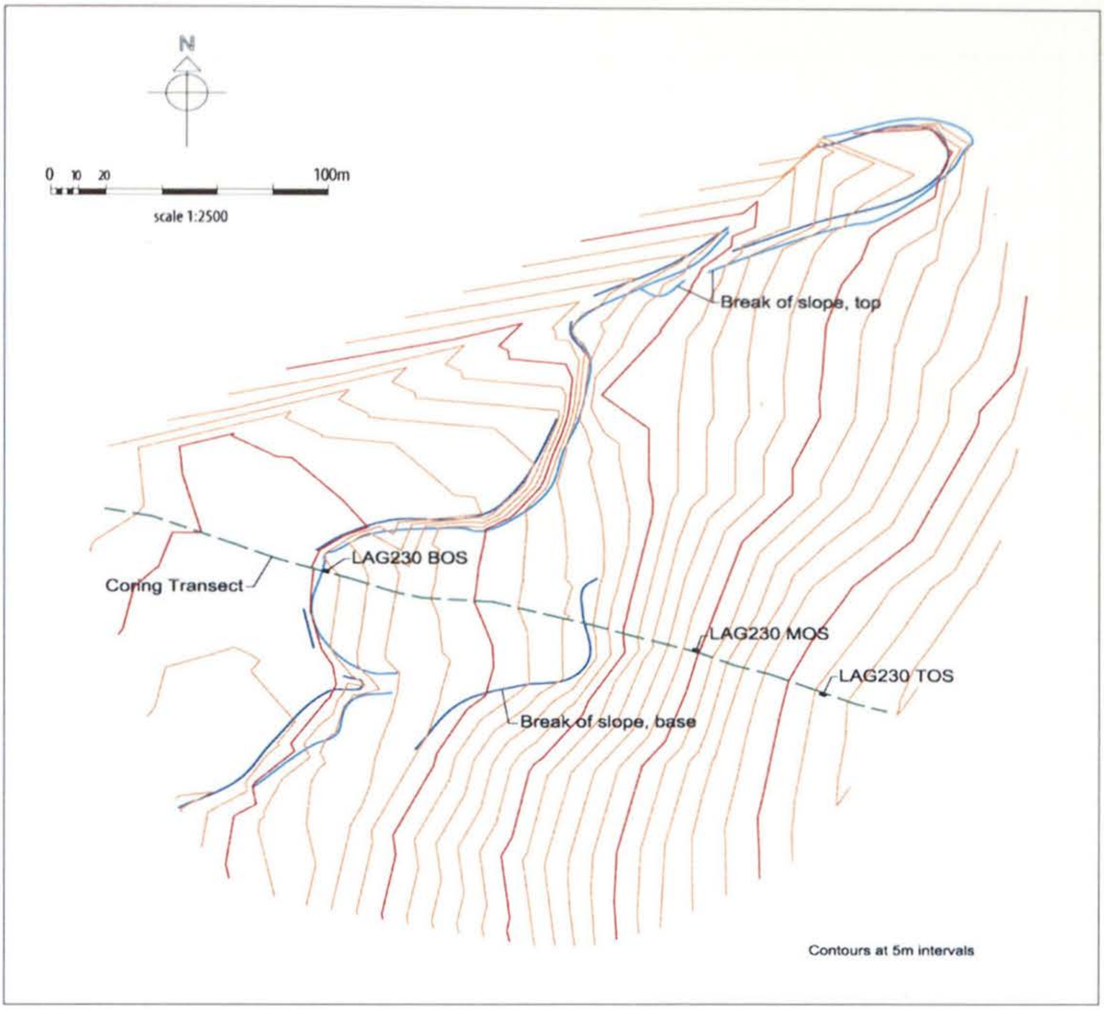


Figure 4.3 (a): Digital terrain model at Lag 230m OD, showing trench locations

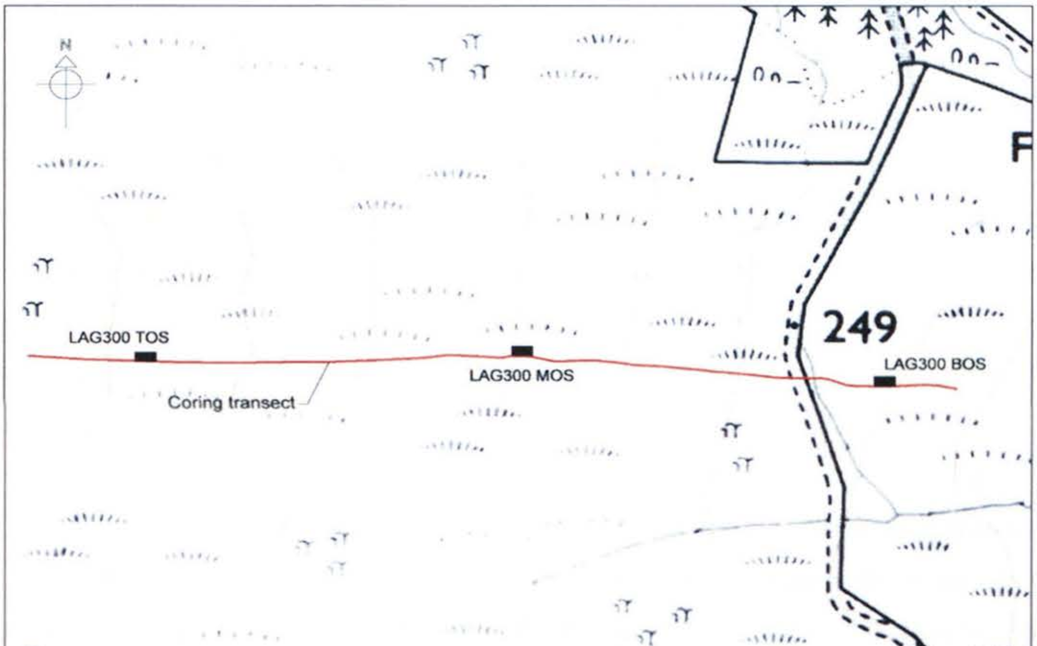


Figure 4.3 (b): Trench locations at Lag 300m OD

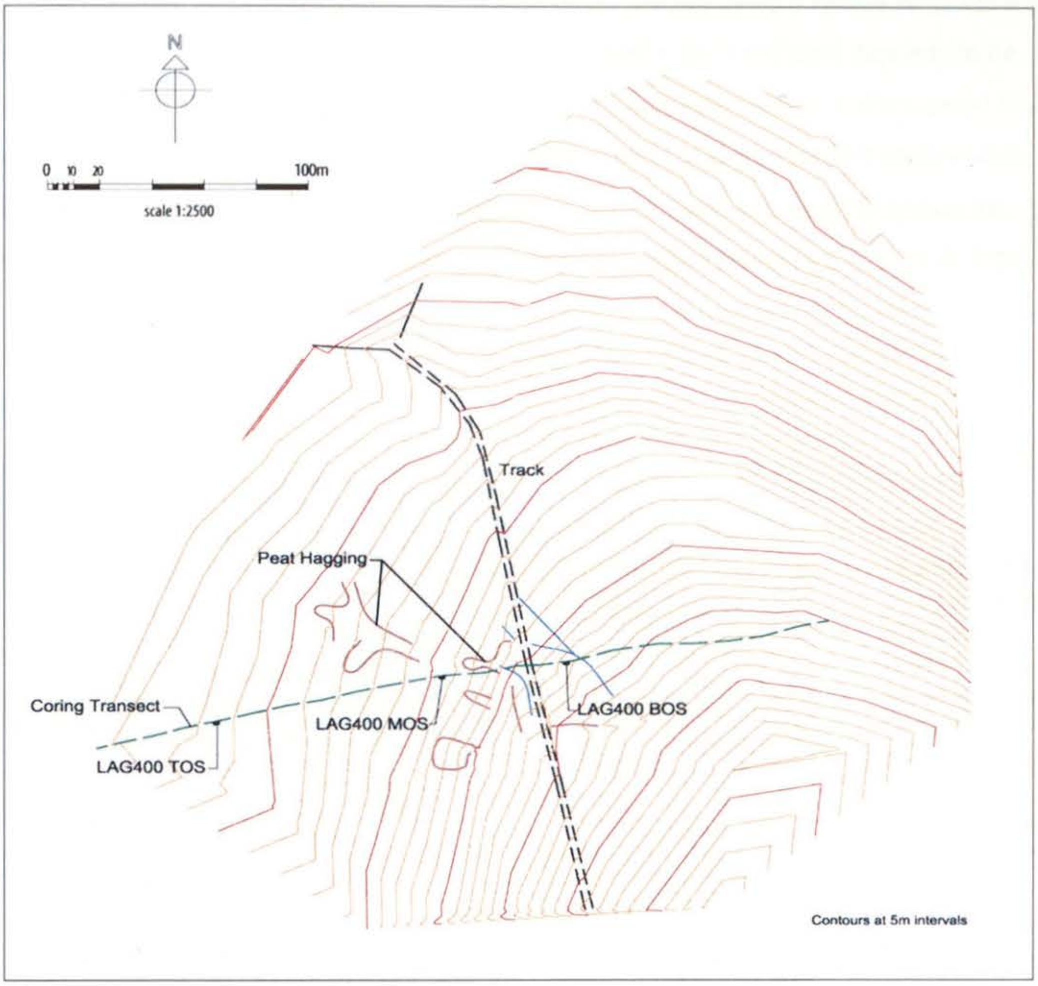


Figure 4.3 (c): Digital terrain model at Lag 400m OD, showing trench locations

4.5 Site Location

The selected sites around the Lagafater Estate lie approximately 13 km north-west of New Luce and are accessed by a single track road that leads up to Lagafater Lodge along the side of the Main Water of Luce valley (see Figure 4.1). Access to site 'Lag 2' (400m OD) was possible only with a 4x4 vehicle along a track leading up towards the head of the burn. The three sites fall within the following Ordnance Survey grid: NX 12 – 14 Easting, 74 – 77 Northing.

A total of nine trenches were excavated from the extensive area of blanket peat (Figure 4.12). A trench was situated at the top, middle and bottom of a gentle slope at each of the three different altitudinal ranges (400m OD, 300m OD and 230mOD). The trenches were either dug into the hillside or excavated in full so that cutting back exposed peat hags, or sections revealed an exposed profile of blanket peat. Coring using a Dutch Auger preceded each excavation to provide a gauge of how representative the local peat deposits to be sampled were and to ensure representative sites were selected. A series of enclosed Russian cores at 5m intervals up and down slope in-between each of the exposed trenches were also taken (Figure 4.12) in order to obtain a detailed record of peat stratigraphy across the landscape and have allowed peat depth maps to be produced (Figures 5.1, 5.15 & 5.29)

Figure 4.4: Peat samples were taken using a Russian corer to obtain a detailed record of peat stratigraphy

A complete sequence of peat blocks from each trench was extracted using a spade and serrated cutting knife in roughly equal sizes and wrapped in Clingfilm and foil to preserve shape and moisture content. Each block was carefully labelled to enable upright storage and preservation of the stratigraphy. Below is a detailed description of the sampling sites and their grid references. Figures 5.2, 5.16 & 5.30 also shows the detailed stratigraphic representations of the cores taken for palaeoenvironmental analysis.

4.5.1 Lag 3, 230m OD, Grid ref. NX 143 747

Trench 1: Bottom of slope (BOS).

This was the lowest altitudinal range of blanket peat within the area (Figure 4.5). A series of peat banks had been exposed with the creation of a neighbouring dam and within these were situated large fragments of silver birch, thought to be representative of a warmer and wetter environment. A north-facing section from an exposed peat hag was cleaned and the section was cut back and fully exposed. It measured 188cm in depth and was situated at the edge of an eroded bank (perhaps an old river course). A series of Dutch cores was taken prior to the sampling of this peat bank in order to ascertain the depth of the underlying peat and to counteract the possibility of sampling an over-deepened or shallow area. It is therefore possible to assume that the peat sampled is representative of blanket peat in the area at that altitude. Peat blocks were taken using a spade and overlapping samples were also obtained.

Figure 4.5: An exposed peat bank at Lag 230m BOS provided an ideal sampling location

Trench 2: Middle of slope (MOS).

A small trench, 104cm in depth was excavated on a gentle slope away from the exposed sections at the bottom of the slope. The west-facing section of the trench was sampled, taking peat blocks using a spade (Figure 4.6). A series of Dutch cores was taken prior to sampling to ensure the best possible position was obtained.

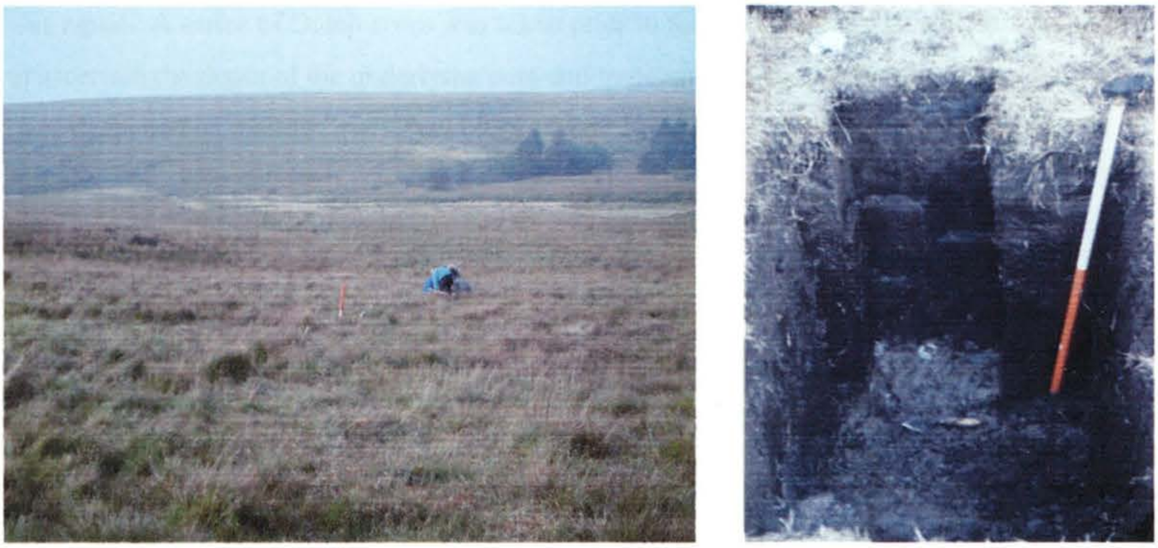


Figure 4.6: A small trench was excavated into the hill side at Lag 230m MOS. The west facing section was cleaned and peat blocks taken using a spade

Trench 3: Top of slope (TOS).

A deep trench (218cm) was excavated at the top of the hill on a gentle slope and the west-facing section of the trench was sampled, taking peat blocks using a spade (Figure 4.7). A series of Dutch cores was taken prior to sampling to ensure the best possible location.

Figure 4.7: Site location of Lag 230m TOS. The colleagues at the edge of the break of slope show the MOS sampling site

4.5.2 Lag 1, 300m OD, Grid ref. NX 132 757

Trench 4: Top of slope (TOS).

An east-facing section from an exposed peat hag was cleaned and the section was cut back and fully exposed (Figure 4.8). It measured 126cm in depth and was situated on a slight slope at the top of the hill so the balance between moisture receiving and moisture shedding was equal. A series of Dutch cores was taken prior to the sampling of this peat bank in order to ascertain the depth of the underlying peat and to counteract the possibility of sampling an over-deepened or shallow area. Peat blocks were taken using a spade and overlapping samples were also obtained.

Figure 4.8: An east facing section at Lag 300m OD TOS was cut back and samples were removed for analysis

Trench 5: Middle of slope (MOS).

An east-facing section from an exposed peat hag was cleaned and the section was cut back and fully exposed (Figure 4.9). It measured 110cm in depth and was situated on a slight slope at the mid-point of the hill so the balance between receiving and shedding was fairly equal. The trench excavated was also equidistant from the top of slope and bottom of slope sampling sites. A series of Dutch cores was again taken prior to the sampling of this peat bank.

Figure 4.9: View of Trench 5 showing location of sampling site looking eastwards

Trench 6: Bottom of slope (BOS).

An east-facing section from an exposed peat hag was cleaned and the section was cut back and fully exposed. It measured 174cm in depth and was situated on a slight slope at the mid-point of the hill so the balance between moisture receiving and moisture shedding was approximate. A series of Dutch cores was again taken prior to the sampling of this peat bank showing an increase in the depth of well humified peat towards the base of the profile at the point of Trench 6. A few meters from the site, the soil depth became increasingly minerogenic and shallow with a change in vegetation (Figure 4.10)

Figure 4.10: The view looking east away from Trench 6 at Lag 300m BOS

4.5.3 Lag 2, 400m OD, Grid ref. NX 134 772

Trench 7: Top of slope (TOS).

A north-facing section from an exposed peat hag was cleaned and the section was cut back and fully exposed. It measured 165cm in depth and was situated on a slight slope at the top of the hill. A series of Dutch cores was taken prior to the sampling of this peat bank in order to ascertain the depth of the underlying peat and to counteract the possibility of sampling an over-deepened or shallow area. Peat blocks were taken using a spade and overlapping samples were also obtained.

Figure 4.11: The view looking north away from Trench 7 at Lag 400m TOS

Trench 8: Middle of slope (MOS).

A small trench, 1m by 80cm was dug into the side of a hill to ascertain a sample of peat from this altitude. No exposed sections of peat hagging were used as they all appeared to have been cut by streams and / or lay at the base of slopes and were therefore moisture 'shedding' rather than moisture 'receiving' sites. A 142cm deep trench was dug into the side of a gently sloping east-facing hillside and samples were retrieved from the east-facing section using a spade. Overlapping blocks were also taken. A series of Dutch cores was taken prior to the excavation of a trench in order to ascertain the best possible location for the sampling of blanket peat.

Trench 9: Bottom of slope (BOS).

A north-east-facing section from an exposed peat hag was cleaned and the section was cut back and fully exposed. It measured 167cm in depth and was situated on a slight slope at the mid-point of the hill. A series of Dutch cores was again taken prior to the sampling of this peat bank.

In this study, coring locations were selected so as to be the most sensitive to change. The middle of slope and top of slope sequences are likely to contain good climatic records as surface wetness is closely linked to precipitation and evaporation, whereas the bottom of slope record may be more influenced by other characteristics such as drainage. Climatic influences at these sites can be assumed to be constant and any differences between the records may be explained by autogenic factors. If the overall patterns and magnitude of change in the surface wetness and palynological records are similar from each coring location, then climate may be the sole influence on hydrological and botanical change. If, however, the records are different, then autogenic factors or localised anthropogenic activity may have contributed to hydrological and botanical changes. Multi proxy analysis of adjacent cores is an assurance procedure, testing the integrity of the palaeohydrological and palynological record. This approach has been used successfully elsewhere, for example at May Moss, North Yorkshire (Chiverrell 2001).

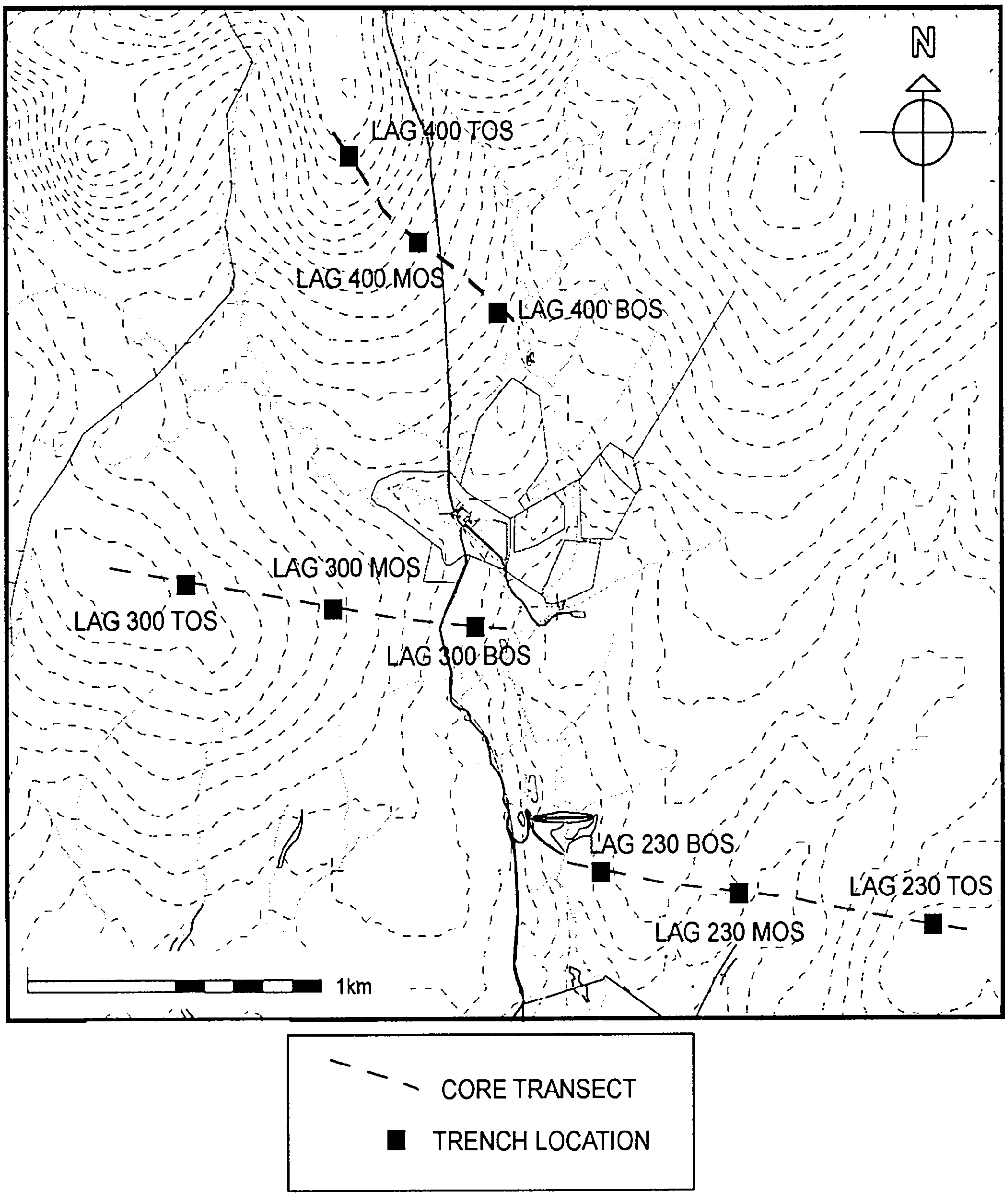


Fig 4.12: Location of transects and final sampling sites at Lagafater.

In addition to the field recording of contexts and sediment descriptions, the samples were also described in the laboratory. The section faces of each monolith were cleaned, drawn and described. The Troels-Smith sediment description system was used (Birks & Birks 1980), with the later modifications of Aaby & Berglund (1986, 238) relating to grain size fractions incorporated. Three major properties are incorporated into this descriptive system: physical properties including appearance and qualities of the deposit; humicitiy, the degree of decomposition of the organic material; and the nature and composition of the materials within the deposit. For most features a five-class scale (0-4) is used. The symbols and terminology used in chapter 5 and which accompany the pollen diagrams are based on the Troels–Smith (1955) classification, which is summarised below.

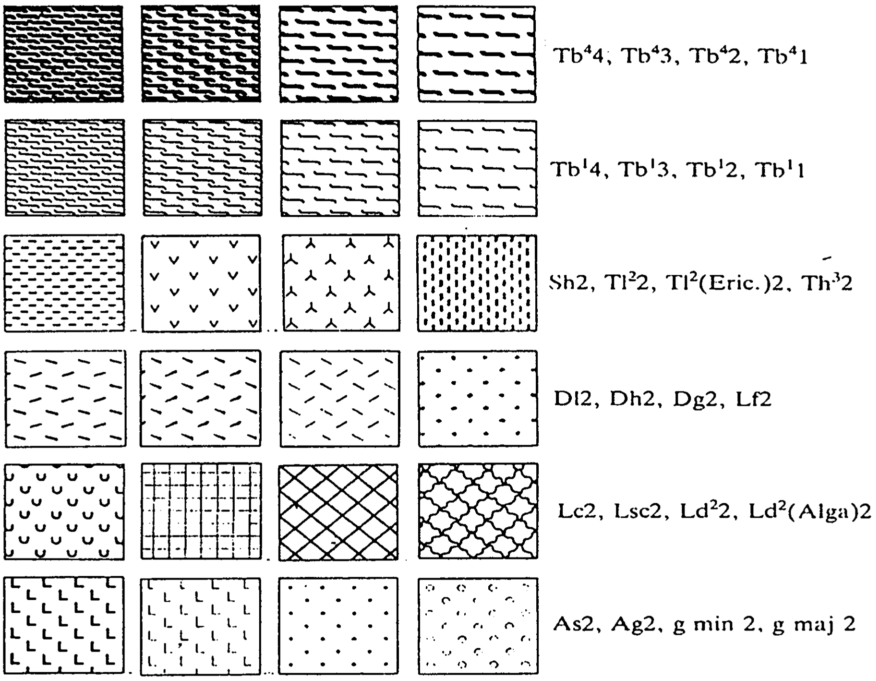


Figure 4.13: Deposit element symbols according to Troels-Smith (1955).

Code	Element	Description
Tb	*Turfa bryophytica*	Mosses +/- humous substance
Tl	*Turfa lignosa*	Stumps, roots, intertwined rootlets of ligneous plants +/- trunks, stems, branches etc. connected with these.
Th	*Turfa herbacea*	Roots, intertwined rootlets, rhizomes of herbaceous plants+/- stems, leaves etc. connected with these.
Dl	*Detritus lignosus*	Fragments of ligneous plants > 2mm
Dh	*Detritus herbosus*	Fragments of herbaceous plants > 2mm
Dg	*Detritus granosus*	Fragments of ligneous and herbaceous plants and sometimes, Animal fossils (except molluscs) <2mm >c.0.1 mm.
Ld	*Limnus detrituosus*	Plants and animals (except diatoms, needles of spongi, siliceous skeletons of organic origin), or fragments of these
Lso	*Limnus siliceus organogenes*	Diatoms, needles of spongi, siliceous skeletons of organic origin, or parts of these. Particles<c.0.1mm
Lc	*Limnus calcareus*	Marl, not hardened like calcareous Tufa, lime and the like Particles c.<0.1mm
Lf	*Limnus ferrugineus*	Rust, not hardened. Particles c.<0.1mm
AS	*Argilla steatodes*	Particles of clay <0.002mm
AG	*Argilla granosa*	Particles of silt 0.06 to 0.002mm
Gmin	*Grana minora*	Particles of sand 2 to 0.06mm
Gmaj	*Grana majora*	Particles of gravel 60 to 2mm
Sh	*Substantia humosa*	Humous substance, homogenous microscopic structure

Table 4.2: Deposit element descriptions according to Troels-Smith (1955) and Aaby & Berglund (1986)

The peat blocks were then cut up into 1cm thick slices and placed in sample bags and kept in a cold store at 5°C. This ensured each 1cm layer of peat was kept clean and allowed consistent sampling from each individual unit.

4.6 *Quantitative sedimentological methods*

4.6.1 Basic Soil Tests

Using the undisturbed sediment cores taken from the Russian corer every 5m downslope, magnetic susceptibility readings were initially measured to help identify the transition from mineral soil to blanket peat and also to identify any possible tephra layers. Peaks in susceptibility often correspond to horizons with high heavy mineral concentrations and they can be used to correlate between sediment cores (Thompson 1986, 320). Measurements were made every 1cm on all of the cores, using a Barrington MS2 meter with a loop sensor to obtain a continuous record. Unfortunately, these readings did not reveal any meaningful results and indicated that the peat from the base had a very low magnetic signal. It was also unsuccessful in determining any possible tephra horizons.

Contiguous 1cm samples from each of the nine trenches were also sampled for moisture content and organic content (Appendix 1). Each sample was oven dried at 40°C for 24 hours following which 5-10grams of the sediment was added to a previously weighed and cleaned crucible. The masses of both were then calculated before being placed into a furnace for 4 hours at 550°C. The crucible was then allowed to cool before re-weighing and the organic component estimated through the following equation:

$$\text{Organic Content} = \frac{(\text{mass of crucible} + \text{sediment}) - \text{crucible mass} \times 100}{(\text{mass of crucible} + \text{sediment after LOI}) - \text{crucible mass}}$$

A cumulative average (the running total of the frequencies) was added to each of the organic content graphs (chapter 5) as readings were similar throughout each peat profile. This also highlighted more clearly changes in organic content when readings deviated from the mean.

4.6.2 Dry bulk density

Peat accumulation rates are affected by two main components in the catotelm: the rate of peat addition, determined at the acrotelm – catotelm interface (sensitive to changes in vegetation type and environmental parameters); and the decay rate which affects older peat and has the effect of 'smoothing' the age-depth profile (Yu et al 2001). Accumulation rates have been smoothed over time as they assume a constant decay rate between pairs of AMS radiocarbon dates (see section 4.6.4). They are distinguished from the volume of organic matter measured per cm³, as the latter is an actual reading of ash-free dry bulk density per cm which may be affected by rates of NPP (Net Primary Production – the rate at which a plant produces new plant biomass), changing water table, higher / lower acrotelm decay or a combination of these factors. The dry bulk density readings may give some indication of the climatic conditions at the time of plant decomposition. Increased bulk density often corresponds to more humified peat sections and thus drier conditions, as plant structure breaks down faster and is compacted so there is more material per unit volume (Roos-Barraclough *et al* 2004; Yu *et al* 2003). Conversely, moist conditions cause high mass production and decreased decomposition, resulting in low bulk density. The organic volume readings in this study, in conjunction with humification records, are used as a palaeoclimate proxy, although the impact of changing vegetation types and decomposition rates through the peat profile is acknowledged. These proxy methods may also be used to identify hydrological changes affected by human activity.

Bulk density is defined as the weight of a volume of soil including its pore spaces, water and air within these. The dry bulk density process allows the moisture content of samples to be calculated, leaving a dry mass per unit area indicative of plant decomposition every 1cm through the peat profile. Hydrological changes up and down slope at various altitudes can therefore be determined at close intervals highlighting localised patterns of increased / decreased decomposition.

Dry bulk density readings were taken every 1cm through contiguous samples of all nine profiles, providing detailed bulk volume records throughout each peat profile (Appendix 2). A 1cm³ sample was extracted using a sharpened cuvette and scalpel. Each sample was dried at 60°C over a 12-hour period, and by recording the difference in weight before and after the process it was possible to calculate the amount of moisture lost from the sample; in heavily waterlogged peat the moisture loss is quite significant. Higher percentages of bulk weight represent sections of the peat where structure has collapsed through increased humification, forcing water out of the peat and increasing the overall bulk density and hence dry weight. Higher values are thus thought to represent periods of bog surface dryness and lower accumulation rates. Readings were also taken of ash free dry bulk density. This was possible as each dry sample was placed in the furnace for 2 hours at 550°C to give the ash content of the original sample. This process helped determine the minerogenic component of each sample from the bulk vegetation, particularly important through the basal sequence where blanket peat sat directly on a soil. The dry bulk density data and ash-free dry bulk density data are presented in chapter 5 to demonstrate the fact that greater bulk density towards the base of the peat core is not always a result of increased minerogenic material but in fact reflects greater decomposition and compaction of humified plant material.

The graphs showing bulk density and ash-free bulk density in chapter 5 are presented against a running mean of every 3 readings to smooth and average the graph curve, in order to identify general patterns of change. Against this, a linear regression line has been added to determine the overall pattern of bulk density accumulation (increasing or decreasing through time). This regression line can be used to depict the relationship between the independent (time) and dependent (bulk density) variables in the graph: the straightness of the line depicts a linear increase / decrease in bulk density through time. The mean dry bulk density data are based on the standard deviation of the ash free dry bulk density data (the 'mean of the mean'), showing how tightly the readings are clustered around the mean and how these readings fall between plus one or minus one standard deviation. A running mean based on the average of three readings has also been overlain to identify a relationship between points. This diagram helps to identify significant changes in patterns either side of the mean and the clustering of points through time indicates the relative uniformity between samples through different sections of the peat core.

4.6.3 Particle Size Analysis

The assessment of particle size distribution through the basal sequences of each peat core will allow an estimation of the porosity of the underlying soil and geological source material beneath the blanket peat, and an identification of the processes of down-wash and translocation of finer particles through the profile. This will indicate the impact that early pedogenic processes may have had on paludification and the eventual initiation of blanket peat as outlined in section 4.2. For the purposes of analysis, the following standard grade of particle size was used:

Particle description	Particle Diameter (μm)
Clay	2.950
Very fine silt	7.700
Fine silt	15.60
Medium silt	31.00
Coarse silt	63.00
Very fine sand	125.00
Fine sand	250.00
Medium sand	500.00
Coarse sand	1,000.00
Very coarse sand	2,000.00

Table 4.3: Particle size Diameter (based on average grain sizes of Udden & Wentworth (1922) and Friedman & Sanders (1978)).

Particle size analysis was performed at 1cm intervals through the underlying organic sandy / silt profiles. Where blanket peat appeared to lie directly on bedrock, the analysis did not occur (e.g. Lag 400 MOS and Lag 400 TOS). Following intensive magnetic susceptibility analysis of all of the profiles at Lagafater, the results indicated very little magnetic input, particularly through the basal profiles, and there was no clear visible evidence for the translocation of sesquioxides and the development of an iron pan. Typically, the soil profiles beneath the blanket peat were very shallow, with a high proportion of quartz and feldspar and very low clay contents.

Samples were dried and sieved to exclude particles > 2000μm (2mm) diameter. They were then treated with Hydrogen Peroxide (H_2O_2), washed and centrifuged before being passed through a laser diffraction analyser (Coulter LS) (Appendix 3). Laser diffraction was used to detect particle sizes in the range of ~ 0.1 to 2000μm equivalent spherical diameter measured by laser diffraction in water, with aggregation being reduced using treatment with ultrasound.

4.6.4 Radiocarbon dating and calibration

The radiocarbon dating technique is based on the production of the radiocarbon 14 isotope (^{14}C radiocarbon) in the upper atmosphere. This isotope interacts with cosmic rays that react with oxygen to produce $^{14}CO_2$. ^{14}C enters the earth's atmosphere as CO_2 and it is assumed that the production of ^{14}C is constant, therefore the exchange with the biosphere is also constant (Libby 1955, Reimer *et al* 2002). This equilibrium is lost upon the death of the plant since gaseous exchange ceases but radioactive decay continues. As a result, if the decay rate of ^{14}C is known, the age since the death of the organic material can be estimated (Pilcher 1991). All radioactive material ^{14}C is subject to decay at a constant rate of 5570±30 years as set by the Radiocarbon conference in 1962 (Godwin 1962).

There are, however, many problems associated with radiocarbon dating. The production of ^{14}C in the atmosphere has not remained constant and has varied over time (Stuiver & Reimer 1993). As a result, the initial ^{14}C activity of organic material has also varied depending on the time of death. Similarly, different plant materials absorb different ratios of carbon isotopes (Pilcher 1990) and young radiocarbon may be introduced from plants which root into the sediment being dated (Törnqvist 1992). Contamination of samples may also occur with the introduction of modern carbon during the preparation procedure.

Variations in the atmospheric ^{14}C have been corrected with the construction of calibration curves based on high precision dendrochronological records (e.g. Pearson *et al* 1993). A single radiocarbon age may intersect the curve at a number of points representing several possible ages. It is therefore common to estimate the mid-point of the intersection of the calibration curve with the highest probability.

Radiocarbon AMS dates used in this thesis were produced at the Scottish Universities Environmental Research Centre (SUERC) and were calibrated using OxCal version 3.10. The application of the accelerator mass spectrometry (AMS) technique compared with a conventional radiocarbon measurement means that smaller samples can be dated with high accuracy (for a full review see Hedges 1991). There is, however, much debate regarding the sample fractions to be radiocarbon dated. Several variations in the AMS radiocarbon dating of specific plant macrofossils have been encountered (Nilsson *et al* 2001; Wohlfarth *et al* 1998) and plant macrofossil studies were not undertaken as part of this study. Bartley & Chambers (1992) argued that the humin fraction of peat could be used to give accurate radiocarbon results, whereas Johnson *et al* (1990) suggest that the age obtained from the humic fraction is more realistic. These problems of bulk dating peat and dating plant macrofossils are clearly outlined in an article by Shore *et al* (1995) and will not be explored further here. Whenever possible, both the humin and humic fractions should be dated but the latter was selected for the purpose of this study. Humic acid is a chemically definable fraction of the peat which is alkali soluble and acid insoluble, unlike the humin fraction which is not clearly definable. Humic acid is relatively immobile within the peat and also forms a larger proportion of the hot alkali pre-treatment, therefore yielding a more precise age estimate (Dugmore *et al* 1995).

The ^{14}C ages are all quoted in conventional years (BP) and the error is expressed at the two sigma level of confidence, which includes components from the counting statistics on the sample, modern reference standard and blank and the random machine error.

4.6.5 Age – depth models

To fully understand the absolute chronology of a stratigraphic proxy record, it is necessary to produce age-depth models. Climatic and vegetational records are meaningless without an adequate chronology. The problems of precisely dating blanket peat initiation have been outlined in section 2.3.1 but radiocarbon dates formed an essential part of this thesis. There are many procedures for constructing age-depth models based on calibrated dates including linear interpolation, splines, linear regression models (Bennett 1994), and more recently, the weighted, non-parametric regression model (Birks & Heegard 2003). All of these models, however, depend on the accuracy of the radiocarbon determination as well as the calibration and level of uncertainty associated with them, and different approaches can give different answers (Bennett 1994; Bennett & Fuller 2002). Other assumptions based on age-depth models include that there are no sedimentary disturbances within the sequence and no gaps due to coring error (Birks & Heegard 2003). As a result, the radiocarbon dates through each of the peat profiles at Lagafater extend only through the blanket peat and not through the mixed soil horizons.

An analysis of age-depth models by Telford *et al* (2004) showed that no model reliably performs well and models are very much dependent on the number of radiocarbon dates obtained for each sequence. Cubic spline models are appropriate when there are many dates and interpolation models are appropriate when there are fewer dated horizons. Bennett & Fuller (2002) in fact found linear interpolation to be the most suitable as linear models have narrow confidence intervals and, as they are forced to pass through the date, are close to reality. Linear interpolation between radiocarbon dates was therefore adopted in this study as it is the simplest explanation of the radiocarbon data and retains all of the known age-depth estimates. Sedimentation rates, particularly through the peat, can change abruptly at the depth of the dates as a result of compaction and cumulative bulk density (which also assumes a linear relationship), as well as resulting from sharp changes in hydrology and / or human activity linear interpolation displays this more accurately than, for example, a smoothing polynomial curve.

4.6.6 Tephra and X-radiography

The application of tephrochronology (the identification of volcanic ash layers) to palaeoenvironmental studies has proved to be a useful tool and has a long history (Dugmore 1989). The identification of geo-chemically precise layers captured within blanket peat allows for an effective chronological marker to be identified across sites. Research in Scotland (Dugmore 1989) and in Ireland (Pilcher & Hall 1992) established a tephrochronology for the British Isles based on Icelandic volcanic eruptions of known ages (Pilcher *et al* 1996; Hall & Pilcher 2002). The dating evidence provided by these well-constrained layers of tephra, invisible to the naked eye, provides an alternative to radiocarbon dating and can improve the chronological precision of palaeoenvironmental studies.

Tephra analysis was carried out along a complete core from Lag 230M TOS at 2cm intervals, to help complement the full palynological record at this site. Methodology for tephra analysis involved the acid digestion of organic samples (after Dugmore *et al* 1992; Pilcher & Hall 1992; Hall *et al* 1994) and analysis of samples through a polarising microscope at 200-400x magnification (Appendix 4). Unfortunately, no tephra shards were identified.

X-radiography of the cores along Lag 230 TOS, MOS and BOS was therefore undertaken. This is a non-destructive method of locating structures and changes in sediment density and it was hoped might identify thin tephra layers (Dugmore & Newton 1992). X-radiography was undertaken at the British Geological Survey in Edinburgh using a SCANRAY 120L machine. Entire 1m samples were x-rayed and best results were obtained using a radiation and intensity time of 35kV, an accelerating current of 2nA and an exposure time of 90 seconds. Following exposure, the plates were developed in a darkroom following standard photographic procedures. Negatives were produced at a scale of 1:1 and placed on a light table for examination. Unfortunately, these also did not reveal any tephra horizons but did show the presence of minerogenic material at the base of all of the cores.

4.6.7 Colorimetric peat humification

Peat decomposition (humification) can be determined by measuring the degree of peat decay colorimetrically in a spectrophotometer to signify palaeohydrological changes during the Holocene (Blackford & Chambers 1993). As organic matter decomposes, humic acid is released and the proportion of this increases as decomposition increases. Litter mass decomposes by 80-90% within the upper oxygenated layers of the acrotelm but once the peat has been submerged below the water table in the anoxic catotelm, this decomposition reduces to c.0.1% of the rate of the acrotelm (Clymo 1984). Assessment of the decay of peat in blanket mires is primarily determined by surface wetness and temperature at the time of peat deposition and therefore provides a proxy record of surface wetness. In wet conditions for example, there will be incomplete decomposition of organic matter as the bacteria required for the breakdown of vegetation are unable to survive in anaerobic conditions, resulting in poor humification. Similarly, in warmer / drier conditions, the rate of plant decomposition increases as vegetation is exposed to aerobic decomposition for longer due to a low water table, resulting in higher humification values. Therefore this method can be used to determine the rate of blanket bog growth, changes in local hydrology and thus localised micro-climate conditions.

Analysis of the decomposition of peat has been used to identify climatic shifts over the last 10,000 years from several ombrotrophic mires, particularly from raised bogs showing shifts to wetter and / or cooler conditions (e.g. Aaby & Tauber 1975; Anderson 1998; Barber *et al* 1994, 2000; Borgmark 2005; Charman *et al* 1999; ; Gunnarson *et al* 2003; Hughes *et al* 2002; Mauquoy & Barber 1999, 2002). More recently the technique has been applied to blanket mire sites (Barber et al 1999; Chambers *et al* 1997; Charman *et al* 1999; Chiverrell 2001; Ellis & Tallis 2000; Gunnarson *et al* 2003). The climatic events identified based on dry / wet shifts have challenged the view that climate has been relatively stable throughout the Holocene. Attempts have been made to link these shifts in climate across regions and with changes in solar activity (Blackford & Chambers 1995; van Geel *et al* 1998, 1999; Mauquoy *et al* 2002), with significant palynological changes (e.g. the decline in *Pinus*) and IRD (Ice rafted Debris) events in the North Atlantic (Anderson 1998).

The use of humification indices is, however, problematic. Interpretation is complicated by the differential decomposition rate of certain species (Pancost *et al* 2003). The differential decay of particular species can be accounted for (Chambers *et al* 1997) but the variability of decay rates of *Sphagnum* species remains harder to elucidate (Johnson & Damman 1988). Recent work (Caseldine *et al* 2000) has also demonstrated that different plant species may be affected to different degrees by the NaOH extraction process. They suggest luminescence spectroscopy as an alternative technique. The processes of humic acid production remain poorly understood and are in fact likely to have been non-uniform through time, particularly given the internal variability of the mire system (Charman *et al* 1999; Caseldine *et al* 2000), making the absolute magnitude of events difficult to discern. Humification, however, still remains a useful proxy in the identification of landscape-scale wet shifts, particularly when it is used in conjunction with other proxy data sets including dry bulk density data and palynology.

In order to distinguish between local autogenic hydrological changes and landscape climate changes, humification results from the nine sites across Lagafater were compared to assess the replicability of climatic signals and to identify changes in local hydrological regimes up and down slope. These results are also compared with the dry bulk density data to assess the impact of changing mire surface wetness on the bulk volume and decomposition rates of the blanket peat. Humification tests were carried out every 4cm through each of the peat columns and every 1cm through the bottom 10cm of each section (to allow detailed changes in mire surface wetness to be assessed at the point of blanket beat initiation). The extraction procedure using NaOH used a standard technique (Blackford & Chambers 1993) (Appendix 5) which removes soluble humic acids from the peat. These are then measured by recording the percentage of transmission of light that passes through the sample using a spectrophotometer at 550nm (CAMLAB). The more light absorbed, i.e. the less light transmitted through the sample, the greater the content of humic acids present and the less the sample has been humified. The results here are expressed as a percentage of transmission through the samples so that high values represent low decay and low values reflect a wet surface. The data are presented as having a mean value of 0 and a standard deviation of plus 1 and minus 1 for normalising along with a three term moving average to remove the stochastic nature of the curve (Ellis & Tallis 2000). The humification profiles through the acrotelm and catotelm are presented in the first of the diagrams (chapter 5) and the second of the diagrams shows the humification profile through the catotelmic peat only, to help pinpoint real hydrological shifts through the main body of the blanket peat. Data through the minerogenic soil profile at the base of the core have not been included in the results.

4.6.8 Pollen analyses

Research involving vegetation history using palynology rests on the principles described by Faegri & Iversen (1975) and Birks & Birks (1980): pollen and spore production is often far in excess of reproductive requirements. The sporopollenin coat is resistant to decay and is preserved under conditions of minimal bacterial activity, principally in anaerobic waterlogged conditions such as peat bogs and lake sediments. As these sediments accumulate, pollen and spores are trapped, providing a record of vegetation history. The relationship between the pollen and spore recorded within a horizon and the actual vegetation that was present at the time is, however, obscured by a range of biotic and abiotic processes (Moore *et al* 1991).

Palaeoecologists are frequently frustrated by the difficulty in defining precisely the geographic area represented by pollen data and the deposition vectors of the assemblage derived from the sediments of a given core site (Oldfield 1970). An appreciation of site taphonomy (Davies 1987, 17) is therefore vital to understand the mechanisms by which species in a sample were assembled and hence the applicability of palaeoenvironmental studies. This involves an exploration of the taphonomic pathways leading from the landscape to the site and the processes of deposition and preservation. In order to appreciate the full taphonomic picture of a site, both extrinsic and intrinsic factors, such as production rate and the size of the catchment, have to be considered to build up a clear story. More recently, sites have been targeted with regards to specific research aims based on local or regional scales of change (e.g. Davies & Tipping 2004). This, along with developments in taxonomic, spatial and temporal precision in palynology (Birks 1996; MacDonald & Edwards 1991), has allowed palynology to make important contributions to developments in ecology and palaeoclimatology.

Pollen analysis has been employed in this project to identify the vegetation history at the point of blanket peat initiation, whether there are any significant changes in the pollen record around this time, the impact of anthropogenic activity at this point, and if the sites supported palynological evidence showing changes to wetter conditions (increases in 'wet indicating mire types'), an approach adopted by Chambers & Blackford (2001). Known regional pollen types, i.e. those originating from 'non mire' plants, can be used to identify distinct horizons within the pollen spectra across the different core sites. Work by Smith & Pilcher (1973) demonstrated that the empirical and rational limits of many tree species, for example, vary in radiocarbon age across the British Isles. Given the close proximity of the sites at Lagafater however, it is hoped that landscape trends can be identified. Careful consideration will be given to more regional variations when a consideration of palynological evidence from other areas of the south-west of Scotland will be made (Chapter 7).

Edwards (1994) extols the virtues that palynology can contribute to studies of past human behaviour. Vegetation changes observed in pollen diagrams that can be attributed to human change can inform us of past land use activities where archaeological evidence may be lacking. The classic model for anthropogenic activity is expressed in expansion and regression or clearance / interference and regeneration phases (Buckland & Edwards 1984; Birks *et al* 1988; Edwards 1994). Phases related to human activity are characterised by changes in vegetation composition and characteristic species associated with human activity. Principally, sudden decreases in woodland cover and increases in open ground taxa are often related to human activity, and weed species such as *Plantago lanceolata* are sensitive to human activity.

Clearance phases will have had an effect on the proportion of regional and local pollen preserved within the sampling site (Edwards & Whittington 1998, 64). Sampling at three different but adjacent altitudinal areas ensures a more accurate identification of landscape-scale palynological changes. Similarly, without sufficient spatial and temporal precision, clearance episodes and changes in mire hydrology may be missed, or several episodes can appear as one continuous event. The duration of clearance and regeneration episodes is also difficult to assess due to inadequate and inaccurate radiocarbon dating (Edwards 1979, 261; Tipping 1994, 5). This thesis presents nine fine-resolution pollen diagrams (every 1cm was analysed) through the blanket peat initiation interface along with three longer cores where analyses occurred at every 4cm. In total, twenty-nine radiocarbon dates were obtained. These detailed studies will therefore allow synchronous events to be correlated and a timescale for local landscape evolution can be put forward.

There are, however, problems in assessing the nature of interference episodes as many different land use strategies can give the same results in the pollen record (Edwards 1979, 256). Determining if the observed vegetation changes are a result of arable or pastoral activities (and assessing the relative importance of each), or a host of other activities such as coppicing is very difficult (Edwards & Whittington 1998, 63). It has been proposed (Edwards 1993) that woodland regeneration following a clearance episode is not always indicative of local abandonment but may be seen as a change to woodland-based farming activities. Similarly, natural events such as disease and wind throw are difficult to distinguish and many agricultural weed species can grow in natural ecotonal settings (Edwards 1979, 257). There are few modern analogues for prehistoric land use practices so present understanding of weed ecology may be less influential (Birks *et al* 1988; Roberts 1998).

There have been numerous attempts to quantify the extent of human disturbance on vegetation. Early work concentrated on total counts of anthropogenic indicator species (Birks *et al* 1998; Berglund & Ralska-Jasiewiczowa 1986). More recent work has been to analyse the whole pollen spectrum using multivariate statistical techniques to detect patterns of change in complex data sets (Birks *et al* 1988, 231; Sugita *et al* 1999)

4.6.8.1 Pollen production rates

Different plants produce different quantities of pollen and the mechanisms by which these are dispersed also vary. For example, wind pollinated species (anemophilous species) such as *Calluna vulgaris* and *Tilia cordata* produce more pollen than insect pollinated species (entomophilious species). Less well represented are the autogamous plants like wheat (*Triticum*) which are self-pollinating and the cleistogamous species which never open and thus rarely release pollen. Within each of these categories there are also variations in the amounts and time of year that pollen is liberated. Establishing pollen production rates for every taxa is therefore difficult but has been attempted by Pohl (1937), who calculated the number of pollen grains an individual flower or tree releases, and Iversen (1975), who made similar observations. At Lagafater, however, the open nature of the site and a limited range of vegetation mean that those taxa that do exist are under environmental stress. They are therefore likely to emit only small amounts of pollen and production rates are an inappropriate consideration here although distribution and abundance may vary between sites.

4.6.8.2 Pollen dispersal mechanisms

An understanding of the processes involved in the transport of pollen from its source to the eventual point of deposition, and the means by which it arrived, is of great importance if we are to understand the local pollen assemblage in the past (Birks & Birks 1980; Bunting *et al* 2004; Lowe & Walker 1984, 164; Moore & Webb 1991). Tauber (1965) constructed a theoretical model showing the mechanisms by which pollen can arrive at a site, with particular reference to a site next to a forested area. More recent work by Bunting *et al* (2004) adopted a simulation approach to explore the variation in taxon parameters, using modern pollen and vegetation data, and landscape patterning on pollen source areas. This study, however, assumed constant basin size during the period of sediment accumulation and showed that values of pollen dispersal are not constant over time. Both studies are of limited relevance to the Lagafater sites because of issues explained below but display clearly the complicated regimes involved in trying to understand pollen source area.

Tauber (1965) considered there to be three major taphonomic pathways:

1) Trunk space component (Ct): Pollen falling from the 'forest' environment and carried by sub-canopy air movements through the trunk space.
2) Canopy Component (Cc): Some of the pollen produced within the canopy will be carried along by air currents moving above the canopy itself; some of which may be transferred by thermals to higher altitudes and can travel long distances by winds.
3) Rain Component (Cr): As with dust particles, pollen grains can act as nuclei around which water droplets form and these will eventually descend as rain, collecting more pollen as they fall. This mechanism accounts for a large proportion of pollen 'fallout'.

Today two other contributions can be added to Tauber's diagram and are more relevant to the core site following more research and a greater understanding of taphonomy:

4) The transport of pollen by water (and/or secondary or inwashed component (Cw)). A large proportion of the pollen arriving at the site may be derived from inflowing streams and groundwater, a proportion of which may also have been deposited elsewhere and simply been remobilised and redeposited. The main sources of streamborne pollen are: (a) direct fall from plants growing alongside stream channels; and (b) bank erosion, particularly during floods, and also surface run-off from the surrounding landscape at times of flood (based on Peck's studies of a Yorkshire lake budget) (Birks & Birks 1980, 180).
5) Local or Gravity component (Cl). A large local input to the pollen assemblage may come from aquatic plants growing in or around the lake or on the surface of a mire.

This may constitute a large proportion of the total input. Similarly, sites that are overhung by trees may be affected in this way.

Overall, the dispersal of pollen in any region is controlled by wind speed and direction, the existence or density of woodland cover, time of pollination of the trees, turbulence of the atmosphere, and the altitude and overall size, shape and position of the source area in relation to the site of deposition (Birks & Birks 1980; Calcote 1995; Fossitt 1994; Jackson & Kearsley 1998; Lowe & Walker 1984; Lynch 1996). Understanding pollen source areas for treeless landscapes is, however, more complicated, with greater variability in pollen dispersal mechanisms from shrubs and herbs, and the possibility of long-distance wind blown pollen swamping the pollen record. Less research has been undertaken on partially wooded or treeless landscapes, but recent experimental work on the relation between plant abundance and pollen source areas in a moorland setting has improved our understanding, highlighting the fact that most pollen in open, moorland situations is dispersed only a few metres (Bunting 2003; Davidson *et al* 1999; Gaillard *et al* 1992; Tipping *et al* 1997, 1999).

4.6.8.3 The Taphonomic Regimes at Glen App, Lagafater

In order to delimit the pollen source area, Jacobsen & Bradshaw (1981) produced a diagram showing the relationship between the size of the site, the areas of origin of the pollen and the means by which the pollen travelled to the site (Figure 4.14).

This model can be used as a useful framework in estimating the dominant source areas of the pollen. Jacobsen & Bradshaw defined ‘local’ pollen as originating from plants growing within 20m of the pollen site, ‘extra-local’ pollen as coming from plants growing between 20m to several 100m of the site, and regional pollen from plants further away.

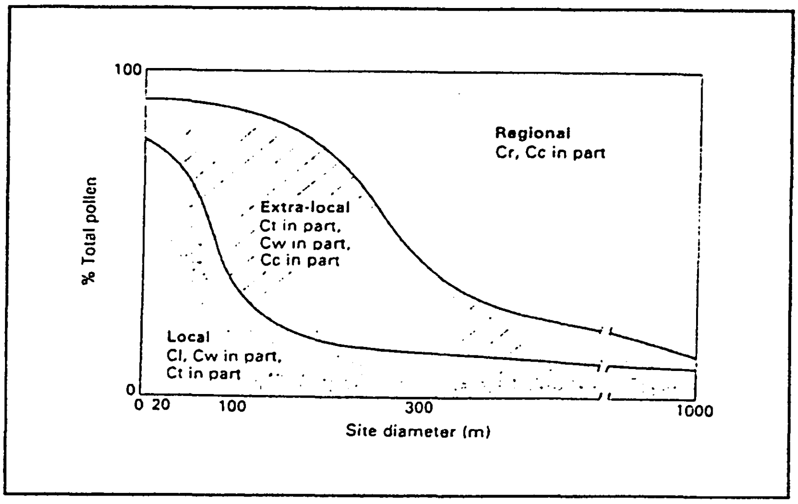


Figure 4.14: The Relationship between Site Size and Various Pollen Sources based on Jacobson & Bradshaw 1981 (Moore *et al* 1991, 14)

These estimates are unsophisticated however, and make a number of assumptions about the specific shape and diameter of the pollen site which is difficult to transfer to larger areas of blanket peat where the current terrain masks the sub-peat topography. Coring at Lagafater has revealed a number of dips and hollows, particularly at the top and bottom of the slopes, suggesting that these may have individually acted as basins where pollen collected prior to the spread of blanket peat. The source area of pollen will therefore have varied according to the nature of the contemporary surface vegetation at the coring point (Sugita 1993, 1994). The majority of estimates for pollen recruitment are also based on wooded landscapes and are limited for open or deforested landscapes (Bunting 2003). This factor therefore makes it difficult when interpreting the palynological record where periods of woodland and woodland regeneration existed between periods of heathland development and a largely open canopy. Theoretical and quantative modelling of open landscapes have provided some insights into the processes operating in the past (e.g. Bostrom *et al* 1998, Sugita *et al* 1999). However, more recent palynological investigations of small, discrete landscape areas within a few hundred metres of each other have highlighted the variety of pollen spectra across securely dated profiles in a largely open landscape, suggesting pollen source areas are very localised and operate across small discrete areas (Bunting & Tipping 2004; Davies & Tipping 2004; Tipping 1998, 1999).

Several studies have also shown that edaphic and topographic factors combined with catchment size can be used to separate local from regional components of the pollen influx (Brubacker 1975; Bunting 2002; Calcote 1995; Fossitt 1994; McAndrews 1988; Sugita 1993, 1994). These studies assume that the pollen influx is made up of a regional background component and showed that interpretations from smaller basins, for instance, revealed changes in past vegetation that are of a finer scale than those from larger basins several 100m in diameter (Jacobsen & Bradshaw 1981, 86). This situation may be transposed onto a large area of blanket peat where the undulating topography will mean parts of the site are moisture shedding and others will be moisture receiving. Those sites at the top of slope, for example, are predominantly water shedding summit locations often containing small dips (see Figures 5.1, 5.15, 5.29). Using Tauber's (1965) model, Moore *et al* (1991) suggest that pollen at such sites comes predominantly from precipitation (Cr), has a canopy component from neighbouring valleys (Cc), or comes from local plants (Cl). Recent work summarised above from open landscapes would indicate that the pollen record might have been predominantly made up of the local plant (Cl) component (see Bunting 2002 & 2003).

Those pollen sites from the middle of slope and the bottom of slope will contain pollen transported by water and inwashed from above (Cw). The absence of any direct inflowing streams to the site has been shown to reduce the local component factor (Pennington 1979), but on sloping ground, surface run-off, particularly during the stages of paludification, will have been great. Those sites situated on the middle of slopes will therefore contain a higher inwash component (Cw), and a local component (Cl) as well as a direct rain component (Cr). The bottom of slopes will contain a similar spectrum with a greater percentage of secondary inwashed pollen.

Cyclonic westerlies provide the dominant climatic vector affecting the taphonomic catchment of the bog. Given that there is nothing west of the site but the Atlantic Ocean, we can therefore deduce that long distance and regional wind-borne pollen is perhaps not the dominant input to the overall pollen spectrum of Lagafater (Figure 4.1), although some transport of lowland pollen to higher altitudes, and vice versa, will occur as localised air currents will be created across breaks of slope. Plant communities at higher altitudes and along the more exposed tops of slopes may also produce less pollen than those in lowland situations. Pollen produced at 230m OD and along the bottom of the slopes may therefore be more strongly represented in all of the percentage diagrams (Faegri *et al* 1986).

Many of the cores taken from the peat sections display a series of early glacial tills and organic silts which lie below the organic sediments relating to the development of 'true' blanket peat. The environmental implications of these are discussed in chapter 6 but it is important here to explore the evolutionary nature of each of the blanket peat stages in order to complete the taphonomic picture of early blanket peat development.

At the base is a sequence of possible Lateglacial till, providing a very local signal of the type of drier vegetation which may have existed in the region at this time. Pollen deposition rates at this point will have been extremely low. This is overlain by layers of coarser minerogenic material developing into finer, organic silt lying above this. What is represented here is a changing energy regime of deposition from low to high at a time when there was little vegetation in the area. The gradual progression in sediment size above this is a factor of increasingly waterlogged conditions, the development of local bog vegetation and, in some cases, an increase in coarser sediments suggests an inwash of material: this could signify a higher energy environment related to human activity. Within this, the pollen species represented will be limited, consisting primarily of herbaceous vascular plants. These will also be poorly preserved due to the severity of the environment of deposition. The pollen sources are likely to have been diverse, a proportion deriving from the local hydrological network (Cw) and a percentage brought in with wind-borne deposits (Cc). Together, these bring extra-local, local and regional pollen into the bog at a time when local dynamics are working to produce the beginning of blanket peat. The coarse minerogenic fraction is gradually replaced by deposits of a higher organic content marking the beginning of the mid-Holocene, when blanket peat was actively accumulating, and a change in ecosystem (Delcourt & Delcourt 1991). This is clearly reflected in the organic content results (discussed in chapter 5). During this period, a complex interaction of extrinsic factors such as climate, vegetation and soil, as well as intrinsic factors linked to hydrological mechanisms, will all have influenced the growth rate of the peat bog, the nature of sediment deposition and taphonomic processes occurring, as well as the patterns of pollen influx (Dearing & Foster 1986; Lowe & Walker 1984; Moore & Webb 1991).

The majority of the sediments, during the development of the blanket bog, are autochthonous in nature resulting from localised vegetation growing on the surface of the bog. Much of the pollen contained within this is therefore derived from the local gravity component (Cl) as well as by water transport from streams (Cw) draining into the site, where contemporary pollen from surface soils of the catchment and erosion of older pollen from peats are transported into the system. In addition, some pollen will arrive direct from the atmosphere (Cc) and some from locally growing plants (Cl), although experiments by Bonny (1978) have shown that only 15% of the total pollen influx comes from local and air-borne sources (Moore & Webb 1991; Jacobsen & Bradshaw 1981).

Tauber's model demonstrates well the variety of taphonomic sources operating during this period at Lagafater. The nature of the sediment and the variety of plant species represented also means that variations within this can be closely linked to climatic phenomena and the degree of human disturbance: this in turn will affect the dominant sources of pollen as outlined above. We must therefore accept that during this period, the ratio of stream-borne components (Cw) to local gravity components (Cl) would have remained high, although fluctuating, with local pollen being represented at all times.

At the top of the core, poorly humified organic detritus can be found in quantity forming a mire ecosystem which receives water from land drainage (Cw) and from precipitation (Cr), typical of an ombrotrophic bog. Its surface is made up of wetter and drier areas developed in response to a range of environmental factors such as climate, vegetation interaction and drainage processes (Moore 1986, 94). It is within the surface layers of the peat, which are periodically aerated and waterlogged, that the breakdown of vegetation occurs and nutrient rich detritus develops: as this occurs the decay rates diminish with depth (Moore & Webb 1991, 14). This type of ecosystem is particularly sensitive to changes in hydrology; the commencement of peat accumulation at a site is itself an indication of a changing hydrological budget. Changes in efflux and influx can similarly lead to peat accretion or development, the pattern of which may be indicative of seasonal, environmental regimes (see Moore 1986 for further discussion).

With the development of blanket peat, the taphonomic regimes operating within the system once more change. The supply of groundwater, for example, becomes less important in supplying local pollen and, as blanket bog encroaches, the relative size and surface area of the site is increased and will show a greater representation of regional pollen (Jacobsen & Bradshaw 1981, 90; Moore & Webb 1991, 17). Similarly, the encroachment of waterlogged, acidic conditions will reduce the variety of plants able to survive. Mire species such as *Sphagnum* and Cyperaceae growing on the surface of the peat means the local or 'gravity' component is therefore increased.

Little information is available concerning pollen migration within the upper peat profile but deeper into the unit, pollen becomes stratified into horizons as it becomes buried by further plant deposits: we may therefore assume a very localised picture of the vegetation growing within the immediate vicinity of the site. The succession from an early Holocene environment to a blanket peat ecosystem is a complicated taphonomic story made more complicated by the different regimes acting at the top, middle and bottom of each slope and at different altitudes. Individual consideration at each of the sites is required when considering the more detailed taphonomic processes. This section has outlined the different pollen sources operating at the top, middle and bottom of the slopes but micro-variations in climate, anthropogenic activity and the timing of blanket peat initiation need all be considered.

4.6.8.4 Pollen Redeposition

Redeposition occurs from erosion of polleniferous deposits that then become incorporated with contemporary pollen (for example, in glacial deposits). Reworked pollen, often synchronous with redeposited pollen, can usually be recognised in the assemblage (Birks & Birks 1980, 189). For example, a pollen assemblage typical of the Late Glacial (containing species such as *Salix* and *Pinus*) may also be found with pollen of thermophilous trees (such as *Alnus, Ulmus* and *Corylus*), clearly indicating a mixing of deposits. Pollen grains which then display etching on their surface or have undergone a morphological change (e.g. the exine is fused or broken) further supports this idea. Vertical movement may also occur by the activities of burrowing animals such as midge larvae and worms, where smaller pollen grains are more susceptible (Birks & Birks 1980, 187). Interpretation of pollen movement through the soil profiles prior to peat initiation at Lagafater is difficult. A stratigraphic approach has been taken for ease of description but caution will be applied in the ecological meaning of the pollen represented.

4.6.8.5 Sampling for pollen analysis

Samples of 1cm^3 were extracted for pollen analysis. Samples from the longer cores were spaced at 4cm and then 1cm at least 10cm either side of the transition to blanket peat. The preparation followed standard procedure after Anderson 1960, Benninghoff 1962, Berglund and Ralska-Jasiewiczowa 1986, Bonny 1972, Erdtman 1960, Faegri & Iversen 1975, and Moore *at al* 1991 (Appendix 6). All samples received a treatment of sodium hydroxide and acetolysis. Pollen from eighty-two samples was subject to a treatment of hot hydrofluoric acid. One *Lycopodium clavatium* tablet was added to each sample (Stockmarr 1971).

Following chemical processing, observation and identification of the pollen grains began. The pollen residue was mounted on a glass slide in a silicon oil medium and a cover slip placed on top. This was then examined under a microscope at x400 magnification, and a statistically representative sample of 400 pollen grains were counted on each slide and recorded on a pro forma sheet. In addition to the identification of the grains their state of preservation was also recorded (i.e. whether it was broken, degraded or crumpled) (Cushing 1967). Pollen identification was made using the identification keys from Moore *et al* (1991) and a pollen reference collection.

The pollen diagrams were created using TILIA and TILIA GRAPH version 2.02 (Grimm 1991-1993). Zonation of the pollen diagrams occurred in TILIA GRAPH, based on observed vegetation changes, but the divisions agree with splits generated by constrained cluster analysis (CONISS). The relative proportions of the different pollen types were expressed as percentages of the total pollen sum and each taxon could be seen clearly compared against one another (Davis 1966). The pollen of arboreal taxa were included in the total sum whilst pollen from aquatic plants and spore producers was excluded; these are locally present and do not necessarily reflect the wider environmental picture. Proportions of the Total Land Pollen (TLP) are calculated as percentages of TLP (% TLP). Proportions of Pediastrum, freshwater algae, were also recorded and expressed as percentages of TLP plus total numbers of spores. A distinction between the different Ericales species was made (Oldfield 1970), and pollen grains of cereals were distinguished from those of wild grass based on annulus and grain size measurements (Andersen 1978; Dickson 1988). Wild grass had a mean annulus measuring < 8μm and a mean pollen size of < 37μm. Hordeum cereals had a mean annulus of 8-10μm with a mean pollen size of 32-45μm and Avena-Triticum group of cereals had a mean annulus of >10μm and a pollen size > 40μm. When a cereal grain was identified, the measurements of its annulus and overall size were recorded.

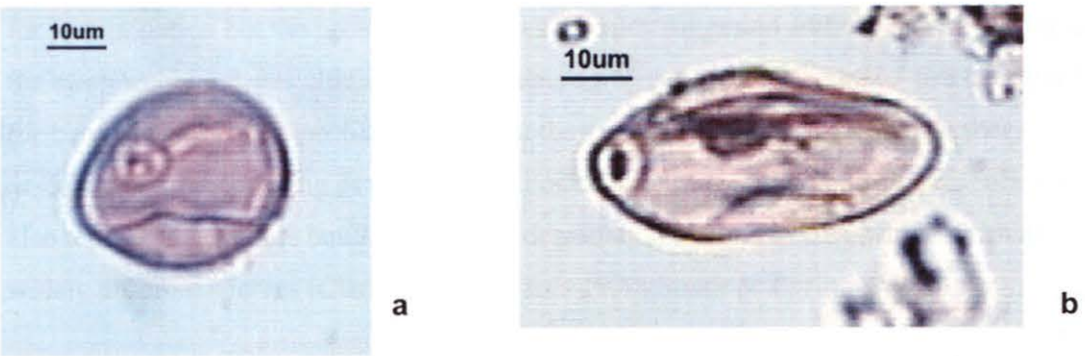


Figure 4.15: Photograph of (a) *Hordeum Vulgare* and (b) *Avena Triticum* from Lagafater

Separating *Corylus* and *Myrica gale* is difficult (Edwards 1981) but the pollen grain of the latter appeared to have larger, more pronounced pores, a thicker exine and at x1000 magnification, its surface was regularly scabrate. A distinction between the two grains was therefore made in this study.

4.6.9 Charcoal analyses

The determination of relative amounts of charcoal provides a greater understanding of past and present environmental changes in the local landscape. Microscopic charcoal was recorded in all of the pollen diagrams through the basal sequences. High charcoal concentrations are thought to represent fire histories (Clark 1982; Ohlson & Tryterud 1999; Swain 1973; Tolonen 1985; Winkler 1985) and can also be used to infer palaeoclimate (Clark 1990; Johnson & Larson 1991).

There are, however, difficulties with both the methods used and the interpretation of the results. Spatial comparisons of charcoal records are difficult as different preparation methods have been used (pollen slides, thin sections, spectrographic analysis etc.) and few studies have compared these methods. Recent work by Tinner & Sheng Hu (2003) demonstrated that differences in charcoal size and size-class distribution between sites are a result of different preparation procedures. Similarly, autogenic factors such as seasonality, differences in vegetation and soil type, and climate can influence the amount of charcoal produced. Post-fire processes such as surface flow, wind and topography might also transport charcoal from its original setting (Ohlson & Tryterud 2000). Several studies have also shown that charcoal particles derive from regional sources 20km to 100km around the pollen site (Clark & Royal 1995; MacDonald *et al* 1991; Tinner *et al* 1998).

Initiation of fires may be natural (principally lightning) or anthropogenic, and separating the cause can be difficult. Charman (1992), who examined the basal peats from four sites at Cross Lochs, Sutherland, was unable to demonstrate any single factor that was responsible for peat initiation but the presence of charred remains suggested anthropogenic burning of the birch woodland was ultimately an influencing force. Charcoal remains are frequent from the base of blanket peat profiles and, whilst they may represent early human activity associated with a lowering of the tree line, coeval with peat initiation, their presence may also represent a residual build up from the degradation of surrounding peat and can have widely different sources (Clark 1988; Edwards 1990; Smith & Taylor 1989).

Typically, the Holocene is also viewed as having several episodes of climatic warming and cooling that may have had a direct effect on the water table and drier vegetation assemblages. It is possible that lower down in the peat core, the presence of higher charcoal levels indicates low water levels (Stoneman 1993).

There is no universally adopted charcoal identification method. The practice adopted in this thesis is the point count method (Clark 1982), which estimates the total particle area but not the number of particle size classes. This approach was used as it is quick and simple and allows an estimation of the increased presence of charcoal through key sediment depths. The basic principle involves using an eyepiece micrometer with a number of points and moving the field of view on transects across the slide (Figure 4.16).

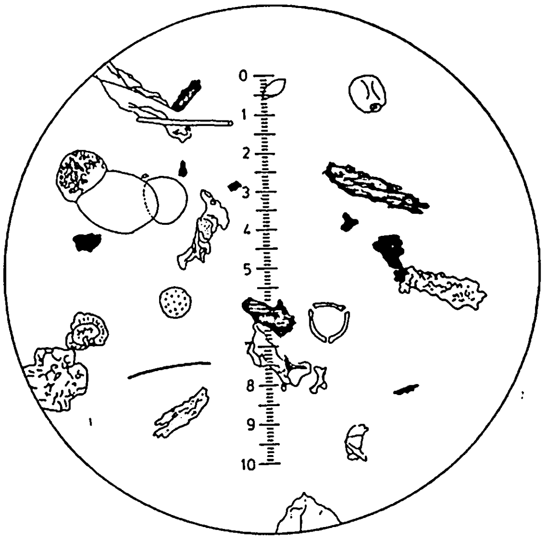


Figure 4.16: A field view in a pollen prep with a standard eyepiece micrometer (Clark 1982).

Of the eleven points defined by the upper ends and numbers across the eyepiece, only one touches charcoal so this is recorded. Magnification of x400 was used so that only one point fell on the majority of charcoal fragments. Transects across the slide were chosen by a predetermined number (56 views were recorded along each transect) to work out the percentage probability of a point falling on a charcoal particle. Charcoal identification was restricted to black, completely opaque and angular fragments (Clark 1988; Swain 1973). Markers (*Lycopodium* spores) were also counted to give the charcoal area, expressed per cm^3 of sediment (Clark 1982). The field of view was moved step by step along transects by advancing the stage. The volume of the sub-sample was not known; therefore the number of exotic marker spores was counted. The total area occupied by the markers was calculated by dividing the total area by the mean area of individual grains of spheres; the formulae (Appendix 7) were based on the methodology of Clarke (1982).

Chapter 5 Results

5.1 *Lithostratigraphy at 230m OD*

5.1.1 Stratigraphy and DTM model at 230mOD

The position of transects 230T, 300T and 400T within the landscape and the main results of the stratigraphical investigations are shown in Figure 5.1 and Figure 5.2 respectively. Symbols used to describe the stratigraphical units follow those recommended by Troels-Smith (1955) (Figure 4.13). The stratigraphical profiles (Figures 5.1 and 5.2) imply a flat surface at the top of each core for ease of drawing; in the field, these profiles were taken across sloping ground. Transects were recorded using a Dutch auger prior to the excavation of three main trenches at the bottom, middle and top of each slope from three different altitudes (400m OD, 300m OD and 230m OD) to ensure representative samples were taken for palaeoenvironmental analysis.

The results presented in this section consider each altitudinal zone separately (230, 300 and 400m OD). The sediment sequence, particle size analysis, mean rates of sedimentation and humification results are presented in the first sections (sections 5.1, 5.2 and 5.3). The pollen analysis through the basal sequences, encompassing the transition into blanket peat, is then considered (sections 5.4, 5.5 and 5.6). More detail and a complete pollen sequence have been obtained from the cores at Lag 230m OD. A complete stratigraphical pollen diagram was analysed to elucidate the impact human activity may have had on the landscape throughout the Holocene and to help identify periods of climatic change. These are presented in the final sections (5.7, 5.8 and 5.9).

The deepest peat (290cm) at 230T (Figure 5.1) was recorded at the top of the slope 20 metres from the selected sampling area. A core was sampled from a basin or dip at the top of the slope: the basal deposits were particularly wet, making sampling difficult. The underlying topography was locally very uneven, exemplified by the varying depths of peat recorded every 10 metres. Across the middle of the slope, peat depth ranged from c.153cm to 55cm and then increased again to 250cm at the bottom of the slope. Sediment accumulation was greatest at the top and bottom of the slope. At the bottom of the slope was the Main Water of Luce and its large incised river channel. Across the slope, four main stratigraphical bands could be identified in the peat, with humification levels identified in the field varying from poor at the top of the cores to well-humified at the base. A series of woody fragments were also noted across the transects, particularly at 82cm, 140-150cm, 160cm and 186cm.

A total of 29 AMS radiocarbon dates were obtained for Lagafater which are presented in Table 5.1.

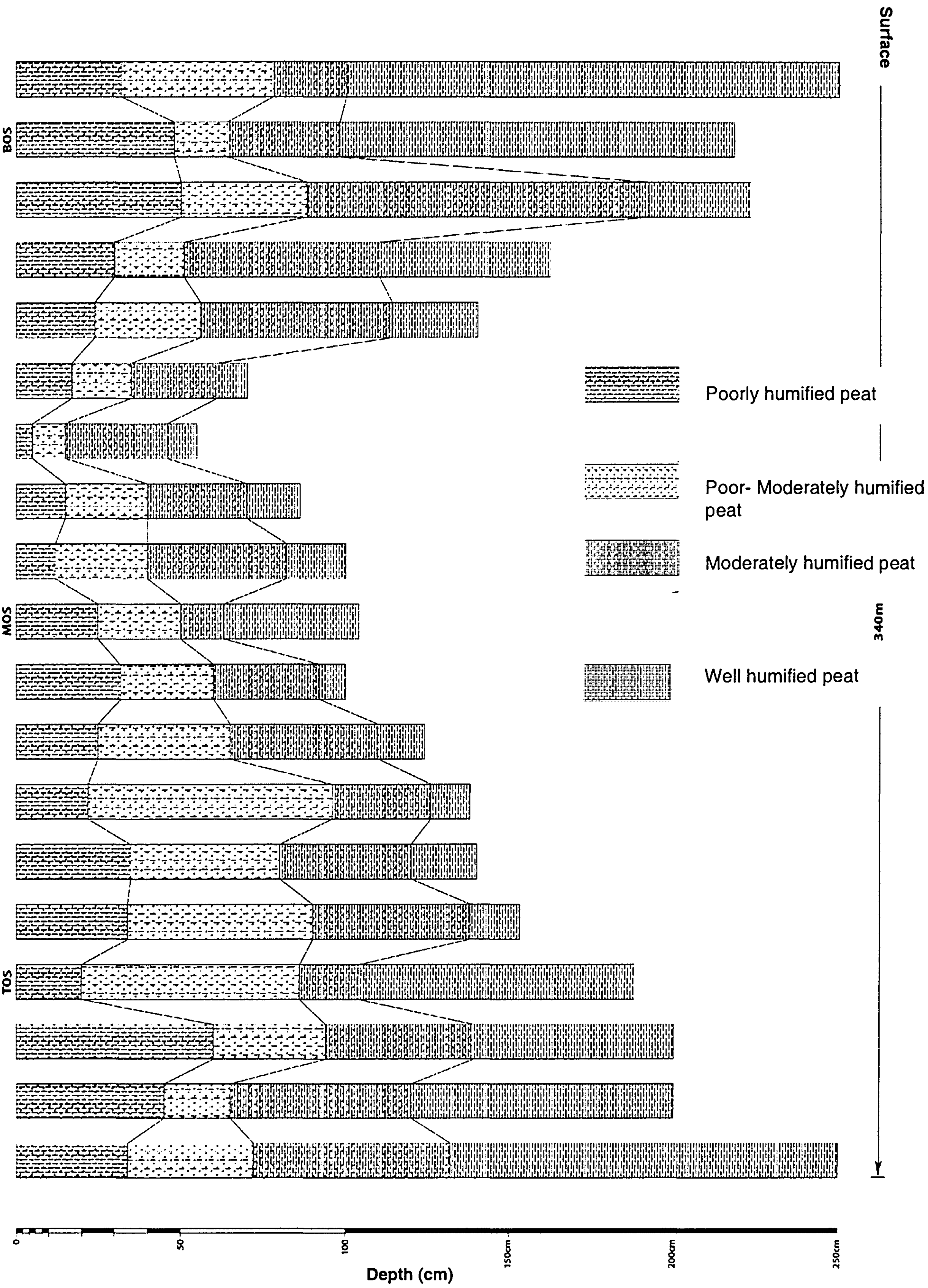


Fig 5.1: Transect across Lag 230m OD showing peat depth and stratigraphy

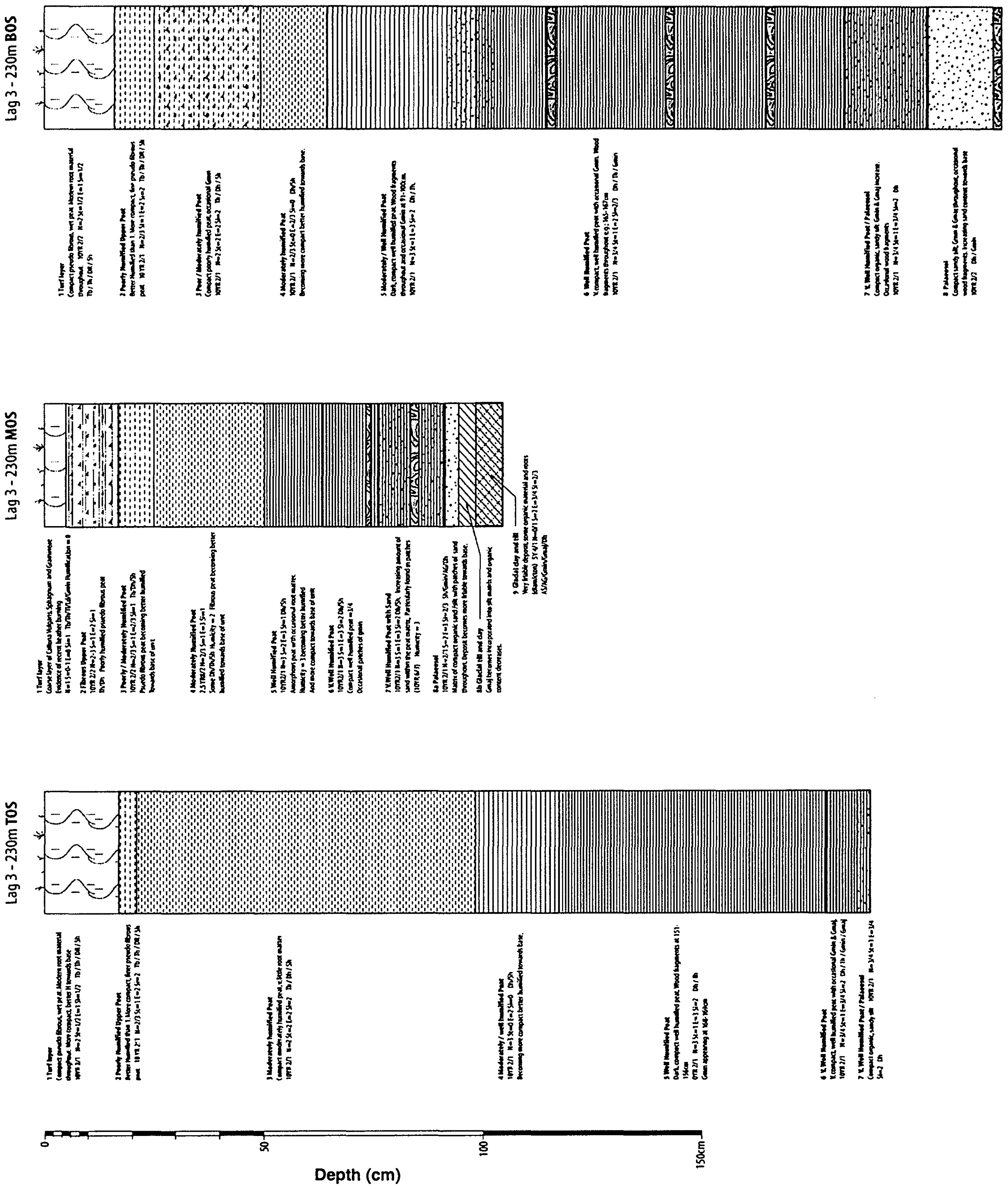


Fig 5.2: Detailed stratigraphic representation of the sections taken for palaeoenvironmental analysis (230m OD).

Altitude	Slope Position	Depth of sample	Material Dated	Lab code	^{14}C Age BP	δ^{13}C	Cal. age BC / AD (± 2.0 σ)	Midpoint used (cal. Age BP)
230m OD	TOS	69-70cm	Humic Acid	SUERC-5974 GU-12887	1620±35	-28.6‰	340-540AD	c.1510
230m OD	TOS	102-103cm	Humic Acid	SUERC-5975 GU-12888	2450±35	-28.7‰	770-400BC	c.2530
230m OD	TOS	121-122cm	Humic Acid	SUERC-5976 GU-12889	3080±35	-28.3‰	1430-1220BC	c.3295
230m OD	TOS	138-139cm	Humic Acid	SUERC-5977 GU-12890	3680±30	-28.7‰	2150-1950BC	c.4025
230m OD	TOS	173-174cm	Humic Acid	SUERC-5978 GU-12891	5040±40	-28.5‰	3960-3710BC	c.5785
230m OD	TOS	184-185cm	Humic Acid	SUERC- 2710 GU-11963	5605±35	-27.9‰	4500-4350BC	**c. 6375**
230m OD	MOS	47-48cm	Humic Acid	SUERC-5979 GU-12892	1140±35	-28.7‰	780-990AD	c.1065
230m OD	MOS	77-78cm	Humic Acid	SUERC-5983 GU-12893	3300±35	-28.7‰	1690-1490BC	c.3535
230m OD	MOS	85-86cm	Humic Acid	SUERC-5984 GU-12894	3965±35	-28.4‰	2580-2340BC	c.4410
230m OD	MOS	90-91cm	Humic Acid	SUERC-2711 GU-11964	4120±35	-28.0‰	2880-2570BC	**c.4675**
230m OD	BOS	73-74cm	Humic Acid	SUERC-5985 GU-12895	1660±35	-28.3‰	250-540AD	c.1555
230m OD	BOS	128-129cm	Humic Acid	SUERC-5986 GU-12896	2860±35	-28.9‰	1190-910BC	c.2970
230m OD	BOS	144-145cm	Humic Acid	SUERC-5987 GU-12897	3285±35	-28.4‰	1690-1450BC	c.3510
230m OD	BOS	175-176cm	Humic Acid	SUERC-5988 GU-12898	3755±35	-26.3‰	2290-2030BC	c.4110
230m OD	BOS	197-198cm	Humic Acid	SUERC-5989 GU-12899	4325±35	-28.6‰	3020-2880BC	c.4905
230m OD	BOS	215-216cm	Humic Acid	SUERC-2712 GU-11965	4545±35	-29.3‰	3370-3090BC	**c.5185**

Table 5.1: Radiocarbon dates at Lagafater and dates for blanket peat initiation (in bold)

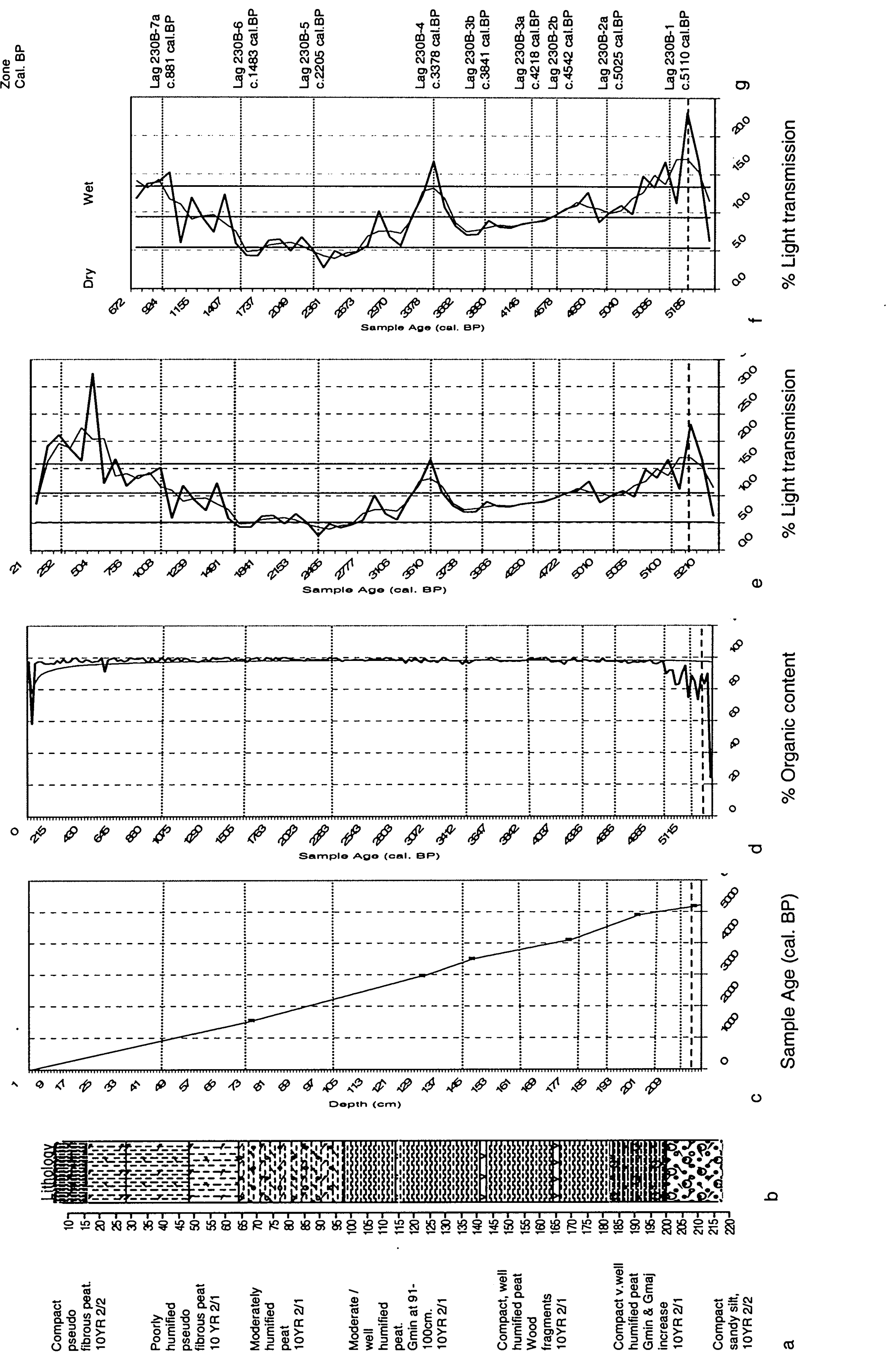
Altitude	Slope Position	Depth of sample	Material Dated	Lab code	^{14}C Age BP	δ^{13}C	Cal. age BC / AD (± 2.0 σ)	Midpoint used (cal. Age BP)
300m OD	TOS	86-87cm	Humic Acid	SUERC-5993 GU-12900	3850±35	-28.0	2460-2200BC	c.4280
300m OD	TOS	120-121cm	Humic Acid	SUERC-2704 GU-11960	5345±35	-28.1	4330-4040BC	**c.6135**
300m OD	MOS	50-51cm	Humic Acid	SUERC-5994 GU-12901	795±35	-28.6	1160-1290AD	c.730
300m OD	MOS	94-95cm	Humic Acid	SUERC-5995 GU-12902	3120±35	-28.2	1500-1260BC	c.3350
300m OD	MOS	101-102cm	Humic Acid	SUERC-2705 GU-11961	3385±35	-28.4	1750-1520BC	**c.3600**
300m OD	BOS	159-160cm	Humic Acid	SUERC-5996 GU-12903	4065±35	-28.9	2860-2470BC	c.4620
300m OD	BOS	173-174cm	Humic Acid	SUERC-2706 GU-11962	4180±35	-29.0	2890-2620BC	**c.4710**
400m OD	TOS	158-159cm	Humic Acid	SUERC-5997 GU-12904	3255±35	-28.3	1620-1430BC	c.3480
400m OD	TOS	166-167cm	Humic Acid	SUERC-2701 GU-11959	4600±35	-28.3	3510-3110BC	**c.5270**
400m OD	MOS	75-76cm	Humic Acid	SUERC-5998 GU-12905	1325±35	-27.8	650-780AD	c.1240
400m OD	MOS	128-129cm	Humic Acid	SUERC-5999 GU-12906	3235±35	-28.0	1610-1420BC	c.3470
400m OD	MOS	141-142cm	Humic Acid	SUERC-2702 GU-11958	4070±35	-28.0	2860-2470BC	**c.4620**
400m OD	BOS	146-147cm	Humic Acid	SUERC-2701 GU-11957	4335±35	-28.4	3080-2880BC	**c.4935**

5.1.2 Sediment sequence at Lag 230m BOS

The organic sequence from Lag 230 BOS (Figure 5.3 (d), see following page) has a total thickness of 220cm and is underlain by a mineral substrate. Fine, well-humified woody / herbaceous deposits were present at the time of peat initiation and woody fragments are present throughout the sequence. Figure 5.3 c shows individual loss-on-ignition analyses and a cumulative mean (solid black line) based on all 216 samples. The dark dashed line below c.5115 cal. BP marks the point of peat initiation where organic matter content is 89.9% and is dated to c.5185 cal. BP. For the purpose of this study, blanket peat initiation is defined as the deepest section of each core with an organic matter content ≥80% (see section 2.1.4).

Between 218cm and 205cm, percentage organic content fluctuates from 24% at the base of the compact sandy silt unit to 89% at 215cm (c.5185 cal. BP). Values then decrease slightly at 212cm and 209cm to 74% before increasing to over 90% at 201cm (c.4965 cal. BP). Organic content remains very uniform (over 90% organic matter content) from 205cm to 0.2cm.

The graphs presented on the following pages (Figures 5.3 & Figures 5.4) have been grouped together in order to help identify trends across the data sets. The horizontal lines across each graph represent the same pollen assemblage zones, identified in section 5.2, but using Microsoft Excel to construct the individual graphs, along with the variables discussed below, have meant that these zones cannot be aligned exactly on each graph. Sampling at a variety of intervals means that equivalent y values are not presented (a factor that could not be resolved using Excel) but the pollen zones provide an accurate indication of time (cal. BP). Similarly, different radiocarbon dates through individual profiles means that time does not increase sequentially as a result of changing values between each set of AMS dates. Graphs and figures have been drawn to present: (a) simplified sediment descriptions; (b) depth and lithology; (c) time-depth drawn on the basis of calibrated AMS dates; (d) organic content of sediments; (e) humification data through the complete profile; (f) humification data omitting the upper layers through the acrotelm / catotelm boundary; and (g) the local pollen zonation. The second set of graphs show: (a & b) humification data; (c) dry bulk density (g/cm^3) with a running mean through every 3 samples & a linear regression line to determine the overall pattern of bulk density accumulation; (d) mean ash free dry bulk density data based on the standard deviation of ash free dry bulk density data with a running mean through every 3 samples; and (e) ash free dry bulk density.



Horizontal lines across each diagram relate to pollen assemblage zones. The approximate age is given in cal. BP. Dashed lines at the base of the diagrams represent the point of peat initiation.

Figure 5.3: LAG 230 BOS (a) Simplified sediment description, (b) depth and lithology, (c) time-depth graph, (d) organic content, (e) humification data, (f) humification data omitting the acrotelm / catotelm boundary and (g) the local pollen zonation.

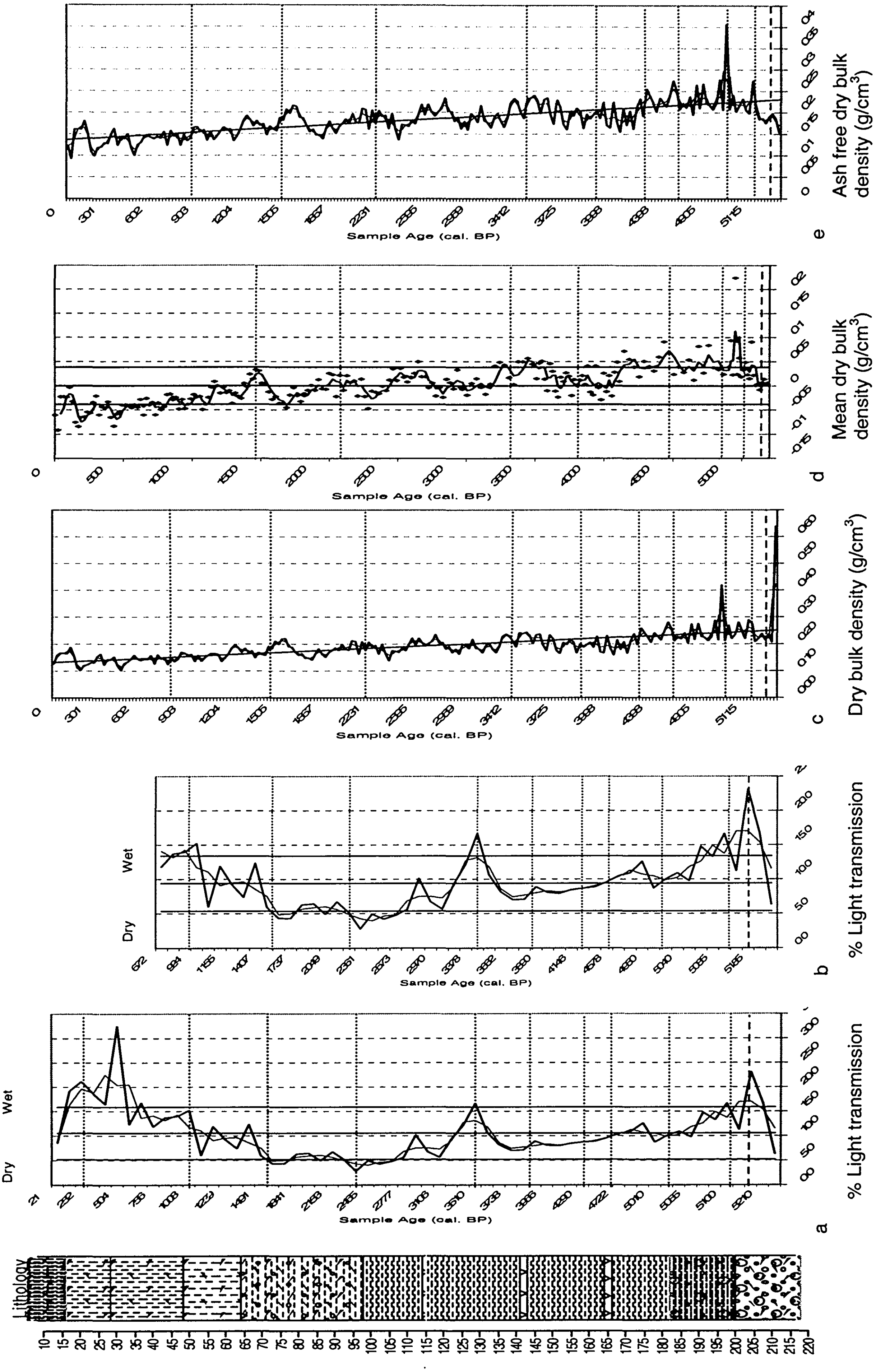


Figure 5.4: Lag 230 BOS (a) humification data, (b) humification data omitting the acrotelm / catotelm boundary, (c) dry bulk density (g/cm³), (d) mean ash free dry bulk density data (e) ash free dry bulk density data.

5.1.3 Sediment Sequence & Mean Rates of Sedimentation at 230m BOS Base

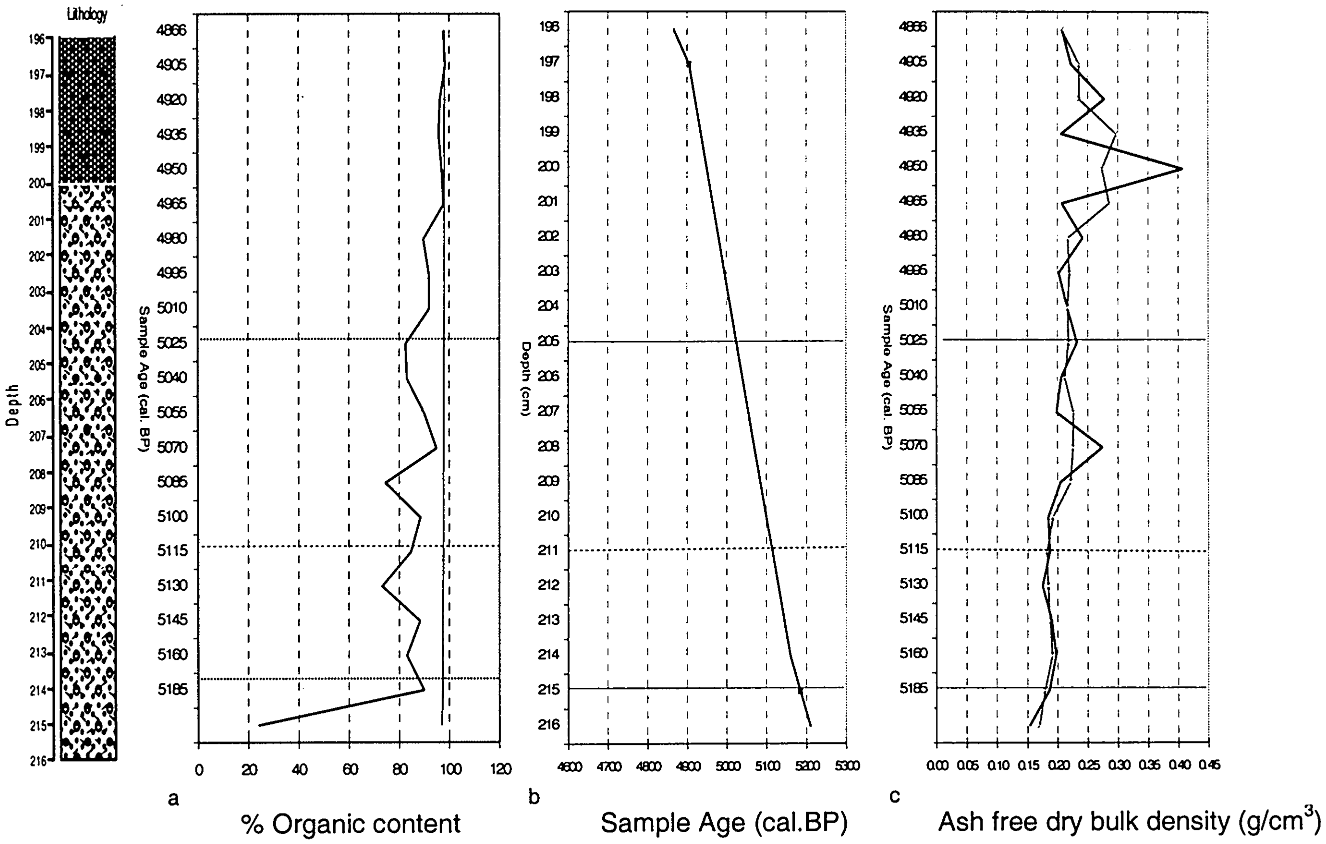


Figure 5.5: (a) organic content from Lag 230BOS Base with cumulative average mean, (b) time-depth curve for Lag 230 BOS Base drawn on the basis of calibrated AMS dates (table 5.2) (c) ash free dry bulk density for Lag 230 BOS with a three term average running mean.

Close analysis of the basal cores of each section was undertaken, through the blanket peat initiation horizon. Figure 5.5 (a) shows that the basal sediment comprised primarily well-humified, fine / woody herbaceous peat with increasing amount of gmin. and gmaj. from 200cm downwards. From 216cm, within the soil horizon, to 215 cm (c.5185 cal. BP), within the blanket peat, organic content increases from 24% to 89%. After a period of fluctuating organic values to c.5070 cal. BP (208cm), levels consistently remain above 80% organic content and after c. 4965 cal. BP (201cm), remain over 90% organic matter.

Figure 5.5 (b) suggests that the mean sedimentation rate from the base of the core at c.5185 cal. BP to c.5070 cal. BP is increasing steadily over c.240 years. The ash free dry bulk density data, Figure 5.5 (c), suggests organic matter accumulated steadily from the base of the core into blanket peat, with values ranging from 0.154 g/cm³ at the base to 0.402 g/cm³ at c.4950 cal. BP. The graph suggests that during this period, there were no sudden increases in moisture which appear to have affected the bulk volume of the peat.

5.1.4 Particle Size Analysis of Lag 230 BOS Base

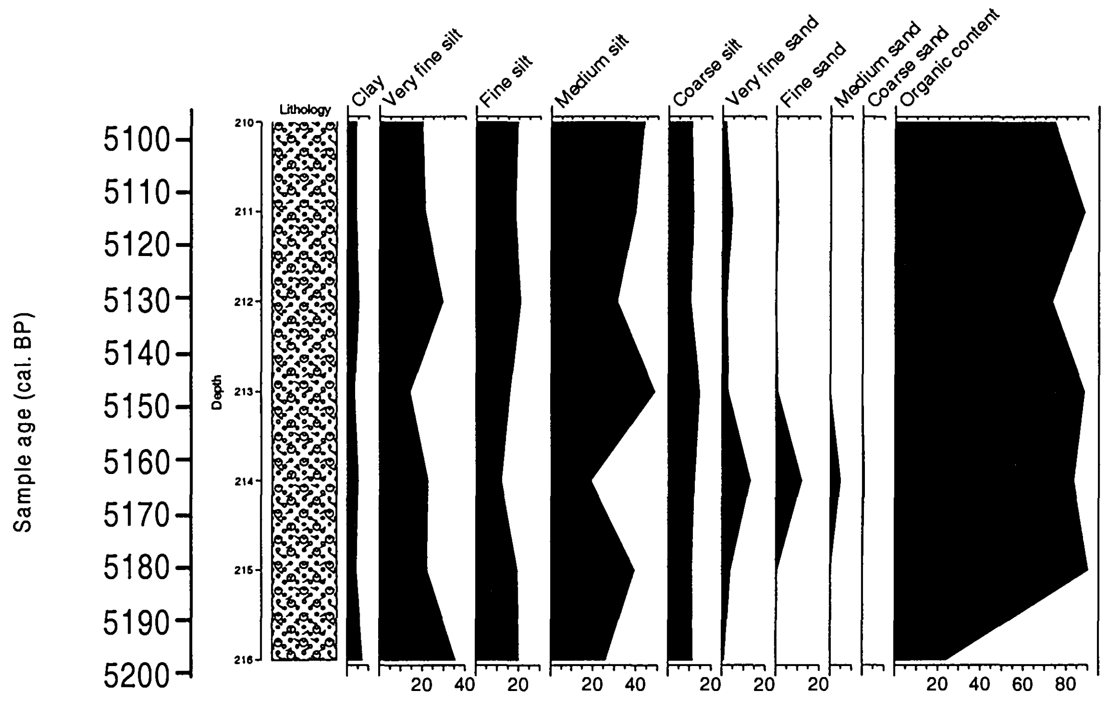


Figure 5.6: Particle size analysis through Lag 230 BOS Base (%)

Particle size analysis through the basal profile (216-210cm) shows a dominance of very fine silt at 216cm and an increase in medium silt to 23.8% at 215cm. A peak in very fine sand, fine sand and medium sand occurs at 214cm. Medium silt and very fine silt then increase in volume up to 210cm. Clay particles remain constant throughout the basal profile, making up only 4% of the sediments. Particle size analysis indicates that there is no trend towards accumulation or translocation of finer material towards the very base of the profile, suggesting these soils were ground-water gley soils rather than surface water gleys, developed over permeable materials.

5.1.5 Mean rates of sedimentation

Sampling at every 1cm³ for dry bulk density has allowed estimations to be made of the weight of organic matter per cm³ (Figure 5.4 (c) and (e)), giving some indication of the mass rate of blanket peat accumulation throughout the core (Yu et al 2000; Gorham *et al* 2003). Bulk density is defined as the weight of a volume of soil including its pore spaces, water and air within these. The dry bulk density process allows the moisture content of samples to be calculated, leaving a dry mass per unit area every 1cm through the peat profile. The dry bulk density data and ash-free dry bulk density data are both presented (Figures 5.4 (c), (d) and (e)) to demonstrate the fact that greater bulk density towards the base of the peat core is not always a result of increased minerogenic material, but in fact reflects greater decomposition and compaction of humified plant material. These figures can be compared with the age / depth model (Figure 5.3 (a)) showing vertical peat growth rates (cm/yr), assuming constant vertical peat growth between each pair of AMS dates. Figure 5.4 (a), the age / depth plot at Lag 230 BOS, shows individual ^{14}C AMS dates marked by a small black square, between which linear interpolation was made.

The graphs showing bulk density and ash-free bulk density in Figure 5.4 (c), (d) and (e) are presented against a running mean of every 3 readings to smooth and average the graph curve, in order to identify general patterns of change. Against this, a linear regression line has been added to determine the overall pattern of bulk density accumulation (increasing or decreasing through time). This regression line can be used to depict the relationship between the independent (time) and dependent (bulk density) variables in the graph: the straightness of the line depicts a linear increase / decrease in bulk density through time. The mean dry bulk density data (Figure 5.4 (d)) is based on the standard deviation of the ash-free dry bulk density data (the 'mean of the mean'), showing how tightly the readings are clustered around the mean and how these readings fall between plus one or minus one standard deviation. A running mean based on the average of three readings has also been overlain to identify a relationship between points. This diagram helps to identify significant changes in patterns either side of the mean and the clustering of points through time indicates the relative uniformity between samples through different sections of the peat core.

5.1.6 Mean rates of sedimentation at Lag 230 BOS.

Six AMS radiocarbon dates were obtained from Lag 230 BOS and an age / depth curve has been produced on the basis of the dating (Figure 5.3 (a)).

Altitude	Slope Position	Depth of sample	Material Dated	Lab code	^{14}C Age BP	δ^{13}C	Cal. age BC / AD (± 2.0 σ)	Midpoint used (cal. Age BP)
230m OD	BOS	73-74cm	Humic Acid	SUERC-5985 GU-12895	1660±35	-28.3‰	250-540AD	c.1555
230m OD	BOS	128-129cm	Humic Acid	SUERC-5986 GU-12896	2860±35	-28.9‰	1190-910BC	c.2970
230m OD	BOS	144-145cm	Humic Acid	SUERC-5987 GU-12897	3285±35	-28.4‰	1690-1450BC	c.3510
230m OD	BOS	175-176cm	Humic Acid	SUERC-5988 GU-12898	3755±35	-26.3‰	2290-2030BC	c.4110
230m OD	BOS	197-198cm	Humic Acid	SUERC-5989 GU-12899	4325±35	-28.6‰	3020-2880BC	c.4905
230m OD	**BOS**	**215-216cm**	**Humic Acid**	**SUERC-2712 GU-11965**	**4545±35**	**-29.3‰**	**3370-3090BC**	**c.5185**

Table 5.2: AMS radiocarbon dates from Lag 230 BOS with blanket peat initiation dates presented in bold.

Figure 5.3 (c) suggests that an average peat accumulation rate of 11.72 years / cm can be calculated through the peat profile, although this rate will have varied through time and these rates do not account for the fact that older peat may have undergone more decay and compaction than younger peat (Clymo 1984, 1988; Clymo *et al* 1998). Overall, Figures 5.4 (c), (d) and (e) show detailed correlation and suggest that dry bulk density has been gradually declining over time but is at its greatest after blanket peat initiation at c.5115 cal. BP to c. 4100 cal. BP. High dry bulk density readings, but a slow vertical rate of growth at this point (15 years / cm), suggest a slow component of decay, with 'peat addition' (high plant production) being greater, higher water table, lower acrotelm decay and more compaction all adding to the weight of organic matter at this stage.

Figure 5.4 (e) represents the deviation of individual ash-free dry bulk density readings around the mean and according to their age. This graph shows that the average dry bulk density falls between c.4095 cal. BP to c.3529 cal. BP before increasing again at c.3446 cal. BP to 0.240g/cm^3 (Figure 5.4 (e)). Values then fall again between c.3174 cal. BP to c.2751 cal. BP before continuing to fluctuate between the plus and minus standard deviation of Figure 5.4 (d) but gradually decline with time. Figures 5.4 (c), (d) and (e) show a decrease in values from the mean over the last c.600 yrs BP, perhaps at the acrotelm / catotelm boundary where decay in the upper acrotelm proceeds slowly as plants are still living. A decrease in dry bulk density near the surface signifies lighter, un-compacted, undecomposed plant material.

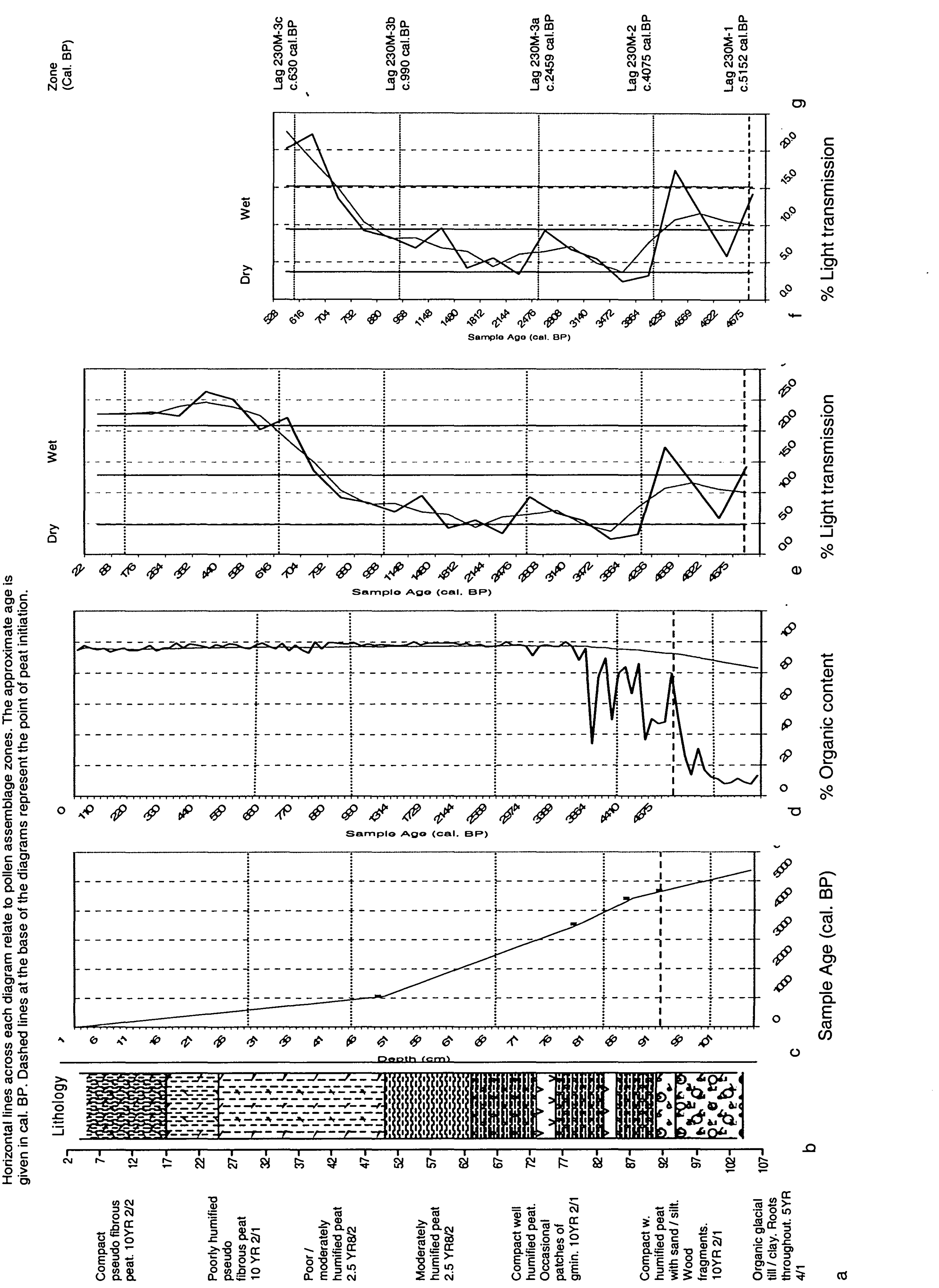
5.1.7 Peat humification profile from Lag 230 BOS

Figure 5.4 (a) and (b) shows humification data from Lag 230 BOS. Data are shown as percentage light transmission. A running mean (lighter shaded line) has been added, produced from an unweighted average of three consecutive readings from contiguous samples every 4cm and every 1cm through the basal 10cm. The data are presented as using a mean value of 0 and a standard deviation of plus 1 and minus 1 for normalising. High percentage light transmission values to the right of the mean may indicate wet shifts in climate. Data through the acrotelm / catotelm boundary, based on dry bulk density data (Figure 5.4 (c), (d) and (e)), have been omitted from Figure 5.4 (b).

The light transmission data in Figure 5.4 (a) and (b) show relatively high values at the base of the peat, peaking at the point of blanket peat initiation (c.5185 cal. BP) and at c.5130 cal. BP and c.5100 cal. BP, before gradually decreasing through the first two pollen zones to c.4950 cal. BP when conditions were much drier. The data show particularly marked shifts to higher light transmission levels (and wetter conditions) at c.4866 cal. BP (196cm) and at c.3378 cal. BP, after which time conditions remain dry, particularly at c.2257 cal. BP (100cm). Percentage light transmission levels increase once more in the upper 64cm, corresponding with a change in peat stratigraphy and suggest wetter conditions at c.1323 cal. BP and a peak in values at c.420 cal.BP to 32% light transmission, perhaps marking the acrotelm / catotelm boundary.

5.1.8 Sediment Sequence at Lag 230m MOS

The long core from 230 MOS (Figure 5.7 (d)), was 104cm long. At its base was a compact organic sand / silt underlain by a glacial till. Fine, well-humified woody / herbaceous deposits with some gmin. are present at the point of peat initiation, which has been placed at 91cm where organic content reaches 80% for the first time (c. 4675 cal. BP). The basal sediment sequence is also interspersed with layers of woody fragments at 73cm and 83cm, similar to Lag 230 BOS. Figure 5.7 (d) (showing the curve for ignition residue compared to the cumulative average) indicates that prior to c.3540 cal. BP, organic content fluctuated from 28% within the underlying soil to 80% at the point of initiation. Following blanket peat initiation, levels fell once more to 49% before stabilising at over 90% organic matter at 75cm (c.3361 cal. BP) where values remain close to the mean.



Horizontal lines across each diagram relate to pollen assemblage zones. The approximate age is given in cal. BP. Dashed lines at the base of the diagrams represent the point of peat initiation.

Figure 5.7: LAG 230 MOS (a) Simplified sediment description, (b) depth and lithology, (c) time-depth graph, (d) organic content, (e) humification data, (f) humification data omitting the acrotelm / catotelm boundary and (g) the local pollen zonation.

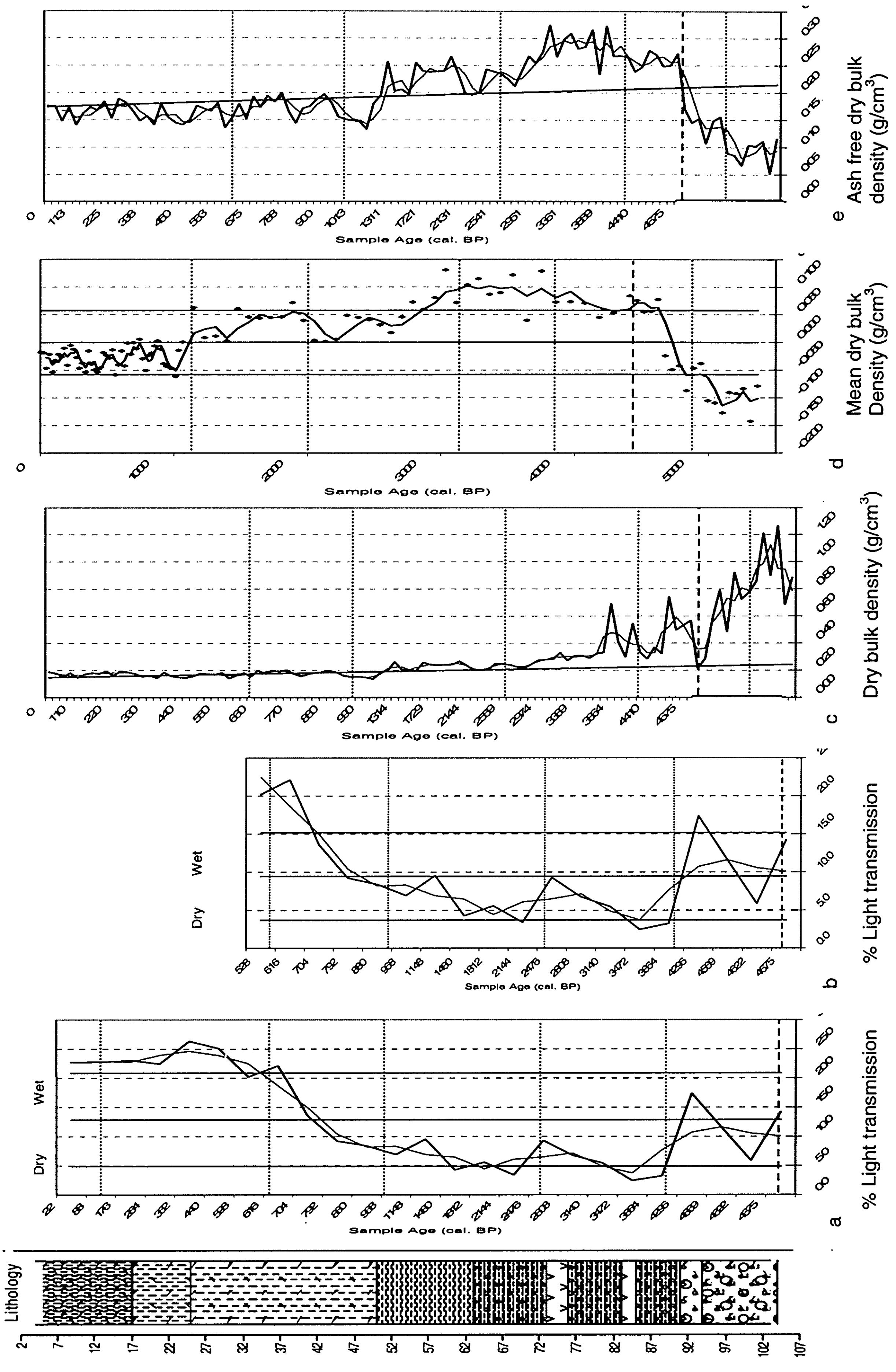
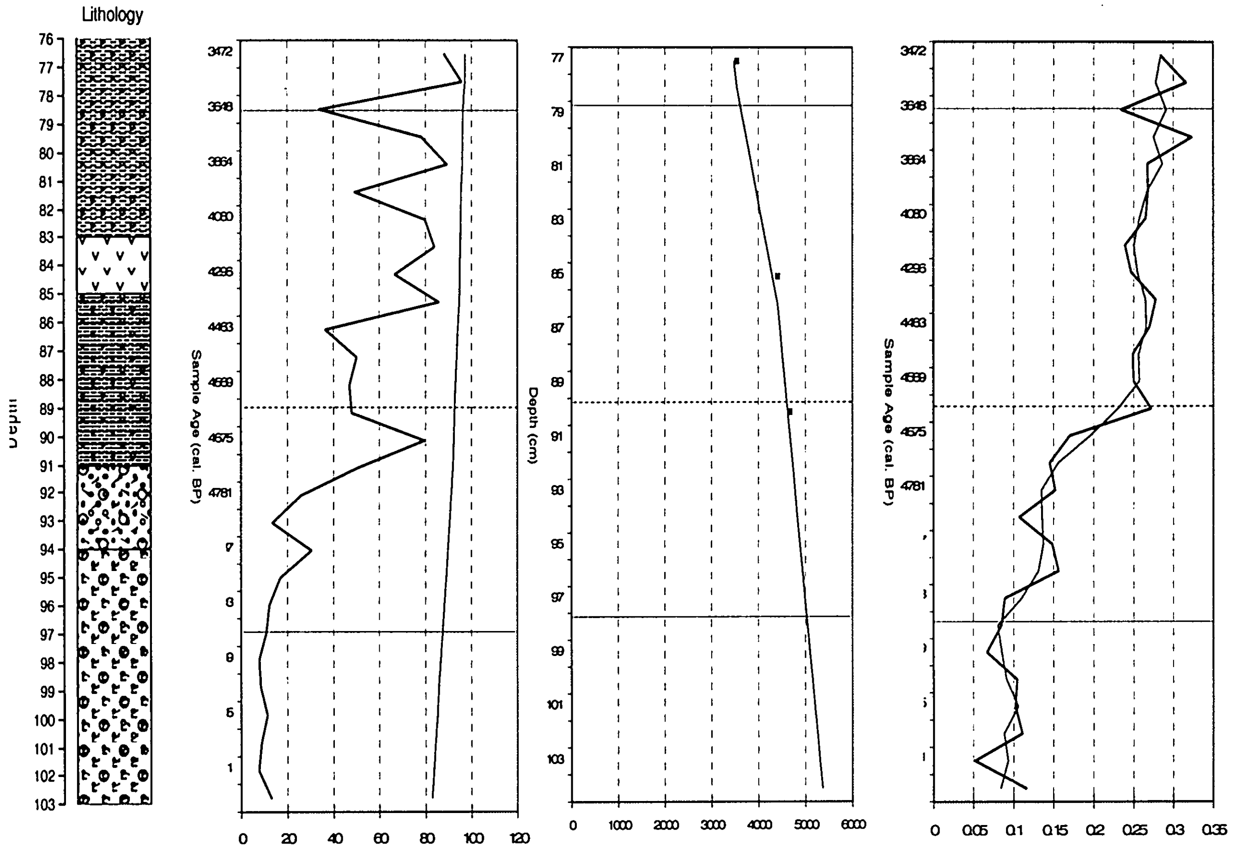


Figure 5.8: Lag 230 MOS (a) humification data, (b) humification data omitting the acrotelm / catotelm boundary, (c) dry bulk density (g/cm³), (d) mean ash free dry bulk density data (e) ash free dry bulk density data.

5.1.9 Sediment Sequence & Mean rates of sedimentation at 230 MOS Base



a % Organic content b Sample Age (cal.BP) c Ash free dry bulk density (g/cm^3)

Figure 5.9: (a) organic content from Lag 230 MOS Base with cumulative average mean, (b) time-depth curve for Lag 230 MOS Base drawn on the basis of calibrated AMS dates (table 5.2) (c) ash free dry bulk density for Lag 230 MOS with a three term average running mean

The basal sediment sequence through Lag 230 MOS (Figure 5.9) consists of a compact, well-humified fine / woody herbaceous peat with an increasing amount of gmin. and gmaj. This overlay a glacial till / clay mix with an organic content of <60%. At 91cm, c.4675 cal. BP, organic content levels fluctuate to 80% (the point of peat initiation), decrease again to 36% and then rise at 84cm (c.4188 cal. BP) to 83%. At 78cm (c. 3540 cal. BP) organic content levels remain over 80%. Several AMS ^{14}C assays were taken through this basal sequence as organic content fluctuated before remaining over 80%.

Figure 5.9 (c) suggests that dry bulk density through the minerogenic layers was low but bulk density and organic content rise to 0.27 g/cm^3 at the point of peat initiation. Following blanket peat initiation, bulk volume appears to remain higher and steady.

5.1.10 Particle Size Analysis at Lag 230 MOS Base

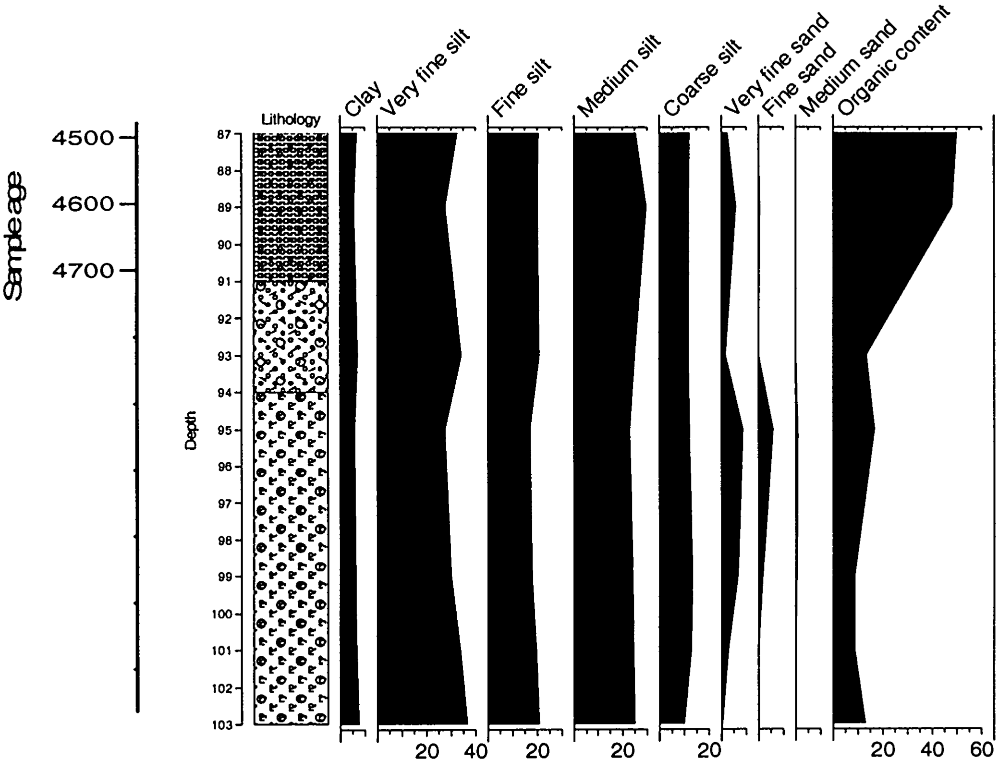


Figure 5.10: Particle size analysis through Lag 230 MOS Base (%)

Particle size analysis through the basal 16cm of Lag 230 MOS show a dominance of very fine to medium silts throughout the basal sequence, and the presence of very fine sand and fine sand from 94cm to 103cm. There is a clear boundary between the glacial till at the base and the increase in organic content at 94cm through the soil horizon (90 to 94cm). There is no clay enrichment at the surface of the soil horizon, suggesting no reduction in porosity, but a peak in fine sand at 95cm, grading towards finer particles down profile suggests the material may have been sorted by flowing water.

5.1.11 Mean rates of sedimentation at Lag 230 MOS

A total of 4 AMS radiocarbon dates were taken from Lag 230 MOS (Table 5.3) and an age / depth curve was produced on the basis of these, assuming constant vertical growth rates between each pair of AMS dates.

Altitude	**Slope Position**	**Depth of sample**	**Material Dated**	**Lab code**	**^{14}C Age BP**	**δ^{13}C**	**Cal. age BC / AD (± 2.0 σ)**	**Midpoint used (cal. Age BP)**
230m OD	MOS	47-48cm	Humic Acid	SUERC-5979 GU-12892	1140±35	-28.7‰	780-990AD	c.1065
230m OD	MOS	77-78cm	Humic Acid	SUERC-5983 GU-12893	3300±35	-28.7‰	1690-1490BC	c.3535
230m OD	MOS	85-86cm	Humic Acid	SUERC-5984 GU-12894	3965±35	-28.4‰	2580-2340BC	c.4410
230m OD	**MOS**	**90-91cm**	**Humic Acid**	**SUERC-2711** **GU-11964**	**4120±35**	**-28.0‰**	**2880-2570BC**	**c.4675**

Table 5.3: AMS radiocarbon dates from Lag 230 MOS with blanket peat initiation dates presented in bold.

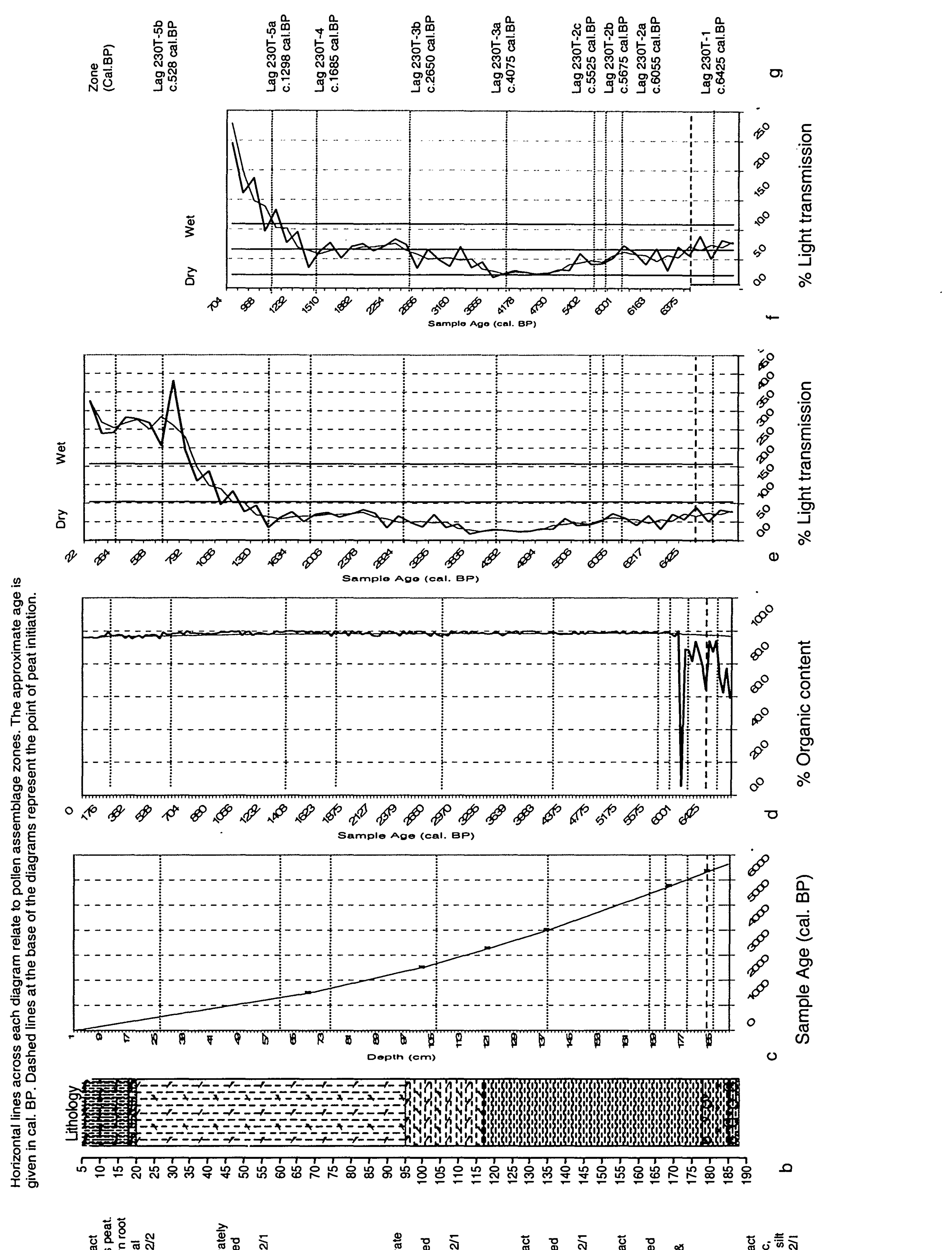
Figure 5.7 (c) indicates an average peat accumulation rate of 51 years / cm through the peat profile. The rate of dry bulk volume accumulation (Figures 5.8 (c), (d) and (e)), however, shows a fluctuating profile with low bulk density through the basal minerogenic material (higher values of dry bulk density are shown in Figure 5.8 (c)) with low levels of organic matter in Figure 5.7 (d). Rates of dry bulk density increase sharply at the point of blanket peat initiation from 0.052g/cm³ to 0.272g/cm³, c. 4675 cal. BP (Figure 5.8 (e)). Over time, a slow decline in bulk density occurs but until c.3115 cal. BP, bulk density remains above the mean (Figure 5.8 (d)) suggesting there was a long period of decomposition and / or compaction. Values decrease slightly after this period, correlating well with a decrease in growth rates of 88 years / cm at this stage. Over the last c.1000 years cal. BP however, rates have declined and a clustering of points to the left of the mean in Figure 5.8 (d) suggest lower peat mass accumulation and lowered peat addition rates, marking the acrotelm / catotelm boundary. The differences in bulk density profiles between Figures 5.8 (c) and 5.8 (e) suggest that by removing the ash component, the bulk density curve becomes clearer to understand (presumably as the data set becomes more sensitive to minor weight changes) giving a clearer indication of smaller scale hydrological patterns.

5.1.12 Peat humification profile from Lag 230 MOS

The first shift to higher light transmission values occurs at the point of initiation at c.4675 cal. BP (90cm) followed by a second increase at c.4296 cal. BP (84cm) (Figures 5.8 (a) and (b)). Conditions then appear to have remained relatively dry, particularly at c.3472 cal. BP and c.2144 cal. BP, with a slight shift to higher values at c.2476 cal. BP. At c.1148 cal. BP and c.792 cal. BP, increased values indicated wetter conditions and the latter perhaps marks the boundary between the acrotelm and catotelm boundary.

5.1.13 Sediment sequence at Lag 230m TOS

The sediment sequence from Lag 230 TOS (Figure 5.11 (b)) was 188cm long. Its base contained a well-humified blanket peat with sandy / silt inclusions. A compact, well-humified woody / herbaceous peat with some fine sand particles is present at the point of blanket peat initiation and this is overlain by a sequence of poorer humified peats. The LOI curve, Figure 5.11 (d), shows a high minerogenic content at the base of the core where levels fluctuate between 60% and 80% organic content. Values drop from 89% at 176cm to only 5% at 175cm (c.5893 cal. BP), suggesting an inwashed band. Following this, organic content rises to 100% after which point levels remain close to the mean and average at 98% organic content throughout the core. The point of blanket peat initiation has been placed at 184cm where organic content initially and abruptly rises to 94%. This depth is ^{14}C dated to c.6375 cal. BP (Table 5.4) and is the earliest peat sequence recorded at Lagafater. An assay has also been obtained at 173cm where organic content is consistently above 90%; this has been dated to c.5785 cal. BP.



Horizontal lines across each diagram relate to pollen assemblage zones. The approximate age is given in cal. BP. Dashed lines at the base of the diagrams represent the point of peat initiation.

Figure 5.11: LAG 230 TOS (a) Simplified sediment description, (b) depth and lithology, (c) time-depth graph, (d) organic content, (e) humification data, (f) humification data omitting the acrotelm / catotelm boundary and (g) the local pollen zonation.

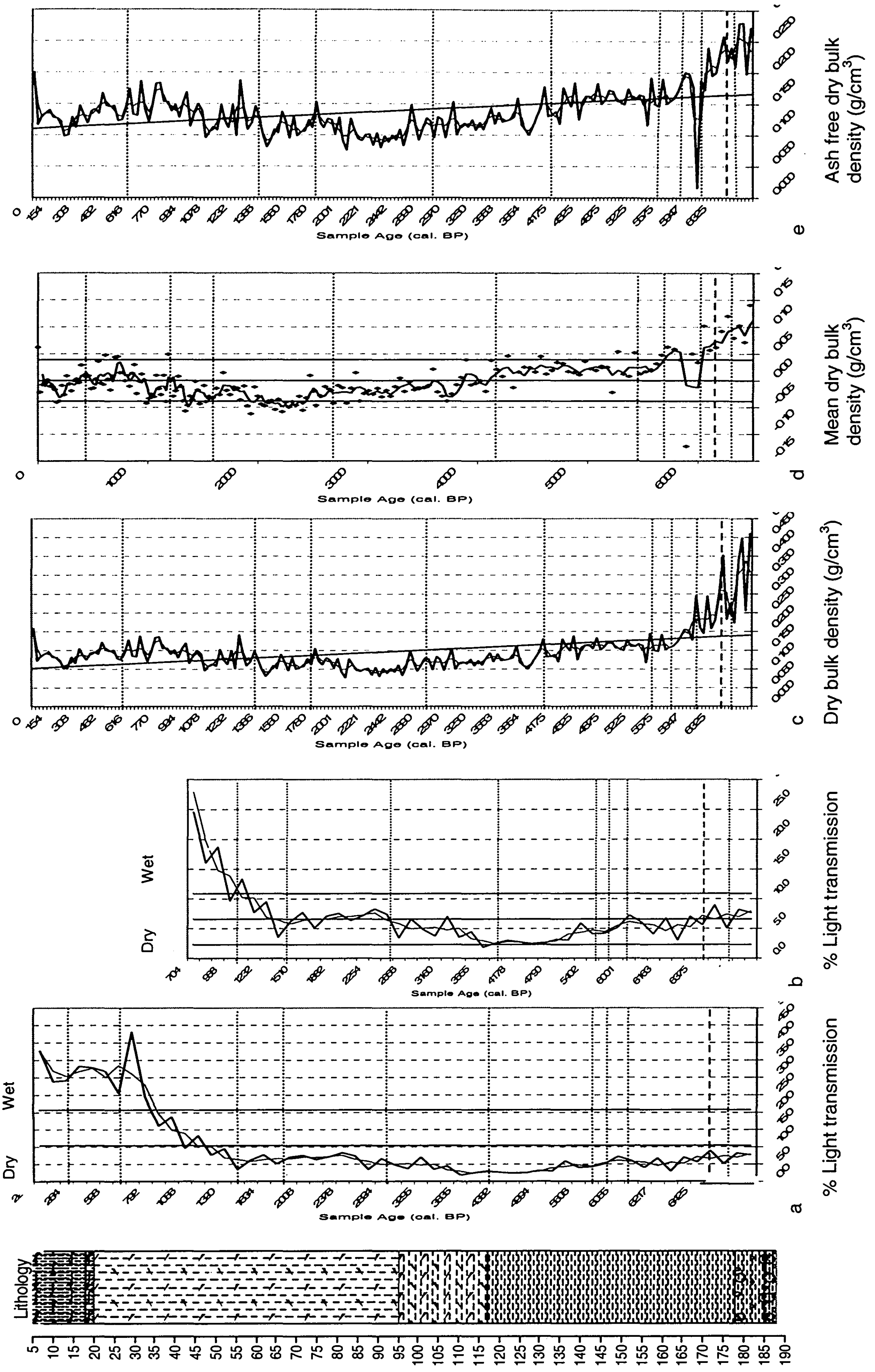


Figure 5.12: Lag 230 TOS (a) humification data, (b) humification data omitting the acrotelm / catotelm boundary, (c) dry bulk density (g/cm³), (d) mean ash free dry bulk density data (e) ash free dry bulk density data.

5.1.14 Sediment Sequence & Mean rates of sedimentation at 230m TOS Base

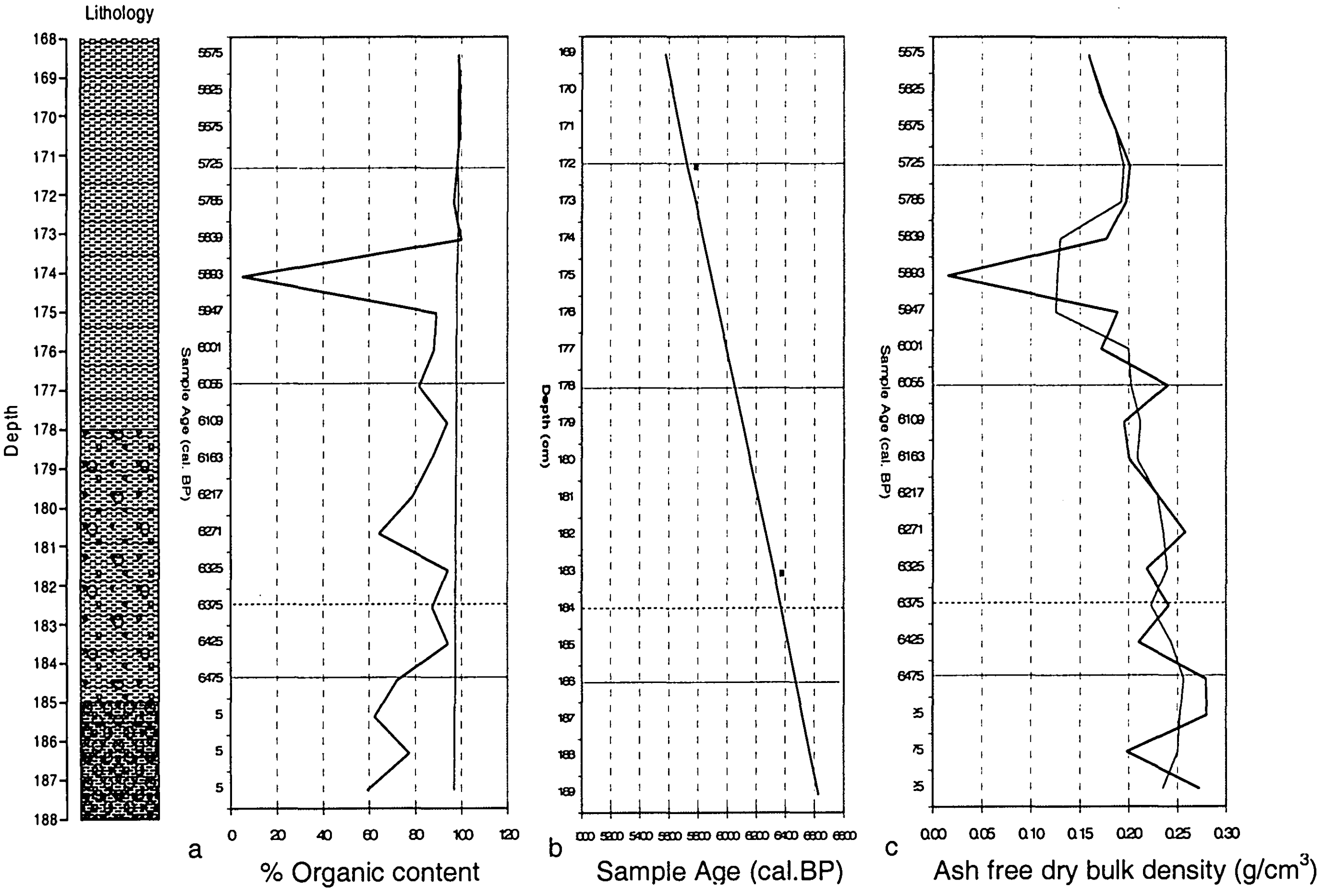


Figure 5.13: (a) organic content from Lag 230 TOS Base with cumulative average mean, (b) time-depth curve for Lag 230 TOS Base drawn on the basis of calibrated AMS dates (table 5.2) (c) ash free dry bulk density for Lag 230 TOS with a three term average running mean

The basal sequence at Lag 230 TOS comprises a well-humified fine/woody herbaceous peat with large amounts of gmin. and gmaj at the very base (185-188cm), where the % organic content rises from 59% to 94%. From 184cm, levels fluctuate and at c.5947 cal. BP, fall again to 5% before rising suddenly to 100% at 173cm, after which point values remain above 95%.

Figure 5.13 (c) shows relatively high but stable levels of bulk density from the base of the core through the point of blanket peat initiation. A small decrease in values at c.5947 cal. BP in Figures 5.13 (a) and (c) perhaps represent a small inwashed band at this level (175cm).

5.1.15 Particle Size Analysis at Lag 230 TOS Base

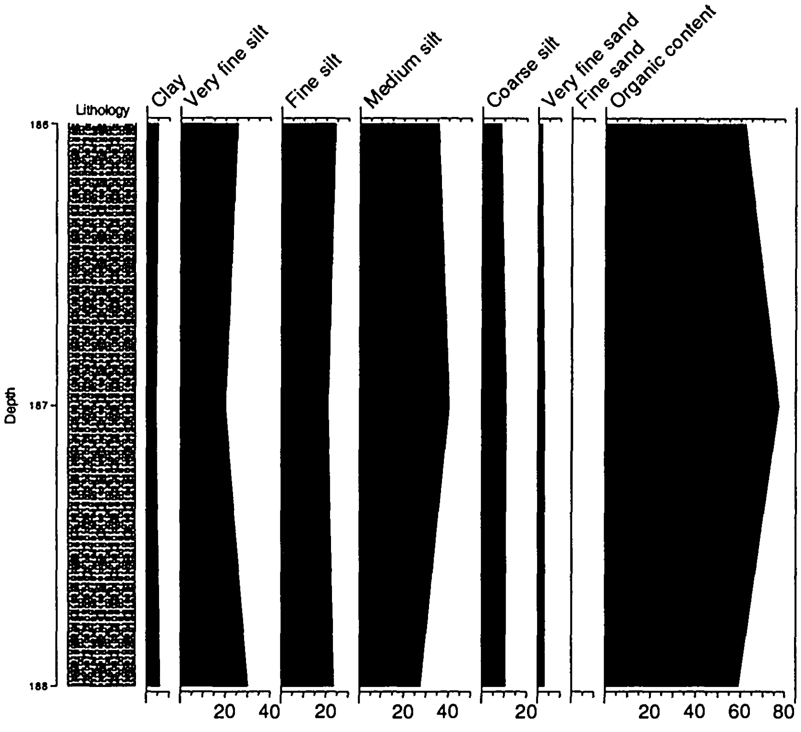


Figure 5.14: Particle size analysis through Lag 230 TOS Base (%). No ^{14}C AMS dates were taken through this soil profile.

The basal 3cm were analysed for particle size as there was only a shallow compact sandy / silt present at the base of the core and organic content values rose quickly through the profile. Very fine silt, fine silt and medium silt were dominant through the profile with very little sand or clay, suggesting the profile was relatively porous and little erosion or translocation of finer materials downwards had occurred.

5.1.16 Mean rates of sedimentation at Lag 230 TOS

A total of 6 AMS radiocarbon dates were obtained from Lag 230 TOS and these are presented in Table 5.4. An age/depth curve and mass rates of accumulation have been estimated based on these dates.

Altitude	**Slope Position**	**Depth of sample**	**Material Dated**	**Lab code**	**^{14}C Age BP**	**δ^{13}C**	**Cal. age BC / AD (± 2.0 σ)**	**Midpoint used (cal. Age BP)**
230m OD	TOS	69-70cm	Humic Acid	SUERC-5974 GU-12887	1620±35	-28.6‰	340-540AD	c.1510
230m OD	TOS	102-103cm	Humic Acid	SUERC-5975 GU-12888	2450±35	-28.7‰	770-400BC	c.2530
230m OD	TOS	121-122cm	Humic Acid	SUERC-5976 GU-12889	3080±35	-28.3‰	1430-1220BC	c.3295
230m OD	TOS	138-139cm	Humic Acid	SUERC-5977 GU-12890	3680±30	-28.7‰	2150-1950BC	c.4025
230m OD	TOS	173-174cm	Humic Acid	SUERC-5978 GU-12891	5040±40	-28.5‰	3960-3710BC	c.5785
230m OD	**TOS**	**184-185cm**	**Humic Acid**	**SUERC-2710 GU-11963**	**5605±35**	**-27.9‰**	**4500-4350BC**	**c. 6375**

Table 5.4: AMS radiocarbon dates from Lag 230 TOS with blanket peat initiation dates presented in bold.

Figure 5.11 (c) shows that several radiocarbon dates were taken through this peat profile and the smoothness of the age-depth curve means the curve is almost exponential. An average accumulation rate of 34 years / cm is estimated for Lag 230 TOS. The dry bulk density results (Figure 5.12 (c), (d) and (e)) show that bulk density at the base of the core is higher, measuring 0.279g/cm^3 at c.6475 cal. BP, suggesting greater compaction and 'peat addition' rates at the base with little minerogenic material. Overall, bulk density has become less per annum as age decreases but throughout the core, values do not deviate greatly from the mean and are similar to Lag 230 BOS. At c.4125 cal. BP all graphs show that the bulk density per cm^3 declines slightly to c.2410 cal. BP, and over the last 2400 years, values have been consistently falling and are lower then the mean, perhaps suggesting the water table has been relatively low at the bottom of slope. It is not clear from Figures 5.11 (c), (d) and (e) where the acrotelm / catotelm boundary lies but a slight rise in values, followed by a decrease at c330 cal. BP (Figure 5.11 (d)) may suggest it lies here at 20cm.

5.1.17 Peat humification profile from Lag 230 TOS

The light transmission data through the Lag 230 TOS profile are relatively low. They show the highest values in decayed peat between c.6475 cal. BP and c.6375 cal. BP to 8.9%, the point of blanket peat initiation, suggesting conditions were wet at the time of peat deposition. The data then show a slight fall in values to c.6001 cal. BP when values rise again, and then a period of drier conditions are recorded for c.2800 years. Shifts to higher percentage light transmission values then occur at c.3160 cal. BP and between c.2378 cal. BP and c.1758 cal. BP. At 56cm (c.1232 cal. BP) a marked increase in values marks the point of the acrotelm / catotelm boundary.

5.2 *Lithostratigraphy at 300m OD*

5.2.1 Stratigraphy and DTM model at 300mOD

A total of 51 cores were taken from Lag 300m OD, extending from the top of the slope down to the bottom, covering 545m in length (Figure 5.15 extending over 2 pages, 142 & 143). The deepest cores were from the top of slope, measuring 174cm and at the base of slope, measuring 200cm (5 metres from which a trench was dug for palaeoenvironmental investigation). From the top of slope, the underlying topography appeared to shelve quite quickly and samples became shallower, averaging 56cm to 155cm down slope. From this point downslope towards the base of slope, cores deepened, ranging from 85cm to 146cm. The middle of slope sequence was taken from an exposed peat hag, situated 165m down slope. The depth of peat across the gently sloping middle section of the slope remained relatively constant at 375cm, and increased in depth across a small basin from which the bottom of slope palaeoenvironmental sample was dug (415m down slope). Towards the very base of the slope, close to the Main Water of Luce, samples became shallow again (c.55cm) and a greater proportion of minerogenic material was found at the base of the cores, along with some evidence of localised iron pan. Across the slope, four main humification bands were identified and woody fragments were noted at the top of slope (c.92cm) and at the base of the slope between 106cm and 118cm. Figure 5.16 shows a detailed stratigraphical representation of the sections taken for palaeoenvironmental analysis (300m OD).

The sediment sequences presented in the following section consider the complete series of cores from the top of slope to the base of slope. The palynological record, however, was only analysed through the basal layers and through the peat initiation sequence. The zones presented in this section for the long cores have, therefore, been derived from the pollen sequence at the base of each core and sediment data based on changes in the dry bulk density and humification data through the upper layers.

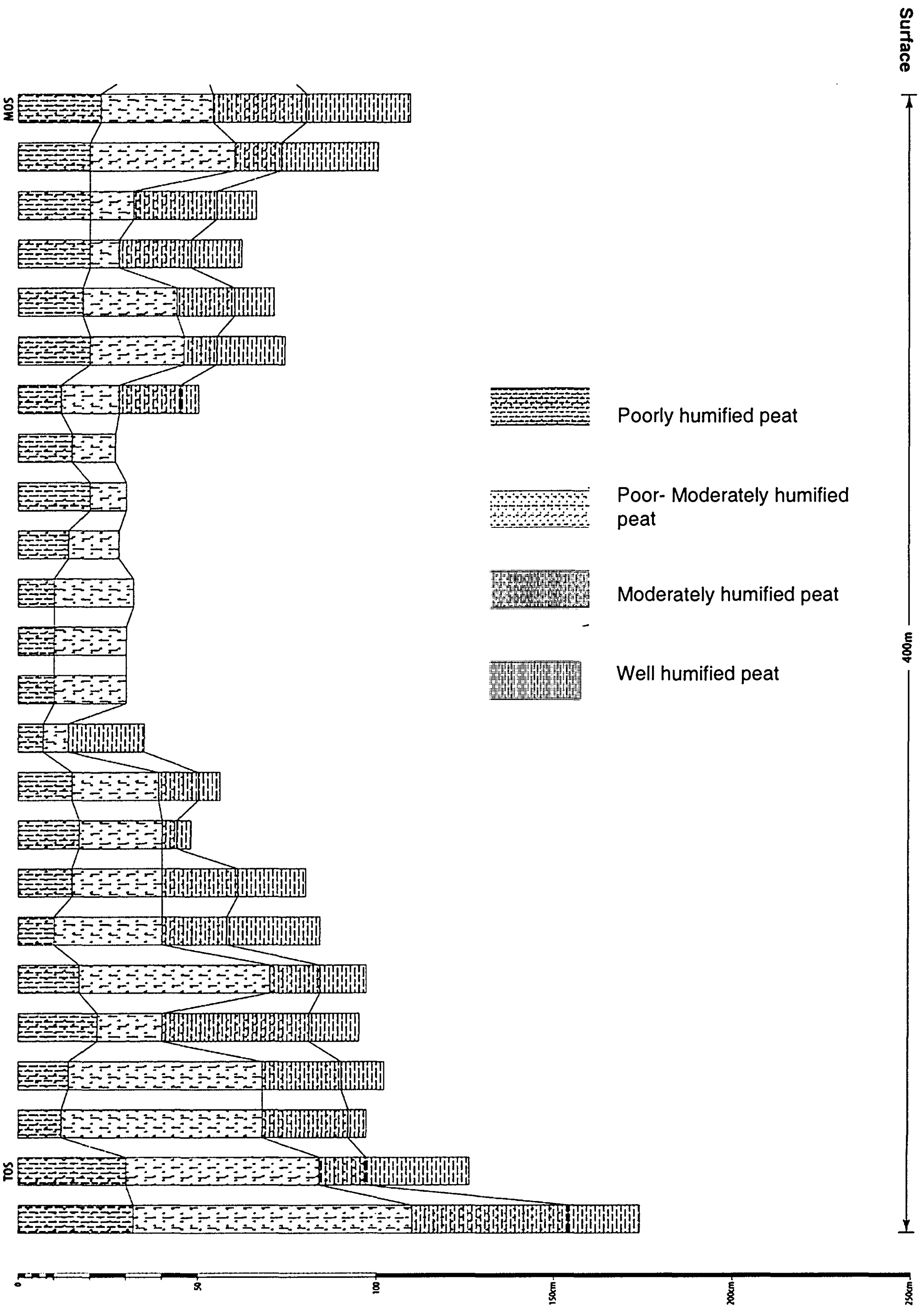


Fig 5.15: Transect across Lag 300m OD showing peat depth and stratigraphy (part a)

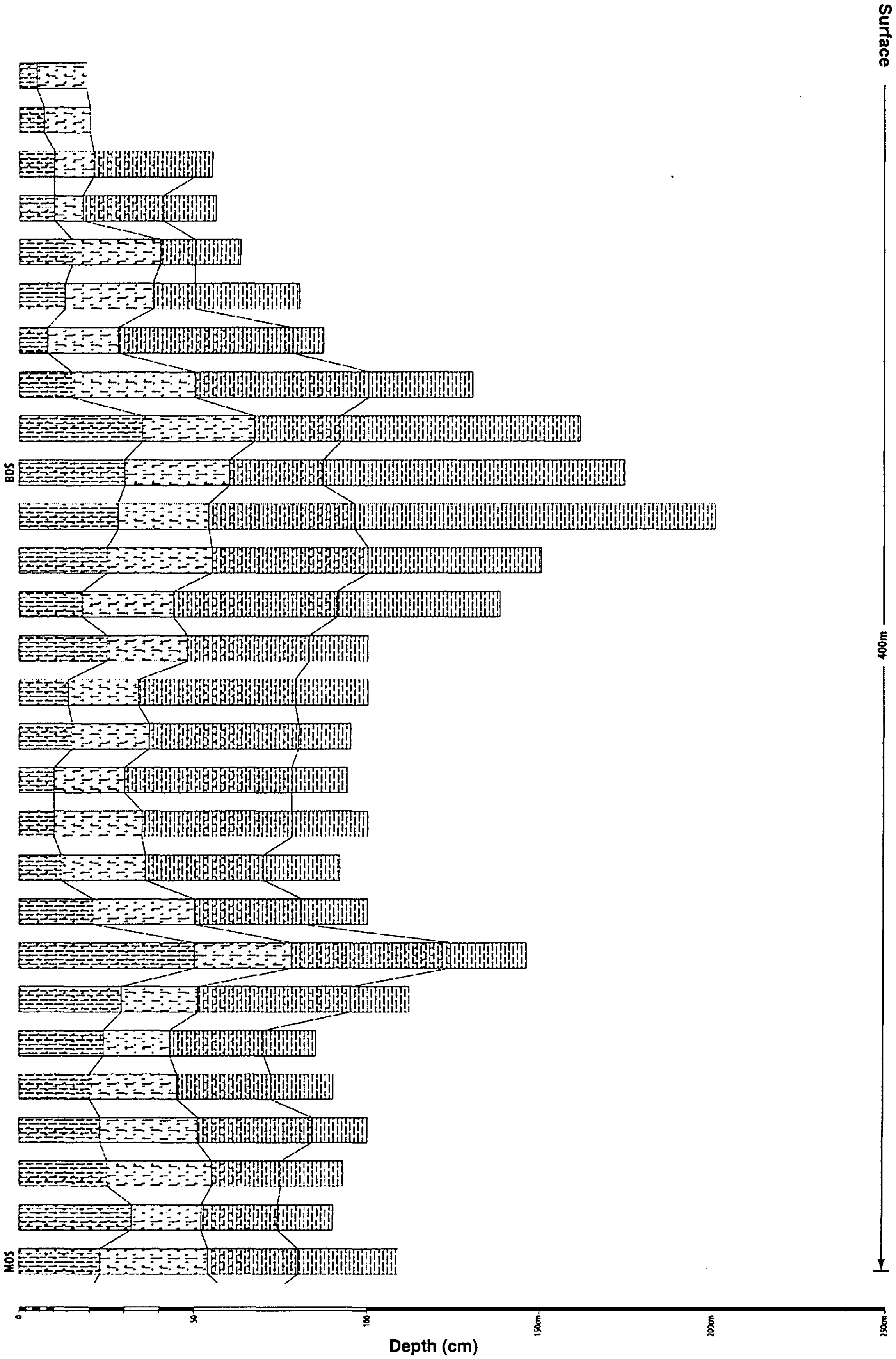


Fig 5.15: Transect across Lag 300m OD showing peat depth and stratigraphy (part b)

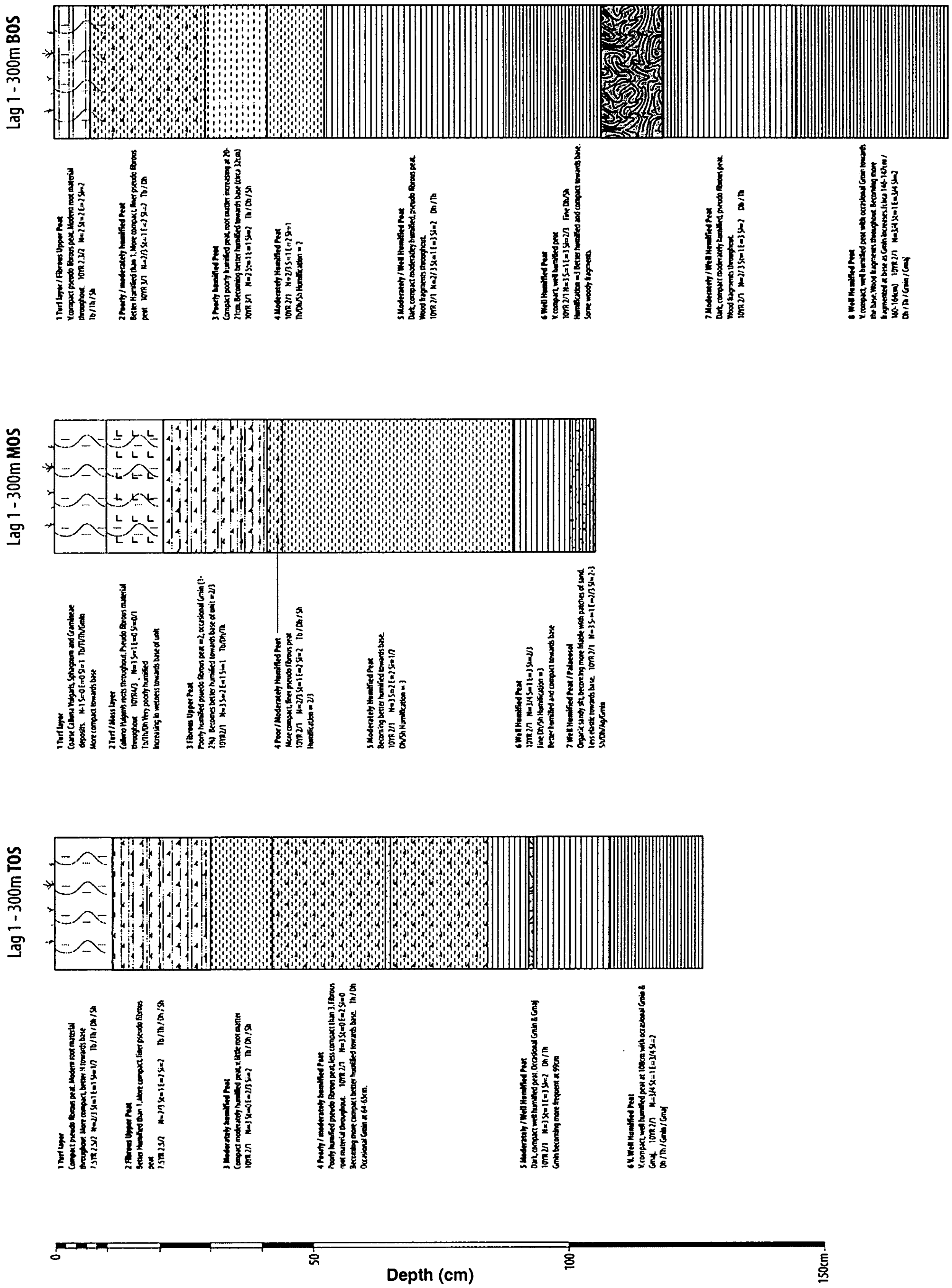
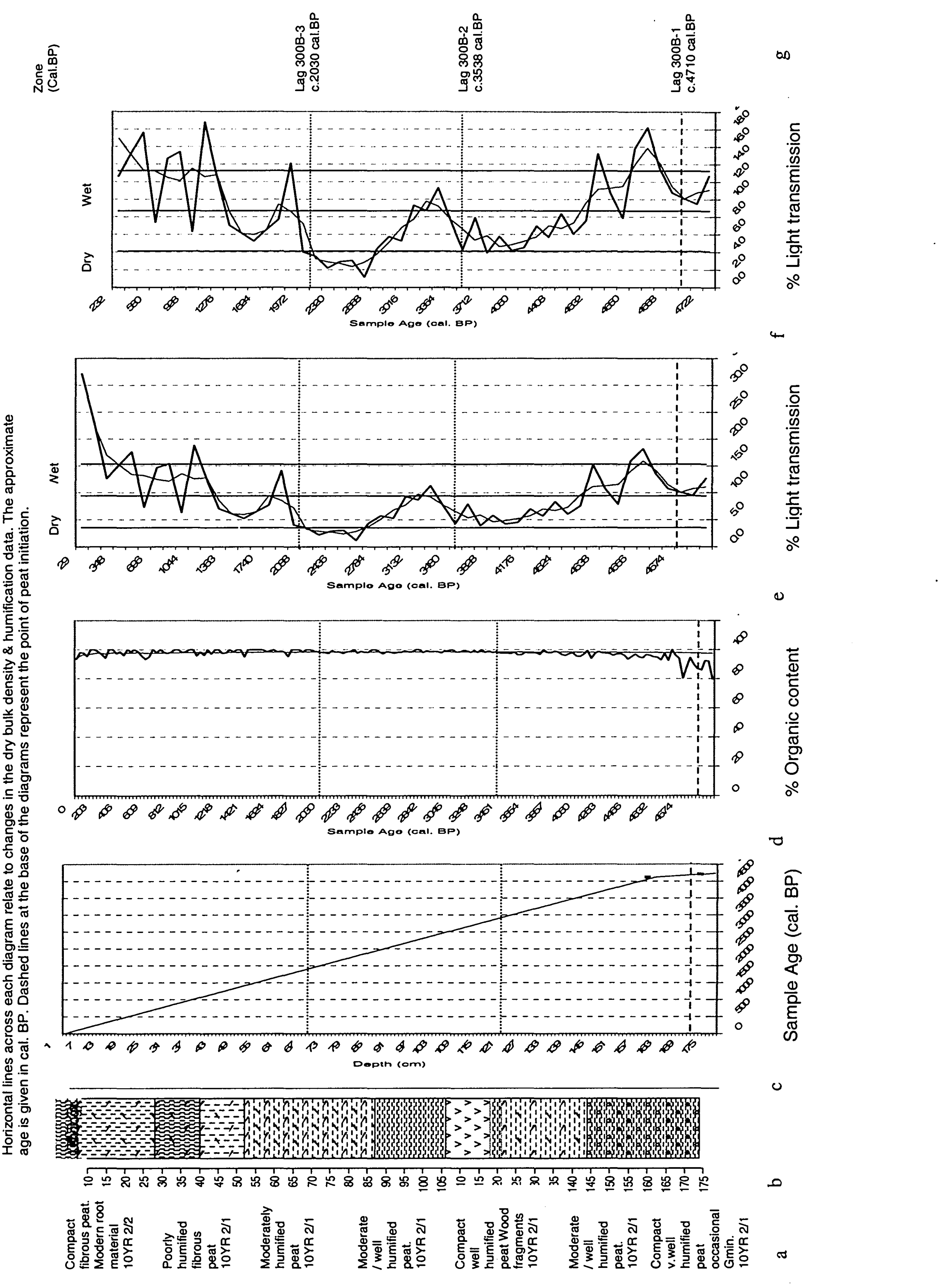


Fig 5.16: Detailed stratigraphic representation of the sections taken for palaeoenvironmental analysis (300m OD).

5.2.2 Sediment sequence at Lag 300m BOS

The sediment sequence through Lag 300 BOS (Figure 5.17 (b)) measures 174cm and consists of compact, well-humified woody / herbaceous peat through the point of blanket peat initiation (dashed line) where organic content values are consistently above 80% (Figure 5.17 (d)). Peat deposits appear to become less well-humified further up the core although organic content throughout the core is consistently above 85%. A large band of wood is present between 106cm and 118cm. The point of blanket peat initiation has been placed at 173cm and is dated to c.4710 cal. BP.



Horizontal lines across each diagram relate to changes in the dry bulk density & humification data. The approximate age is given in cal. BP. Dashed lines at the base of the diagrams represent the point of peat initiation.

Figure 5.17: LAG 300 BOS (a) Simplified sediment description, (b) depth and lithology, (c) time-depth graph, (d) organic content, (e) humification data, (f) humification data omitting the acrotelm / catotelm boundary and (g) the local pollen zonation.

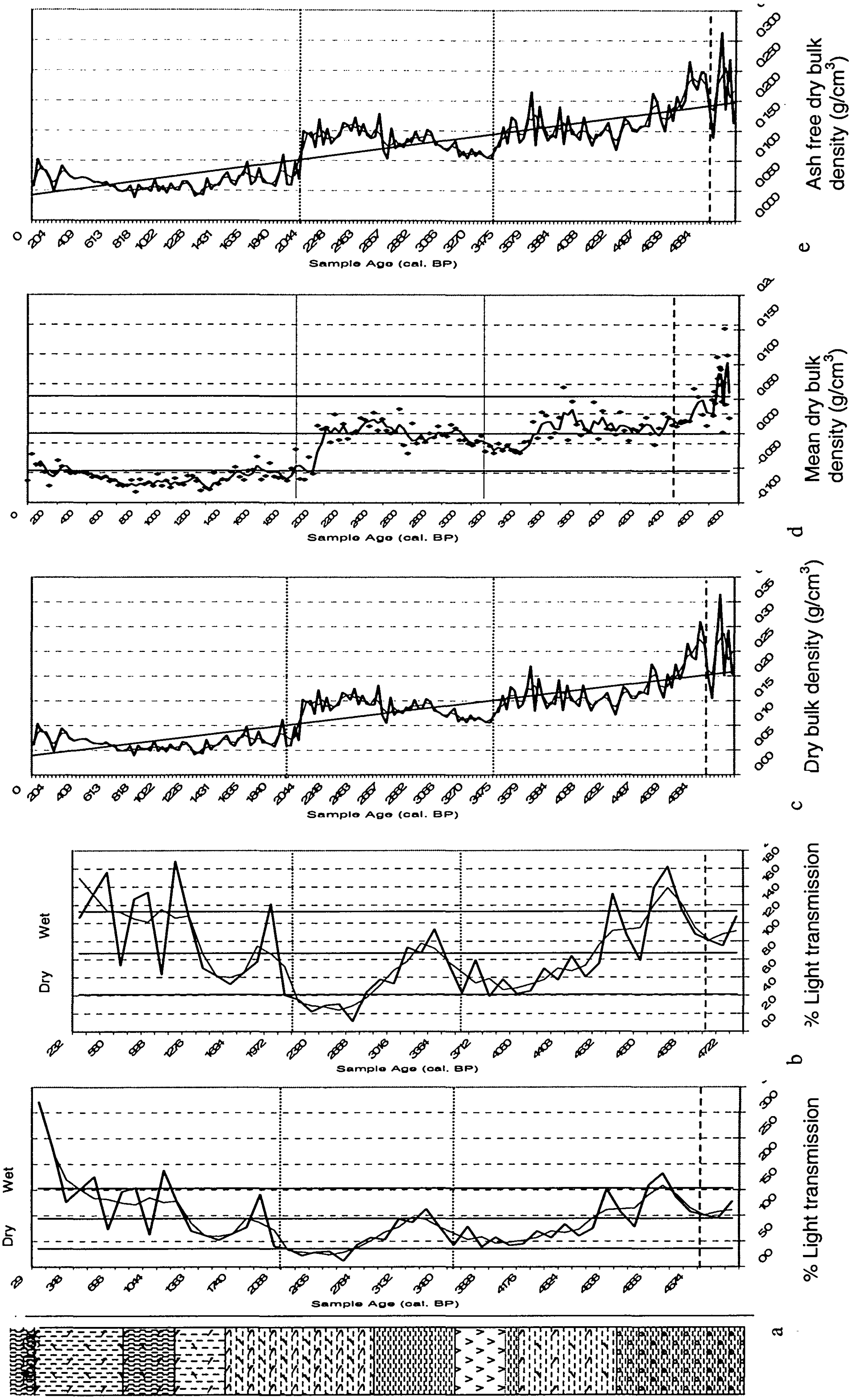
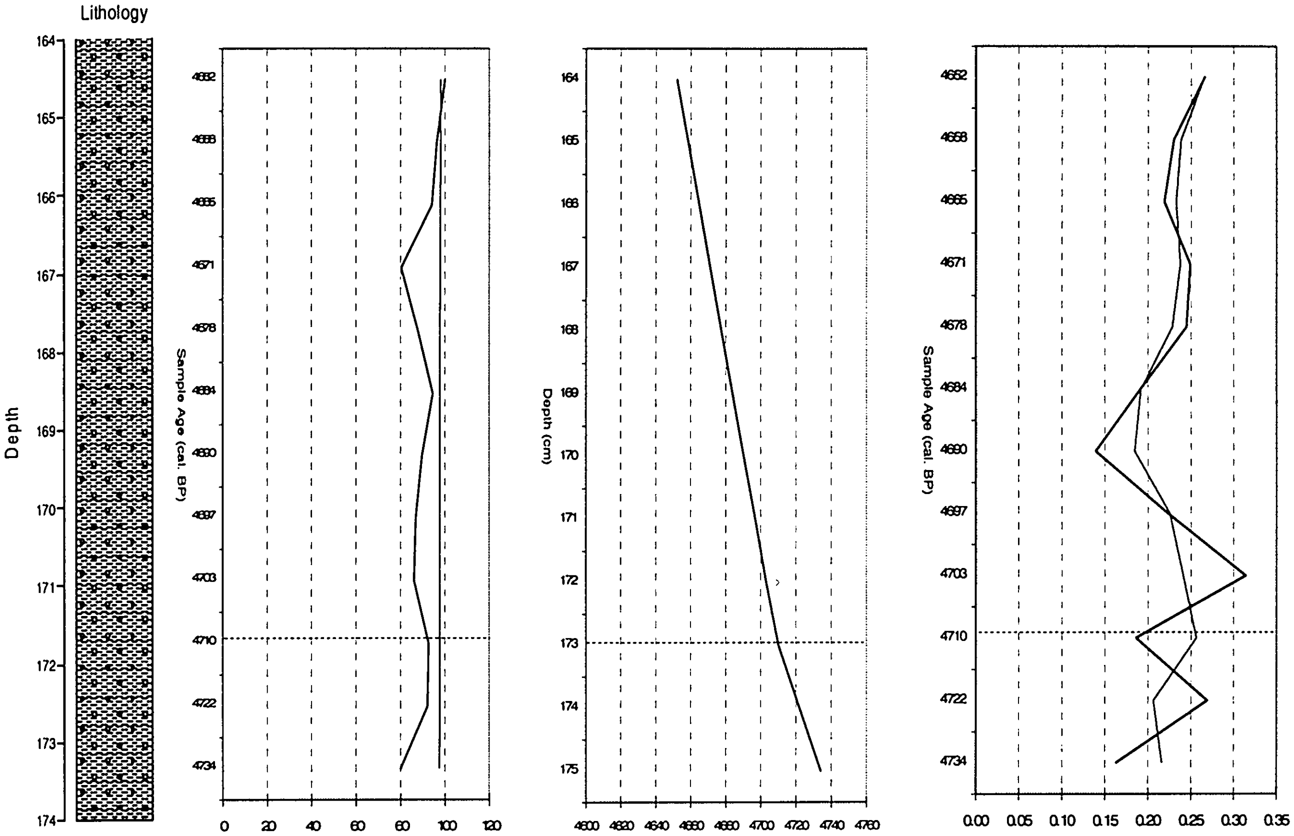


Figure 5.18: Lag 300 BOS (a) humification data, (b) humification data omitting the acrotelm / catotelm boundary, (c) dry bulk density (g/cm³), (d) mean ash free dry bulk density data (e) ash free dry bulk density data.

5.2.3 Sediment sequence & mean rates of sedimentation at 300m BOS Base



a % Organic content b Sample Age (cal. BP) c Ash free dry bulk density (g/cm³)

Figure 5.19: (a) organic content from Lag 300 BOS Base with cumulative average mean, (b) time-depth curve for Lag 300 BOS Base drawn on the basis of calibrated AMS dates (table 5.6) (c) ash free dry bulk density for Lag 300 BOS with a three term average running mean.

Lag 300 BOS Base contains a well-humified blanket peat from the base of the core up to 144cm and this is reflected in the high % organic content (Figure 5.19 (a)), suggesting this deposit sat directly over bedrock. High but variable rates of dry bulk density are shown in Figure 5.19 (c), suggesting compaction of the blanket peat at the base core, particularly as slow vertical growth rates (6.4 years / cm), resulting in a steep age / depth graph at this point, indicate less rapid decomposition of the peat (Figure 5.19 (b)). The point of blanket peat initiation has been placed at 173cm (c.4710 cal. BP), just before a rise in ash-free bulk density.

5.2.4 Particle size analysis at Lag 300 BOS Base

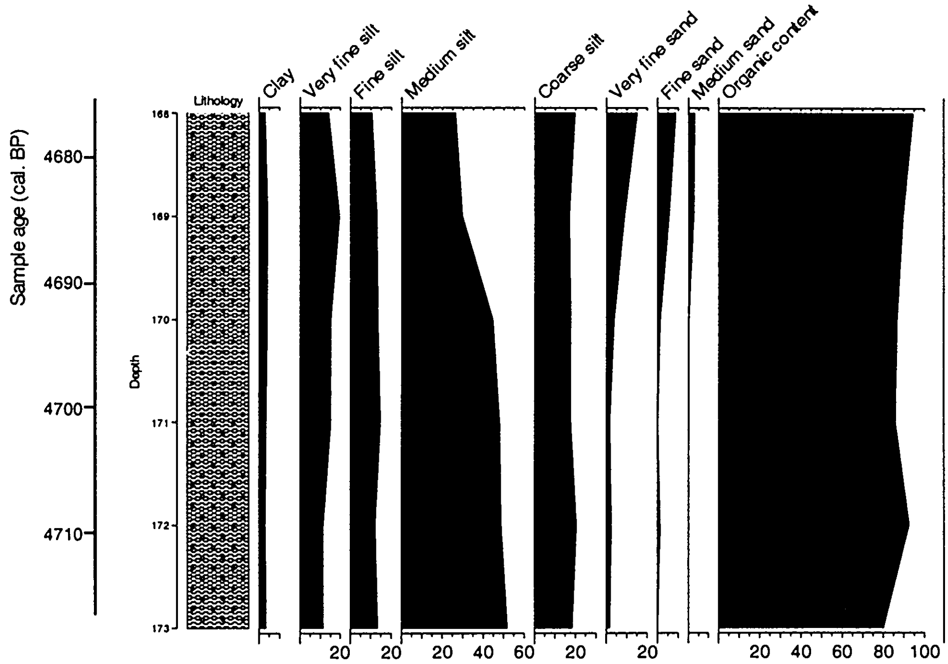


Figure 5.20: Particle size analysis through Lag 300 BOS Base (%)

The basal 6cm through compact, well-humified peat with occasional sand / silt particles was analysed for particle size. Figure 5.20 shows that mineral matter was coarsening above c.4690 cal. BP within a highly organic peat. This may suggest bioturbation or higher energy transport of sand grains and limited soil disturbance upslope during this period.

5.2.5 Mean rates of sedimentation at Lag 300 BOS

Two ^{14}C dates were obtained for Lag 300 BOS. These are presented in Table 5.5 and an age / depth curve was produced on the basis of these, assuming constant vertical growth rates between each pair of AMS dates.

Altitude	**Slope Position**	**Depth of sample**	**Material Dated**	**Lab code**	**^{14}C Age BP**	**δ^{13}C**	**Cal. age BC / AD (± 2.0 σ)**	**Midpoint used (cal. Age BP)**
300m OD	BOS	159-160cm	Humic Acid	SUERC-5996 GU-12903	4065±35	-28.9	2860-2470BC	c.4620
300m OD	**BOS**	**173-174cm**	**Humic Acid**	**SUERC-2706 GU-11962**	**4180±35**	**-29.0**	**2890-2620BC**	**c.4710**

Table 5.5: AMS radiocarbon dates from Lag 300 BOS with blanket peat initiation dates presented in bold.

Figure 5.17 (c) suggests that an average peat accumulation rate of 29.2 years / cm can be calculated through the peat profile, although this rate will have varied through time. There is little difference between Figures 5.18 (c) and (e) as a result of the highly organic nature of the deposits. Zone 300B-1 is distinguished by higher values of dry bulk density, with basal layers measuring 0.314g/cm³ at c.4703 cal. BP, which fall gradually to 0.1576g/cm³ at c.4263 cal.BP, after peat initiation. Values then remain relatively stable for some time, staying close to the mean (Figure 5.18 (d), but fall slightly at c.3328 cal. BP. A gentle rise in dry bulk density is then recorded up to c.1927 cal. BP at 0.069g/cm³ (67 cm), after which point values decrease and fall below minus 1 standard deviation (Figure 5.18 (d)), to 0.048g/cm³. Over the last 1800 years, values have remained low, perhaps marking the acrotelm / catotelm boundary. Overall, Figures 5.18 (c & e) and 5.17 (c) suggest there was greater dry bulk density at an early stage of blanket peat development, although this accumulated slowly and only over a period of c.114 years (with an addition rate of only 6 years / cm). Following this, rates of accumulation and organic volume remain steady but have decreased over the last c.1800 years.

5.2.6 Peat humification profile from Lag 300 BOS

The light transmission data in Figure 5.18 (a) and (b) show relatively high values at the base of the core, becoming wetter after blanket peat initiation at c.4684 cal. BP and c.4623 cal. BP. Following this, conditions appear to have become drier for a period of c.1143 years. Further wet shifts are recorded at c.3248 cal. BP and c.1856 cal. BP. Towards the top of the core the light transmission curve fluctuates, suggesting there was a change in mire wetness at c.1022 cal. BP, c.788 cal. BP and c.464 cal. BP, before moving into the acrotelm / catotelm boundary.

5.2.7 Sediment sequence at Lag 300 MOS

The sediment sequence through Lag 300 MOS (Figure 5.21 (b)), measured 109cm in length. At its base it contains a well-humified peat, becoming more friable with patches of sand in the bottom 5cm, representative of soil erosion post peat accumulation. Blanket peat initiation is placed at 101cm at the top of this boundary and is dated to c.3600 cal. BP. Compact substantia humosa is present from 89cm downwards and above this, fine woody / herbaceous deposits are present at different stages of humification. Figure 5.21 (d) shows the curve for ignition residue, compared to the average mean, indicating that organic content levels were lower in the basal sequence, measuring 57.4 % at 103cm and at 94cm (c.3350 cal. BP) become >95% organic content.

Horizontal lines across each diagram relate to changes in the pollen record through the basal layers and changes in the dry bulk density & humification data in the upper profile. The approximate age is given in cal. BP. Pollen zones before peat initiation have been identified but no dates prescribed. Dashed lines at the base of the diagrams represent the point of peat initiation.

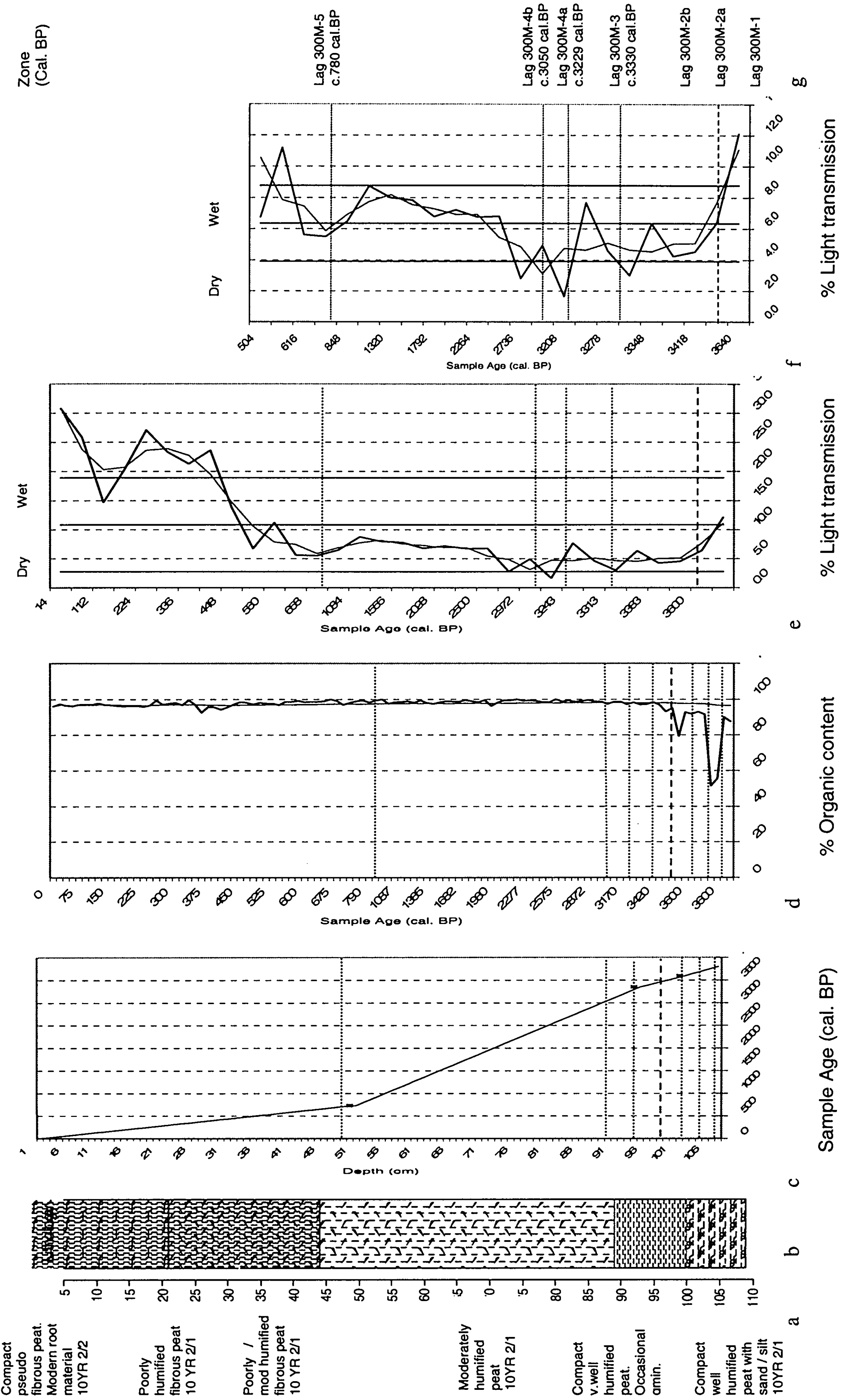


Figure 5.21: LAG 300 MOS (a) Simplified sediment description, (b) depth and lithology, (c) time-depth graph, (d) organic content, (e) humification data, (f) humification data omitting the acrotelm / catotelm boundary and (g) the local pollen zonation.

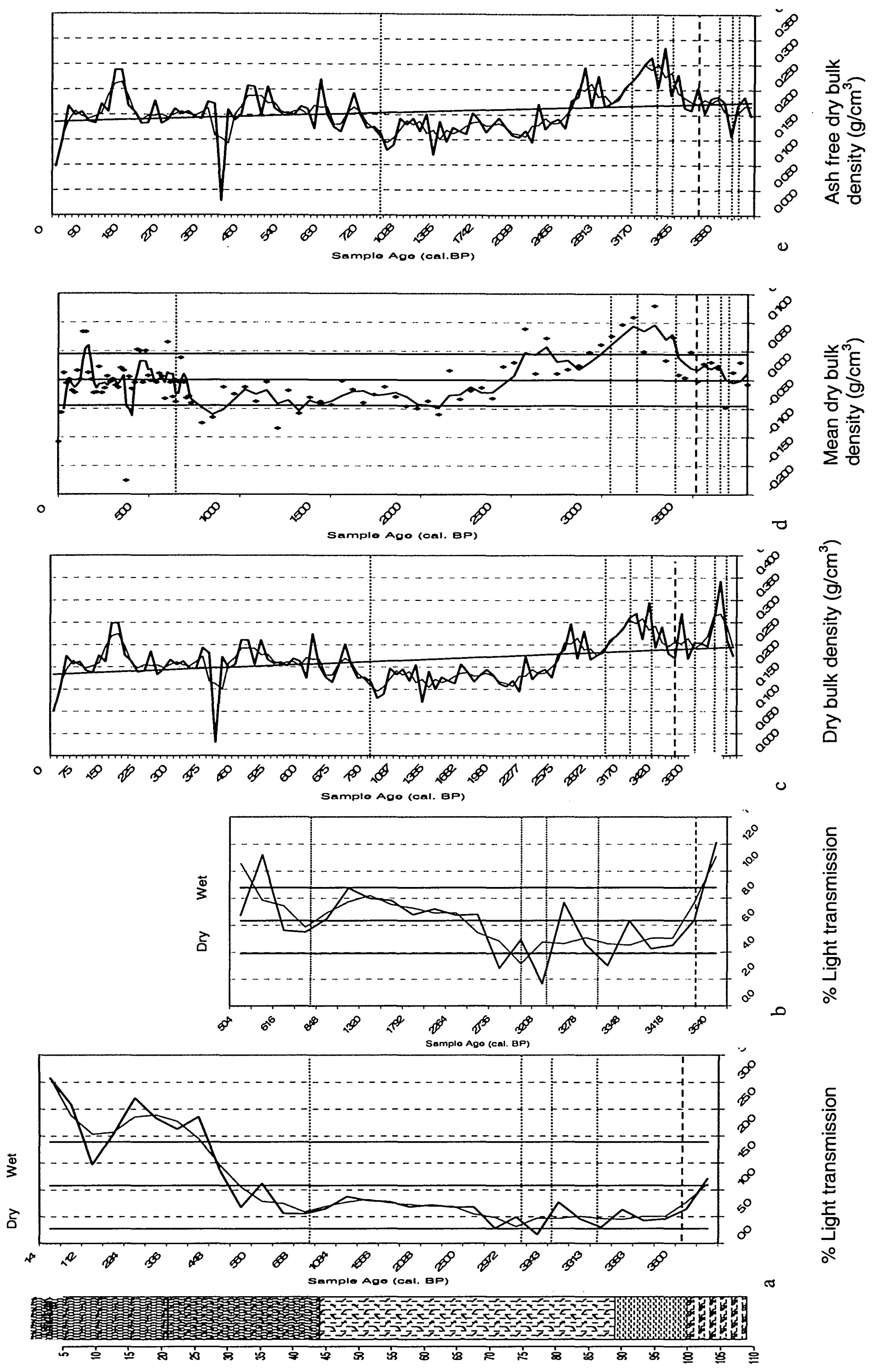


Figure 5.22: Lag 300 MOS (a) humification data, (b) humification data omitting the acrotelm / catotelm boundary, (c) dry bulk density (g/cm³), (d) mean ash free dry bulk density data (e) ash free dry bulk density data.

5.2.8 Sediment sequence & mean rates of sedimentation at 300m MOS Base

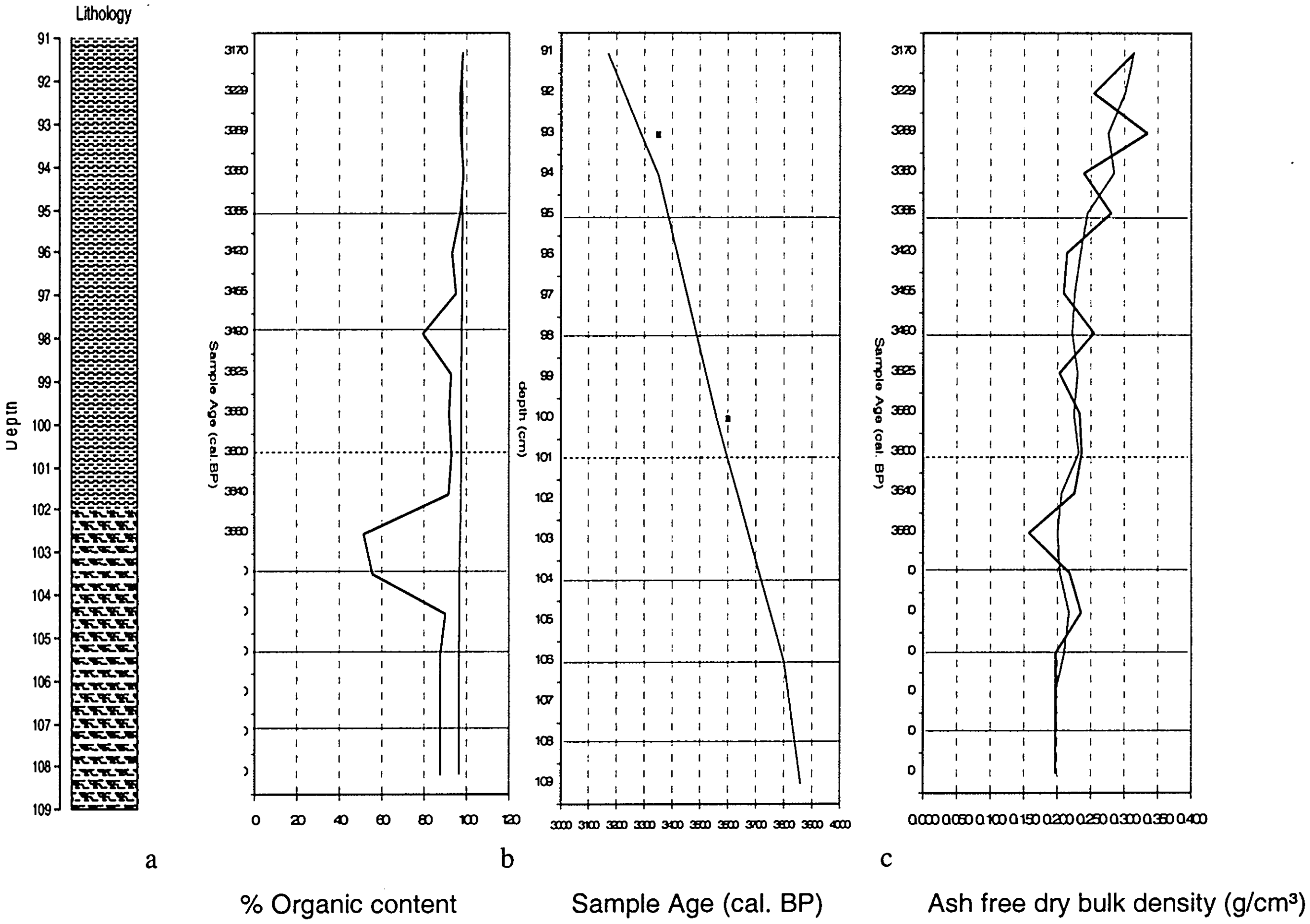


Figure 5.23: (a) organic content from Lag 300 MOS Base with cumulative average mean, (b) time-depth curve for Lag 300 MOS Base drawn on the basis of calibrated AMS dates (table 5.6) (c) ash free dry bulk density for Lag 300 MOS with a three term average running mean.

The stratigraphy through the basal sequence of Lag 300 MOS shows an organic sand / silt overlain by a well-humified blanket peat. The LOI graph (Figure 5.23 (a)) indicates that the very basal deposits were predominantly organic with > 80% readings but at 104cm, organic content decreases to 55.6 % before increasing again at c.3600 cal. BP, the point of peat initiation. Figure 5.23 (c) suggests dry bulk density through the basal sequence has been gradually increasing, measuring 0.236g/cm^3 at the point of peat initiation, with a vertical growth rate of 34 years / cm (Figure 5.23 (b)).

5.2.9 Particle size analysis at Lag 300 MOS Base

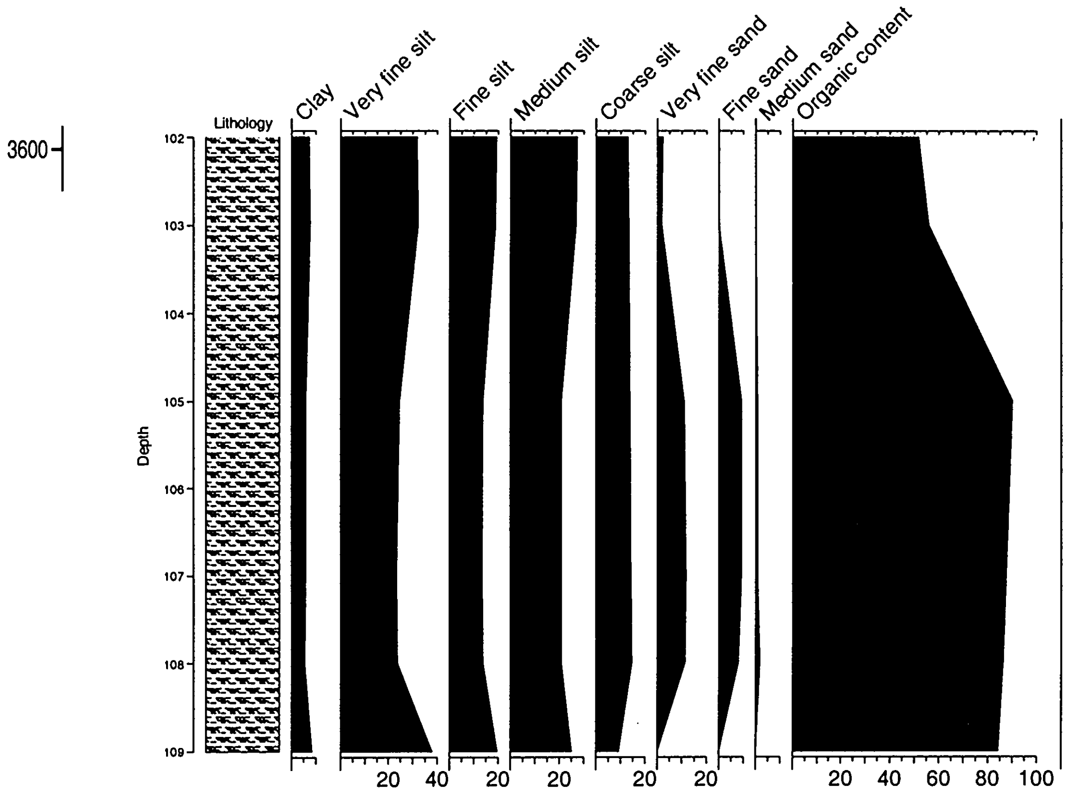


Figure 5.24: Particle size analysis at Lag 300 MOS base (%).

Particle size analysis through Lag 300 MOS shows a variety of particle types with a predominance of very fine silt, fine silt and medium silt through the basal 8cm, with a slight increase in clay, very fine silt, fine silt and medium silt between 108cm and 109cm. The mixture of clast sizes, however, suggests little translocation of material down the profile, although the decrease in organic content at 103cm and increase in silts (see also Figure 5.23 (a)) suggest some transport of material downslope from above, at c.3680 cal. BP.

5.2.10 Mean rates of sedimentation

Three AMS radiocarbon dates were obtained for Lag 300 MOS (Table 6.6), allowing an age-depth curve to be produced and an estimate of mass accumulation rates to be made (Figure 6.22).

Altitude	**Slope Position**	**Depth of sample**	**Material Dated**	**Lab code**	**^{14}C Age BP**	**δ^{13}C**	**Cal. age BC / AD (± 2.0 σ)**	**Midpoint used (cal. Age BP)**
300m OD	MOS	50-51cm	Humic Acid	SUERC-5994 GU-12901	795±35	-28.6	1160-1290AD	c.730
300m OD	MOS	94-95cm	Humic Acid	SUERC-5995 GU-12902	3120±35	-28.2	1500-1260BC	c.3350
300m OD	**MOS**	**101-102cm**	**Humic Acid**	**SUERC-2705** **GU-11961**	**3385±35**	**-28.4**	**1750-1520BC**	**c.3600**

Table 5.6: AMS radiocarbon dates from Lag 300 MOS with blanket peat initiation dates presented in bold.

Figure 5.21 (c) suggests that sediment accumulation initially occurred at a rate of 35-40 years / cm from c.3680 cal. BP to c.3350 cal. BP. During this period, dry bulk density (Figures 5.22 (c), (d) and (e)) steadily increases, particularly following peat initiation, to c.2396 cal. BP, measuring 0.3340g/cm³ at its greatest, indicative of a compact, well-humified peat. From this point, values decrease slightly to below minus 1 standard deviation (Figure 5.22 (d)) and continue to fall, particularly after c.2277 cal. BP. At c.735 cal. BP, values increase and the deviation of points around the mean (Figure 5.22 (d)) suggest that bulk density has remained relatively consistent over the past c.735 years. The acrotelm / catotelm boundary is unclear from Figures 5.22 (c) and (e), but Figure 5.22 (d) would suggest that at Lag 300 MOS it lies in the upper 30cm after c.500 cal. BP, where values begin to fall below the mean.

5.2.11 Peat humification profile from Lag 300 MOS

Figure 5.22 (a) shows relatively low light transmission data through the profile, with increasing values at the top of the profile through the acrotelm / catotelm boundary at c.448 cal. BP (32cm) which correlates well with Figure 5.22 (d). Figure 5.22 (b) however, which only considers those values through the main peat core and not the upper levels, suggest that there are several shifts to higher light transmission levels, beginning at the base of the core when conditions appear to have been wetter, through the point of peat initiation at c.3600 cal. BP. A slight peak in values is then recorded at c.3348 cal. BP and c.3243 cal. BP before values fall, suggesting conditions became drier for some c.743 years. At c.2500 cal. BP to c.848 cal. BP a rise in values suggest that mire surface conditions remained wet for some time before improving, and a further peak in values at c.560 cal. BP highlights a move to wetter conditions once again before moving into the acrotelm / catotelm boundary.

5.2.12 Sediment sequence at Lag 300m TOS

The core taken from Lag 300 TOS measured 126cm in length (Figure 5.25 (b)). A well-humified peat with an increasing sand content at its base is reflected in the LOI curve (Figure 5.25 (d)) through the basal 7 cm, with 17% organic content recorded at the very base. At 121cm (c.6135 cal. BP), the point of blanket peat initiation, values rise to 90% organic content but at c.4388 cal. BP, a small decrease in % organic content is recorded. Following this, values return to >90% organic content, with minor peaks at c.2200 cal. BP and c.1000 cal. BP.

Horizontal lines across each diagram relate to changes in the pollen record through the basal layers and changes in the dry bulk density & humification data in the upper profile. The approximate age is given in cal. BP. Pollen zones before peat initiation have been identified but no dates prescribed. Dashed lines at the base of the diagrams represent the point of peat initiation.

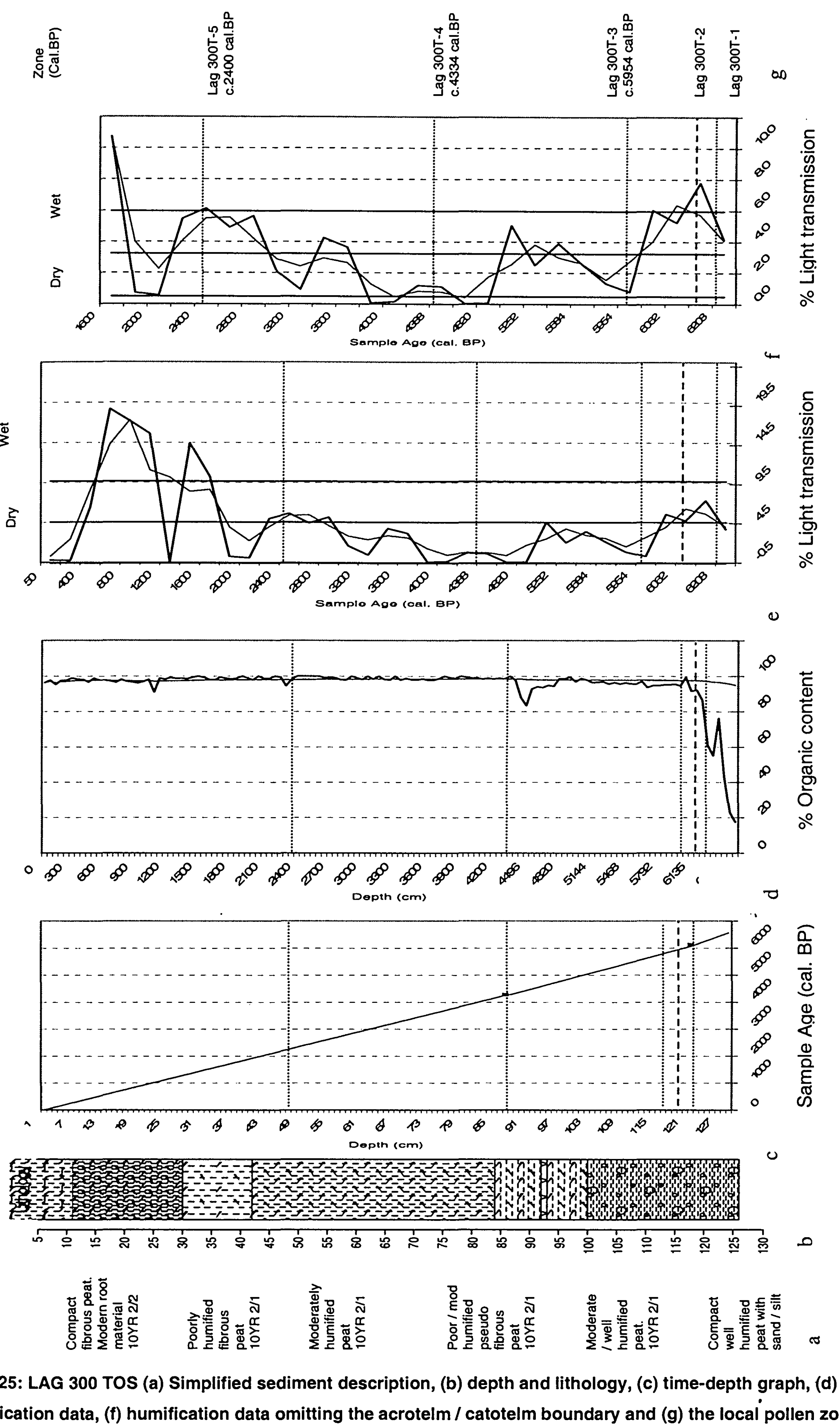


Figure 5.25: LAG 300 TOS (a) Simplified sediment description, (b) depth and lithology, (c) time-depth graph, (d) organic content, (e) humification data, (f) humification data omitting the acrotelm / catotelm boundary and (g) the local pollen zonation.

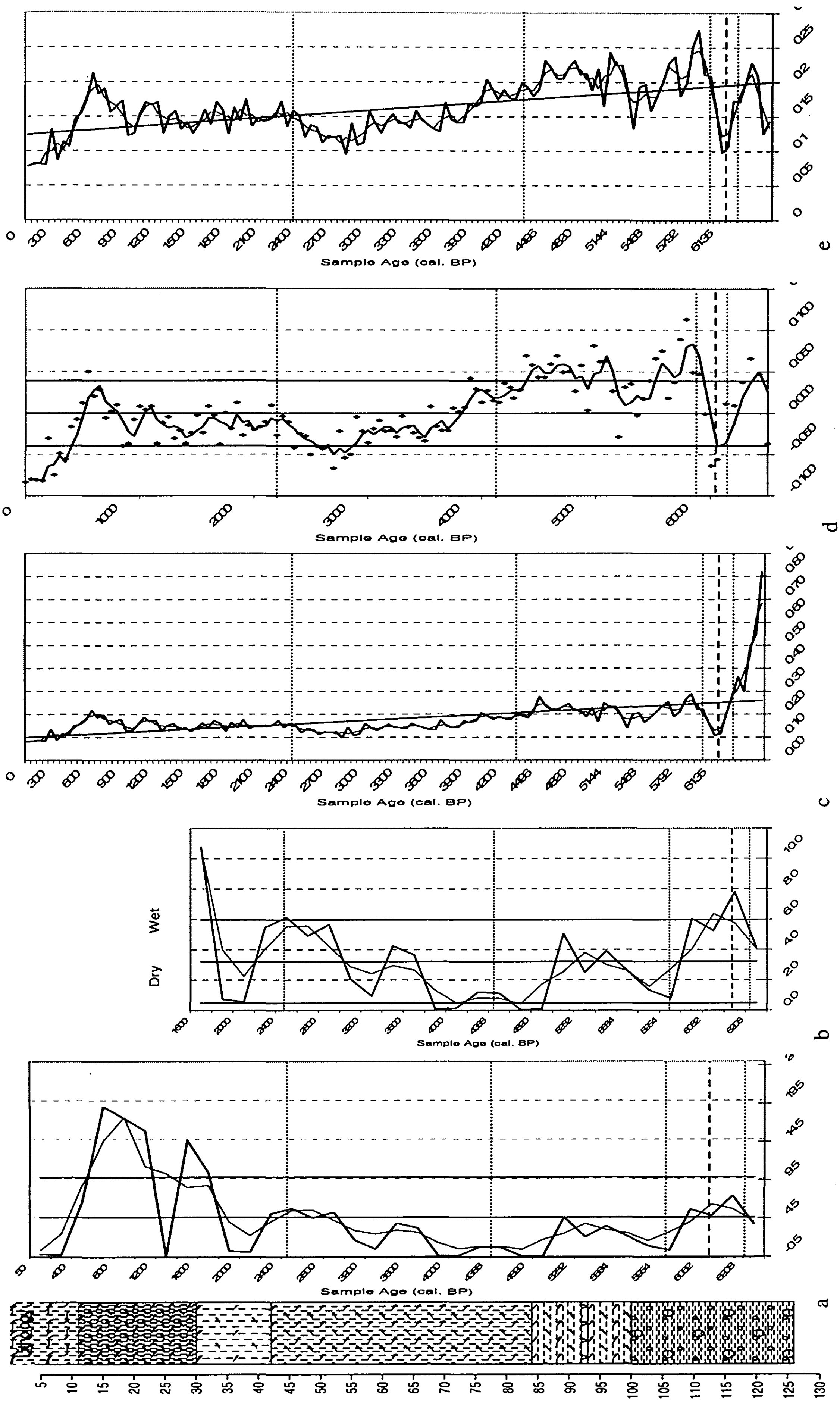


Figure 5.26: Lag 300 TOS (a) humification data, (b) humification data omitting the acrotelm / catotelm boundary, (c) dry bulk density (g/cm³), (d) mean ash free dry bulk density data (e) ash free dry bulk density data

5.2.13 Sediment sequence & mean rates of sedimentation at 300m TOS Base

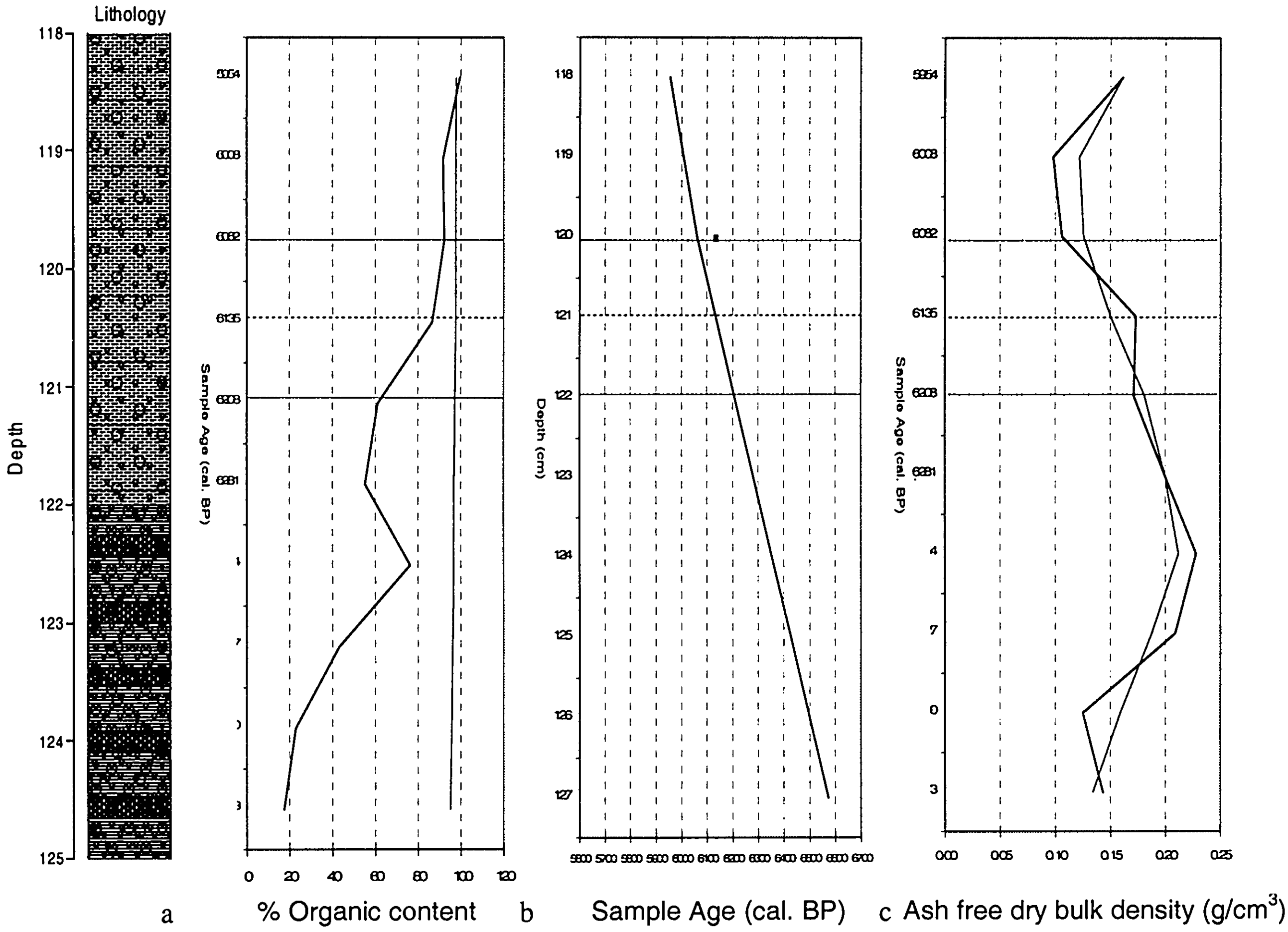


Figure 5.27: (a) organic content from Lag 300 TOS Base with cumulative average mean, (b) time-depth curve for Lag 300 TOS Base drawn on the basis of calibrated AMS dates (table 5.7) (c) ash free dry bulk density for Lag 300 TOS with a three term average running mean.

Very well-humified peat with occasional sand particles can be found at the base of Lag 300 TOS. The graph showing organic content (Figure 5.27 (a)) suggests that the mineral component at the very base of the core is high, with readings of <20% organic content. These slowly decrease up the core to c.6135 cal. BP, the point of peat initiation, where levels of organic content increase to over 80%. The age/depth graph (Figure 5.25 (b) shows a steady rate of vertical accumulation (73 years / cm), paralleling relatively high values of ash free dry bulk density (Figure 5.27 (c)), indicating high levels of compaction and decomposition from the base of the core.

5.2.14 Particle size analysis at Lag 300 TOS Base

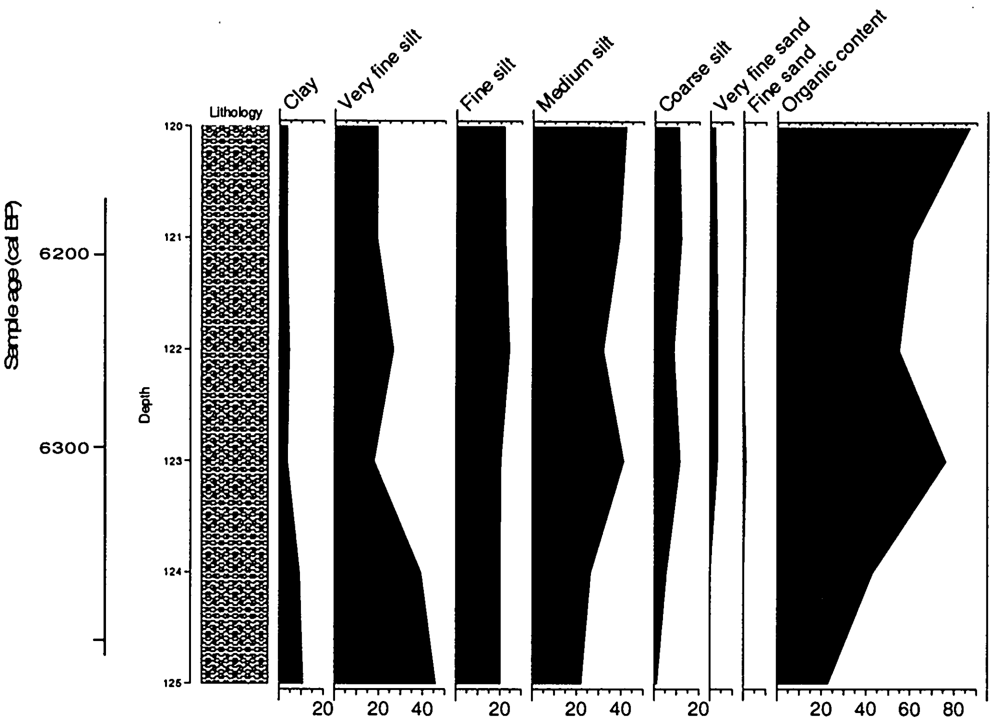


Figure 5.28: Particle size analysis at Lag 300 TOS (base (%)

Particle size analysis though the basal 5cm at Lag 300 TOS shows the majority of particles to consist of very fine silt, fine silt and medium silt from 123cm to 125cm. There appears to be no clay translocation and an overall increase in mean particle size prior to peat initiation would suggest some slope instability at Lag 300 TOS. There is a peak in medium silts, coarse silts and very fine sands at 123cm (c.6281 cal. BP) accompanied by an increase in organic content to 61%. Following this, there is an increase in medium and coarse silts and organic content increases to 91%.

5.2.15 Mean rates of sedimentation at Lag 300 TOS

Two AMS radiocarbon dates were obtained from Lag 300 TOS (Table 5.8).

Altitude	**Slope Position**	**Depth of sample**	**Material Dated**	**Lab code**	**^{14}C Age BP**	**δ^{13}C**	**Cal. age BC / AD (± 2.0 σ)**	**Midpoint used (cal. Age BP)**
300m OD	TOS	86-87cm	Humic Acid	SUERC-5993 GU-12900	3850±35	-28.0	2460-2200BC	c.4280
300m OD	**TOS**	**120-121cm**	**Humic Acid**	**SUERC-2704 GU-11960**	**5345±35**	**-28.1**	**4330-4040BC**	**c.6135**

Table 5.7: AMS radiocarbon dates from Lag 300 TOS with blanket peat initiation dates presented in bold.

At the base of the core, AMS radiocarbon dates suggest peat accumulated at a rate of 54-73 years / cm. High dry bulk density values (Figures 5.26 (c), (d) and (e)) at the base of the core suggest a high proportion of mineral matter sat within the peat matrix prior to peat initiation. At c.6135 cal. BP, values of dry bulk density initially fall but increase sharply at c.5738 cal. BP after which a sustained period of peat decomposition and compaction occurred. From c.4200 cal. BP to c.2250 cal. BP, lower bulk density values are recorded (Figure 5.26 (d)) and values fall below the mean, suggesting poorer humified peat existed in the middle of the core, supporting visual descriptions of the peat matrix (Figure 5.26 (a)). The acrotelm / catotelm boundary appears to lie at c.20-25cm below the surface (c.800 cal. BP), where values of dry bulk density fall sharply.

5.2.16 Peat humification profile from Lag 300 TOS

Figures 5.26 (a) and (b) show percentage light transmission values through Lag 300 TOS. An early wet peak is recorded at c.6135 cal. BP and continues to c.6008 cal. BP, after which time values decrease. Further wet peaks are then recorded from c.5468 cal BP to c.5036 cal. BP and at c.3600 cal. BP to c.3350 cal. BP. These peaks are more clearly demonstrated in Figure 5.26 (b) where a more detailed scale has been applied. A final wet phase is recorded between c.2800 cal. BP and c.2200 cal. BP and values then fall sharply before increasing at c.1600 cal. BP, where the acrotelm / catotelm boundary appears to lie.

5.3 Lithostratigraphy at 400m OD

5.3.1 Stratigraphy and DTM model at 400mOD

A total of 29 cores were taken from Lag 400m OD over a slope length of approximately 310m (Figure 5.29). Four stratigraphical units were identified within each core taken and, towards the bottom of the slope, basal soil and clay horizons were also recorded. From the top of slope, the first 60m recorded a relatively uniform underlying topography with cores measuring 152cm in length on average. The deepest core from the top of slope measured 168cm in depth and an exposed peat hag at this point provided the location for palaeoenvironmental samples. Mid-section cores were shorter in length but a trench dug at 130m down slope provided samples for palaeoenvironmental analyses of 142cm in length. At 200m along the transect, towards the bottom of the slope, samples increased in depth to 175cm as the underlying topography shelved towards the Main Water of Luce. A trench was dug to obtain samples for further analyses (Lag 400 BOS), measuring 165cm, and evidence of a pre-peat soil was present at the base. Only one clear layer of woody fragments was noted at 93cm depth in the middle of slope cores. Figure 3.0 shows a detailed stratigraphical representation of the sections taken for palaeoenvironmental analysis (400m OD).

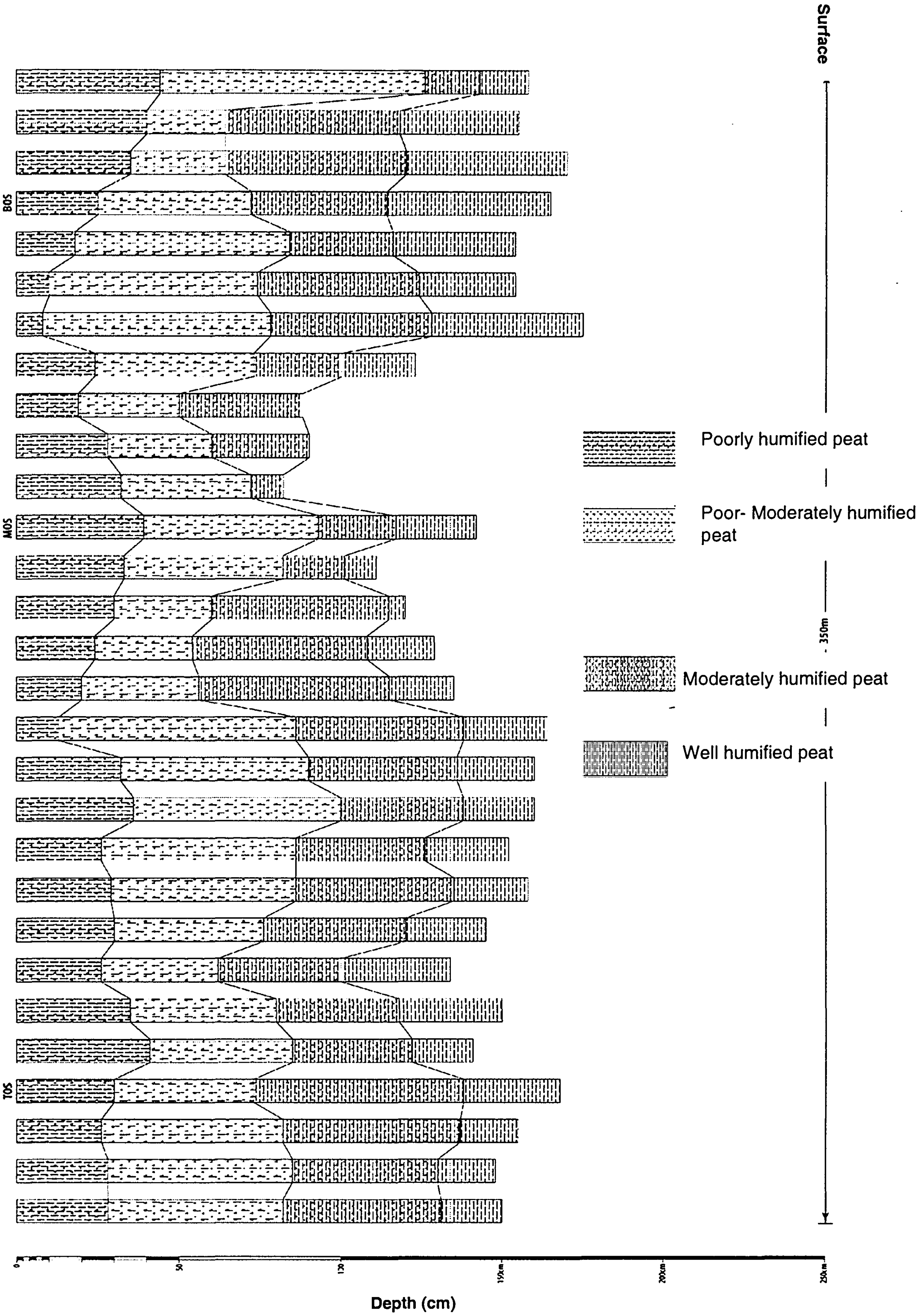


Fig 5.29: Transect across Lag 400m OD showing peat depth and stratigraphy

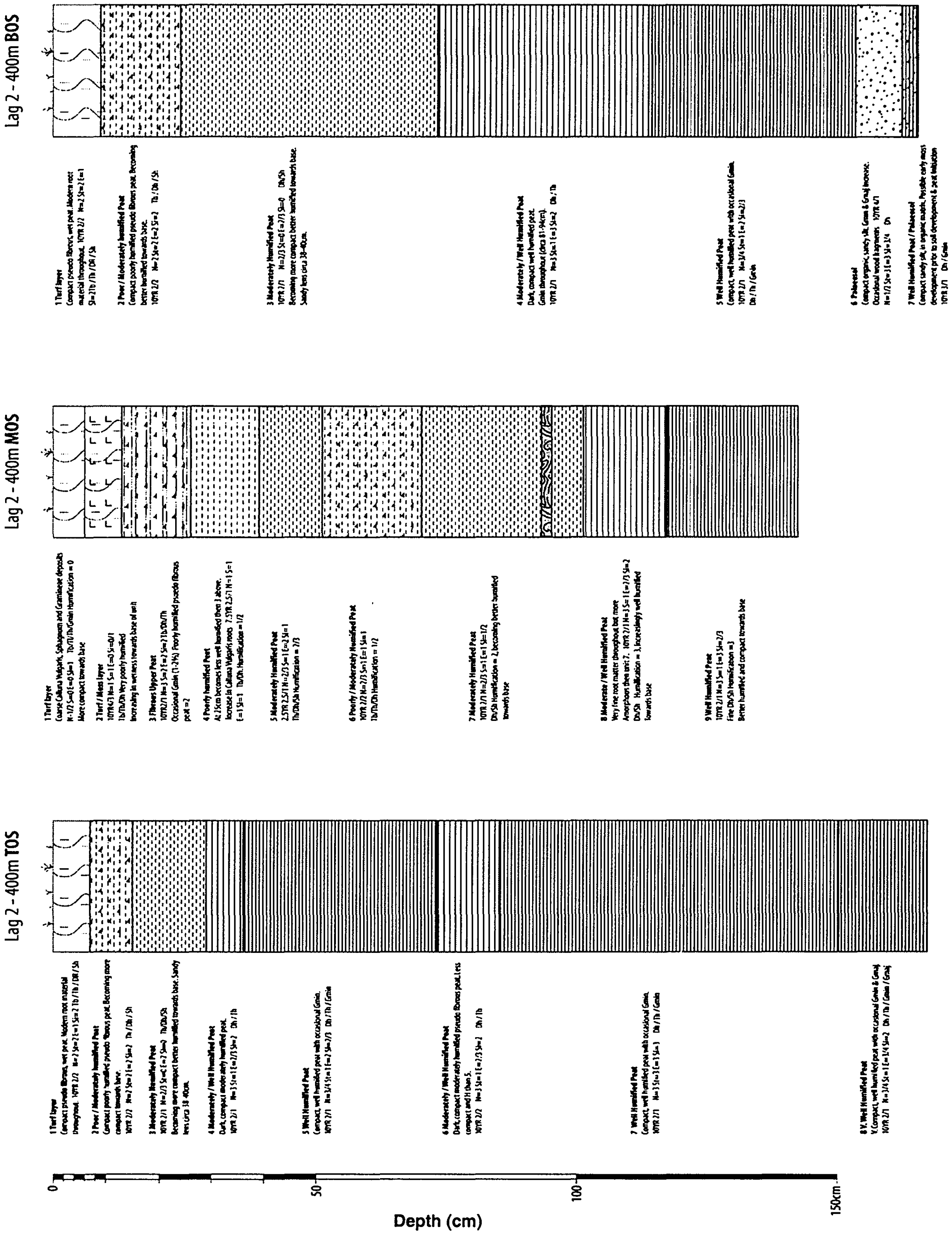


Fig 5.30: Detailed stratigraphic representation of the sections taken for palaeoenvironmental analysis (400m OD).

4.3.2 Sediment sequence at Lag 400m BOS

The sequence from the long core had a total length of 165cm. At its base is a sandy /silt with an organic content of 20% (Figure 5.31 (d)). At c.4935 cal. BP, organic content rises to 93%, the point of peat initiation. Two clear decreases in organic content are recorded through the profile, the first at c.4522 cal. BP where levels fall to 64%, and a clear, sharp decrease at c.3196 cal.BP to c.3264 cal. BP (95 to 97cm), perhaps indicative of mineralization of the surface drying out (although dry bulk density does not appear to change) or an in-wash band from the stream at the valley bottom. Organic content levels rise again at 94cm to remain above 80%.

Horizontal lines across each diagram relate to changes in the pollen record through the basal layers and changes in the dry bulk density & humification data in the upper profile. The approximate age is given in cal. BP. Pollen zones before peat initiation have been identified but no dates prescribed. Dashed lines at the base of the diagrams represent the point of peat initiation.

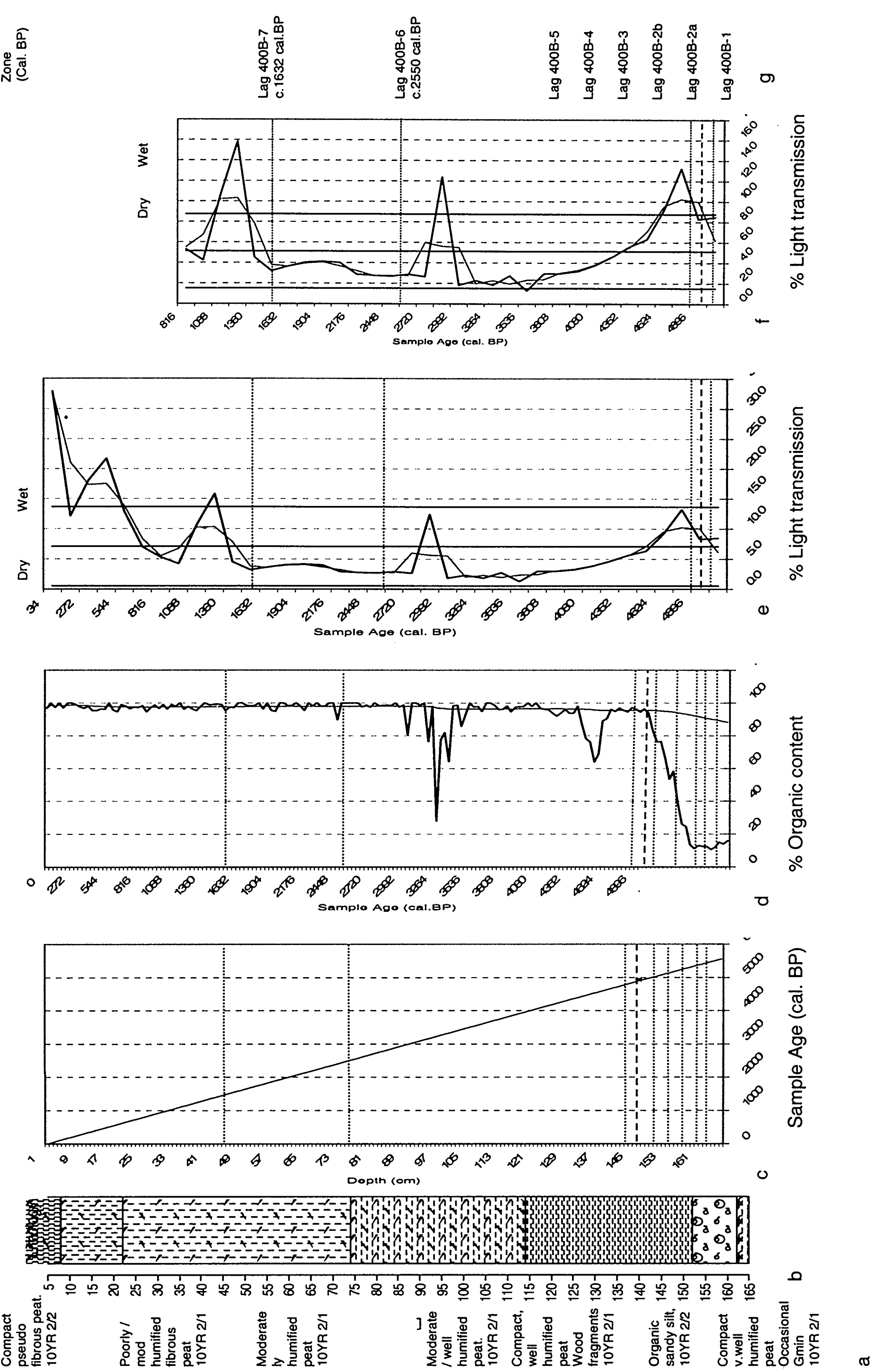


Figure 5.31: LAG 400 BOS (a) Simplified sediment description, (b) depth and lithology, (c) time-depth graph, (d) organic content, (e) humification data, (f) humification data omitting the acrotelm / catotelm boundary and (g) the local pollen zonation.

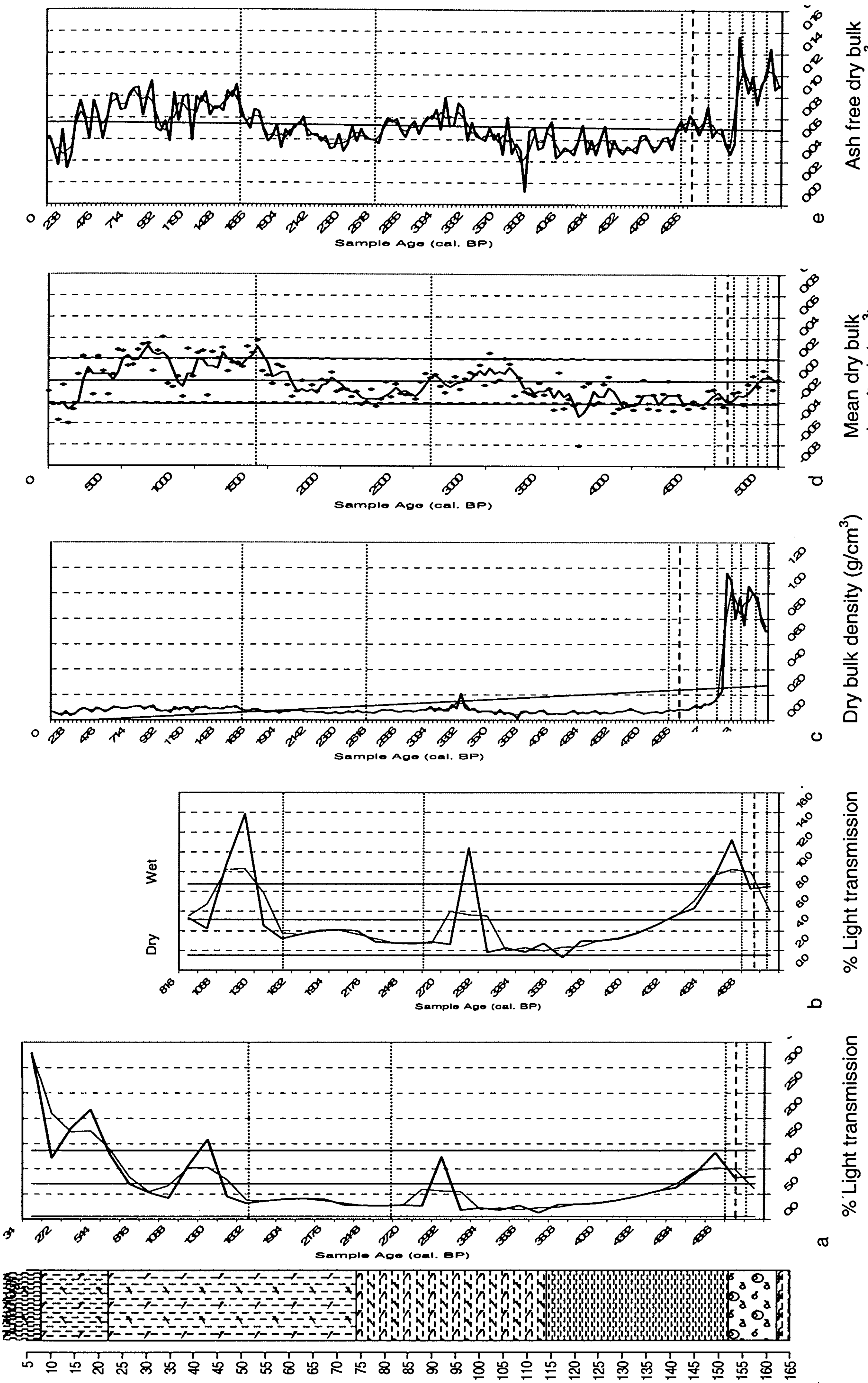


Figure 5.32: Lag 400 BOS (a) humification data, (b) humification data omitting the acrotelm / catotelm boundary, (c) dry bulk density (g/cm³), (d) mean ash free dry bulk density data (e) ash free dry bulk density data.

5.3.3 Sediment sequence & mean rates of sedimentation at 400m BOS Base

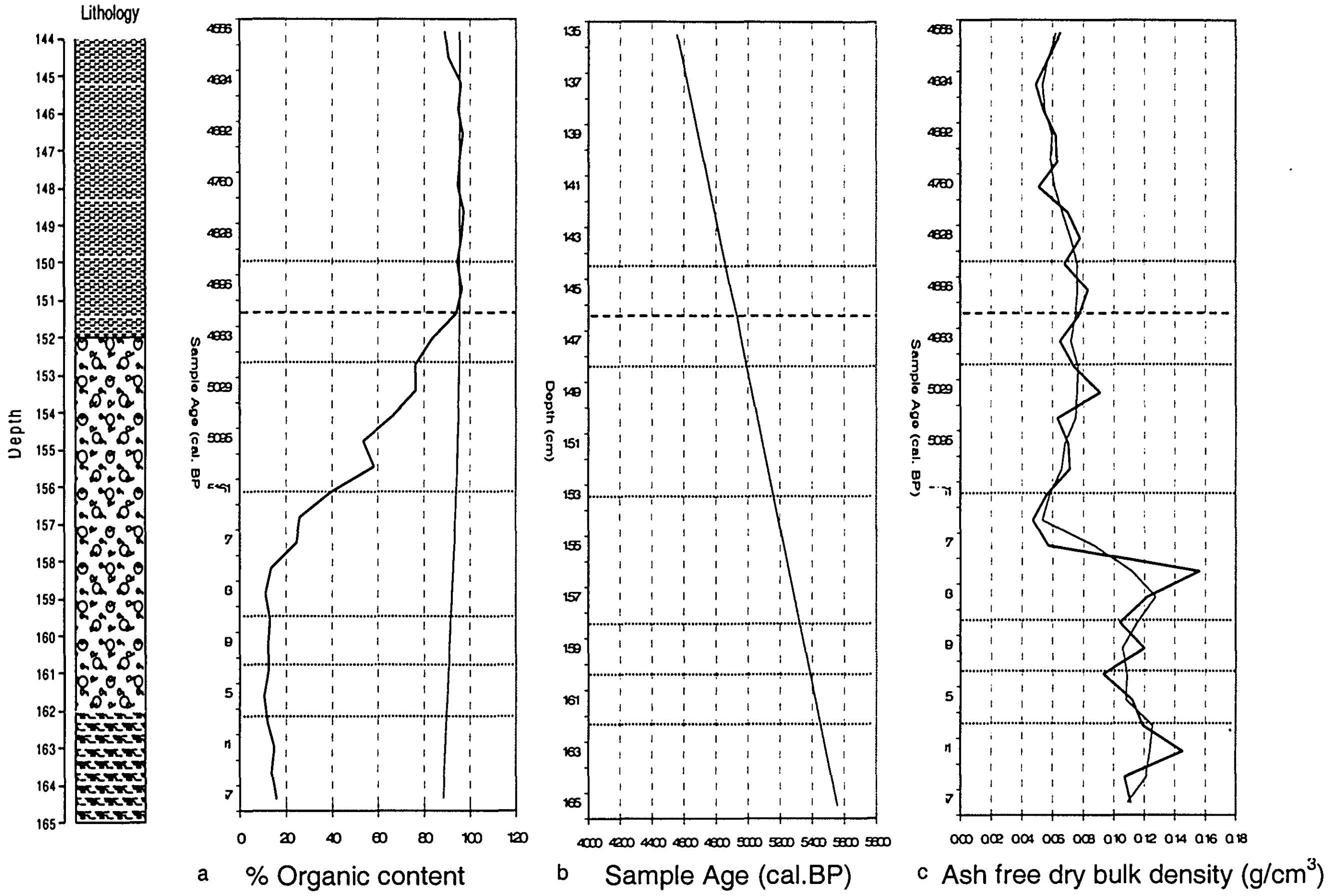


Figure 5.33: (a) organic content from Lag 400 BOS Base with cumulative average mean, (b) time-depth curve for Lag 400 BOS Base drawn on the basis of calibrated AMS dates (table 5.8) (c) ash free dry bulk density for Lag 400 BOS with a three term average running mean.

The basal sediments of Lag 400 BOS comprise a well-humified blanket peat overlying a compact, organic sandy silt. The nature of these deposits is reflected in the LOI graph (Figure 5.33 (a)), with a gradual rise in organic content to over 80% at 146cm (c.4935 cal. BP), marking the point of peat initiation. Figure 5.33 (b) and (c) suggest a vertical rate of 33 years / cm and at the base (c) shows higher values of bulk density through the basal layers where peat is beginning to form. After this early phase, values fall to 0.06g/cm³ through the true blanket peat phase where decay rates start to increase.

5.3.4 Particle Size Analysis at lag 400 BOS Base

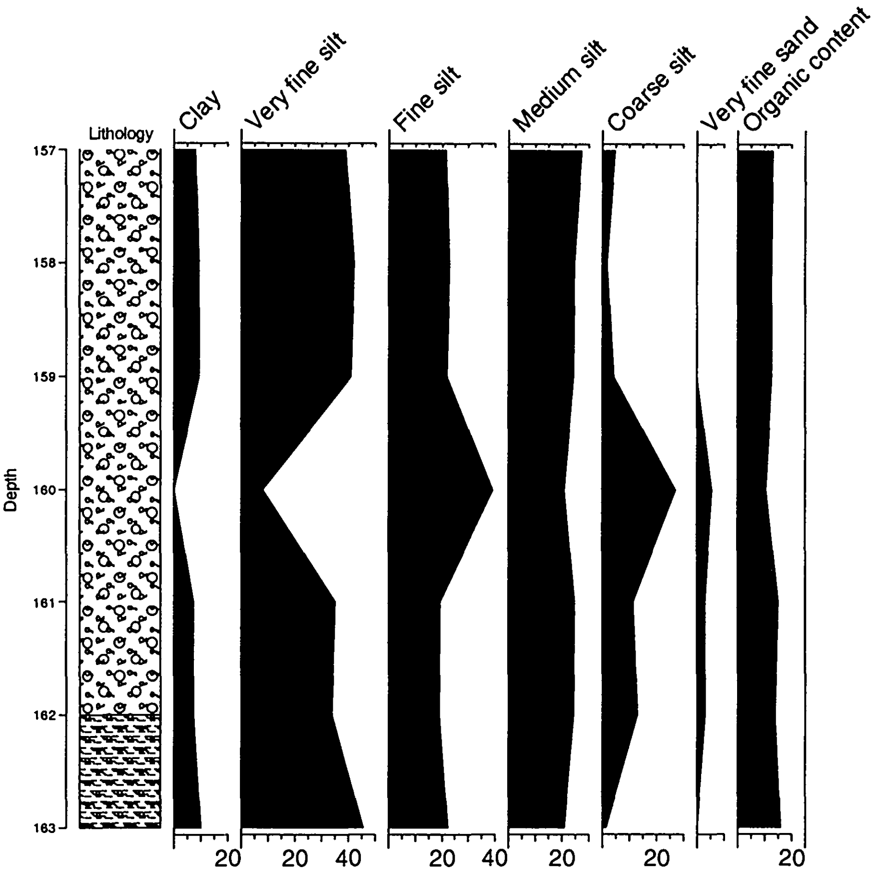


Figure 5.34: Particle size analysis at Lag 400 BOS Base (%)

Particle size analyses through the basal sediments of Lag 400 BOS (a well-humified peat with gmin. and gmaj. throughout and an organic sandy / silt) demonstrate a high proportion of very fine silt, fine silt and medium silt at its base, with a sharp decrease in values at 160cm (c.3764 cal. BP) and a corresponding peak in fine silt and coarse silt. Following this, fine silts once more increase and clay particles make up only a small percentage of the overall sedimentary mix.

5.3.5 Mean rates of sedimentation at Lag 400 BOS

One date was obtained for peat initiation at Lag 400 BOS. This is presented in Table 5.8 and a tentative age / depth curve was produced on the basis of this, assuming constant vertical growth rates between the AMS radiocarbon date and the peat surface.

Altitude	**Slope Position**	**Depth of sample**	**Material Dated**	**Lab code**	**^{14}C Age BP**	**δ^{13}C**	**Cal. age BC / AD (± 2.0 σ)**	**Midpoint used (cal. Age BP)**
400m OD	BOS	146-147cm	Humic Acid	SUERC-2701 GU-11957	4335±35	-28.4	3080-2880BC	c.4935

Table 5.8: AMS radiocarbon date from Lag 400 BOS.

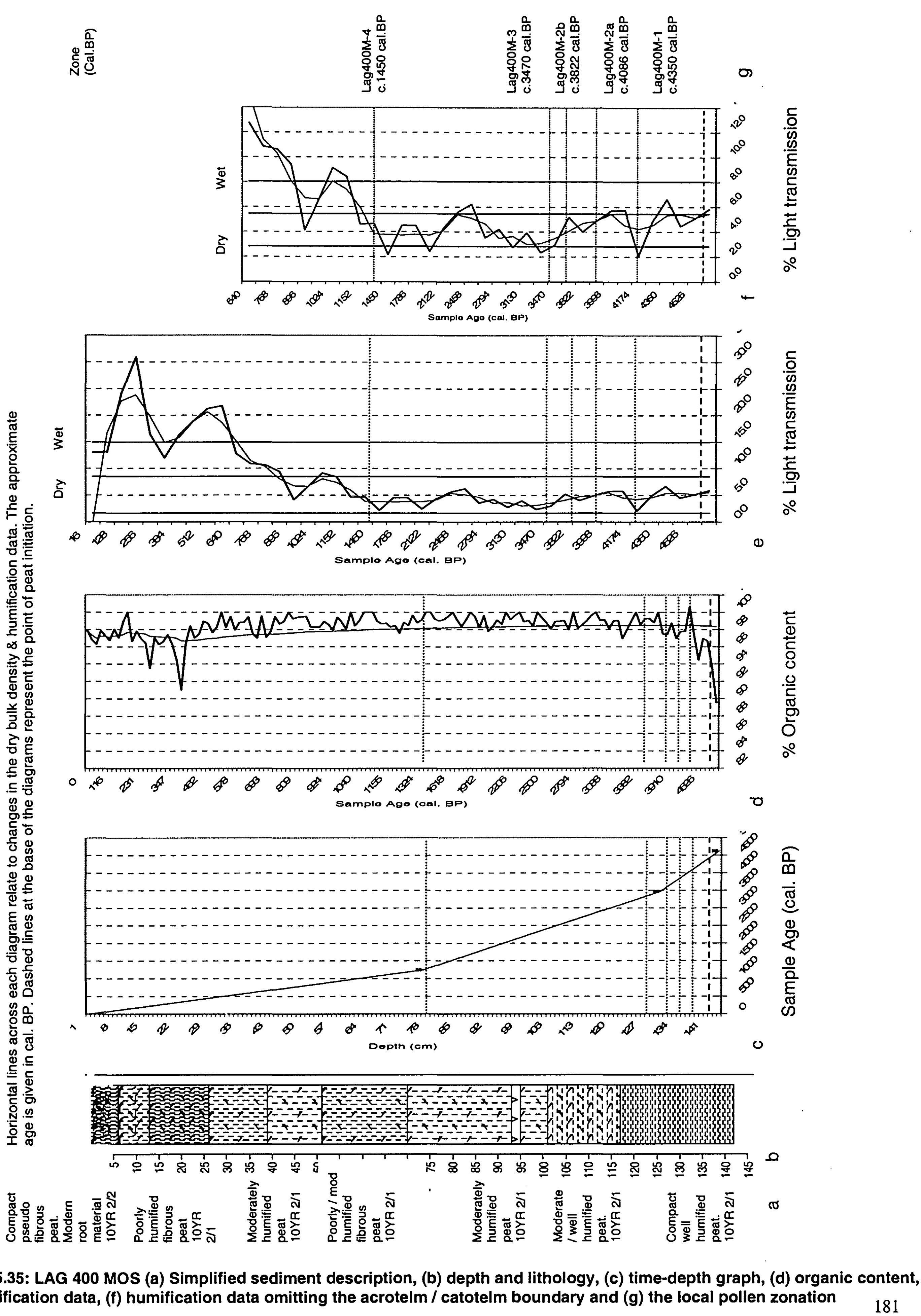
Only one AMS date was obtained through the sequence at the initial point of blanket peat accumulation (Figure 5.31 (c)). If constant rates of growth and decay are assumed, the average accumulation rate is 33 years / cm. Figures 5.32 (c) and (e) show dry bulk density and ash free dry bulk density. Both graphs show high values of bulk density at the base of the core, indicating compaction and decomposition of early organic material which overlay bedrock. On top of this, more organic sandy silts developed, typical of a soil. Unfortunately, no ^{14}C dates were obtained through this early phase of organic accumulation. Through the soil horizon and into peat initiation at c.4935 cal. BP, dry bulk density values fall, suggesting a lower level of compaction. Figure 5.32 (d) shows the values of bulk density remained low, fluctuating around minus 1 standard deviation to c.3400 cal. BP, at which point values rise. A further fall in values is recorded at c.2550 cal. BP, following which levels rise to 0.10g/cm^3 at c.1428 cal. BP (Figure 5.32 (e)). Values of bulk density in the upper layers appear to decrease at c.500 cal. BP, suggesting the acrotelm / catotelm boundary lies at c.20-25cm.

5.3.6 Peat humification profile from Lag 400 BOS

Graphs 5.32 (a) and (b) show the percentage light transmission values for Lag 400 BOS through the blanket peat transition horizon and through the main peat core, suggesting there were three main increases in values. A wet peak is recorded following peat initiation at c.4726 cal. BP, after which values gradually decline indicating a prolonged period of relatively dry conditions. A sharp peak is then recorded at c.2822 cal. BP (84-85cm) and at c.1190 cal. BP. Figure 5.32 (a), showing values through the upper layers, indicates the position of the acrotelm / catotelm boundary, placing it at c.374 cal. BP.

5.3.7 Sediment sequence at Lag 400 MOS

The sediment sequence for Lag 400 MOS is 142cm long and consists of an entirely organic sequence from the base (89% organic content) to the top, with varying degrees of humification. Two minor decreases in % organic content are recorded towards the top of the core, at c.346 cal. BP and c.231 cal.BP where levels drop to 91% organic content. A lens of woody fragments was recorded at 93cm and the point of peat initiation is placed at 142cm, c.4620 cal. BP.



Horizontal lines across each diagram relate to changes in the dry bulk density & humification data. The approximate age is given in cal. BP. Dashed lines at the base of the diagrams represent the point of peat initiation.

Figure 5.35: LAG 400 MOS (a) Simplified sediment description, (b) depth and lithology, (c) time-depth graph, (d) organic content, (e) humification data, (f) humification data omitting the acrotelm / catotelm boundary and (g) the local pollen zonation

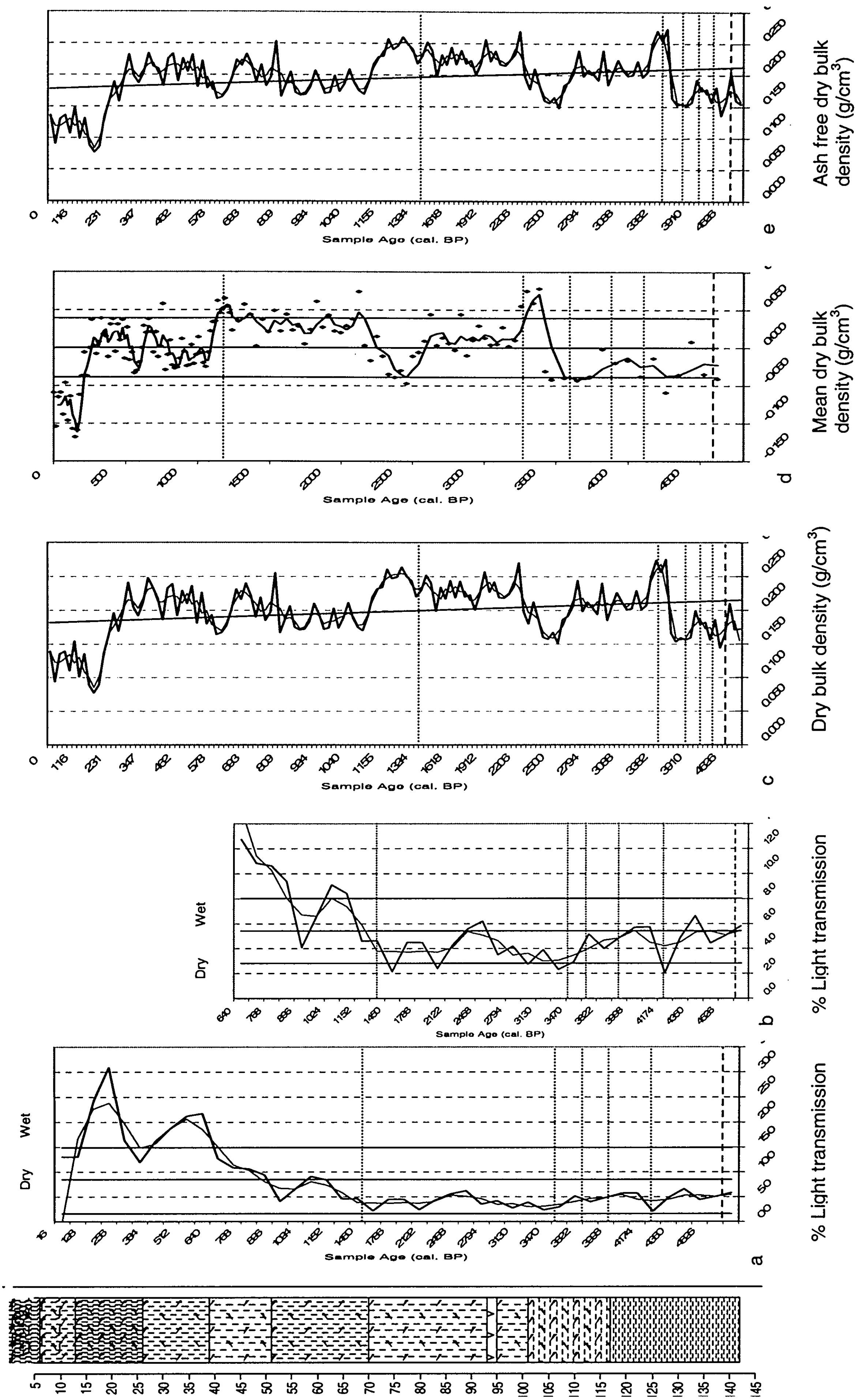


Figure 5.36: Lag 400 MOS (a) humification data, (b) humification data omitting the acrotelm / catotelm boundary, (c) dry bulk density (g/cm³), (d) mean ash free dry bulk density data (e) ash free dry bulk density data.

5.3.8 Sediment sequence & mean rates of sedimentation at 400m MOS Base

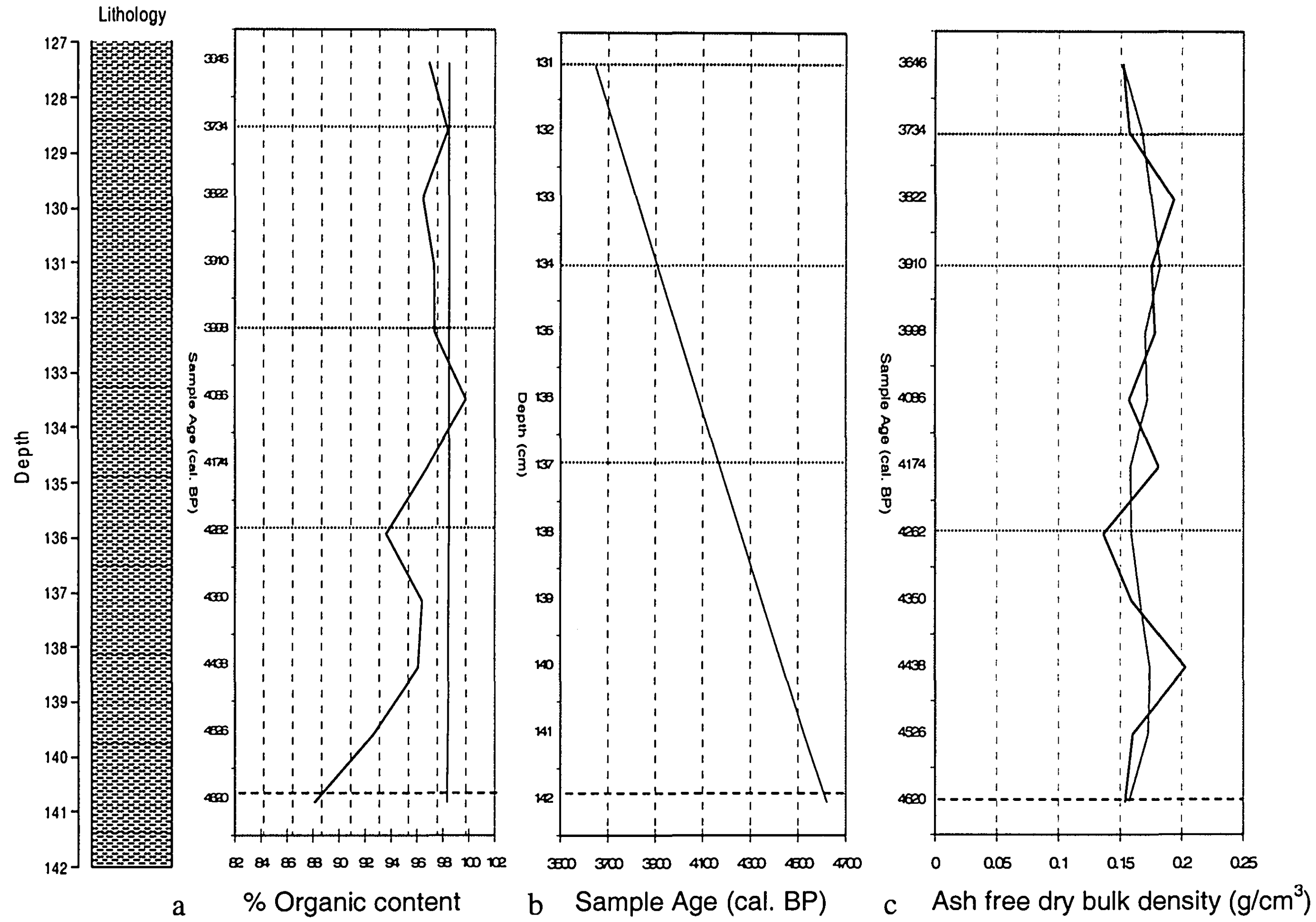


Figure 5.37: (a) organic content from Lag 400 MOS Base with cumulative average mean, (b) time-depth curve for Lag 400 MOS Base drawn on the basis of calibrated AMS dates (table 5.9) (c) ash free dry bulk density for Lag 400 MOS with a three term average running mean.

Figure 5.37 (a) shows the basal core comprises a well-humified fine / woody herbaceous peat sitting directly on bedrock, with an organic content of between 89% and 100%. Figure 5.37 (b) suggests the mean sedimentation rate through the base was low, c. 88 years / cm. Bulk density values from the base have remained relatively constant and high, fluctuating between 0.15g/cm^3 and 0.20g/cm^3 (Figure 5.37 (c)) further suggesting highly decomposed and compacted blanket peat sits directly on bedrock (there are no apparent transition horizons). No particle size analysis was undertaken through these basal layers due to their highly organic nature.

5.3.9 Mean rates of sedimentation at Lag 400 MOS

In total, three AMS radiocarbon dates were obtained for Lag 400 MOS (Table 5.9), allowing an age-depth curve to be produced and an estimate of mass accumulation rates to be made (Figure 5.35).

Altitude	**Slope Position**	**Depth of sample**	**Material Dated**	**Lab code**	**14 C Age BP**	**δ13C**	**Cal. age BC / AD (± 2.0 σ)**	**Midpoint used (cal. Age BP)**
400m OD	MOS	75-76cm	Humic Acid	SUERC-5998 GU-12905	1325±35	-27.8	650-780AD	c.1240
400m OD	MOS	128-129cm	Humic Acid	SUERC-5999 GU-12906	3235±35	-28.0	1610-1420BC	c.3470
400m OD	**MOS**	**141-142cm**	**Humic Acid**	**SUERC-2702 GU-11958**	**4070±35**	**-28.0**	**2860-2470BC**	**c.4620**

Table 5.9: AMS radiocarbon dates from Lag 400 MOS.

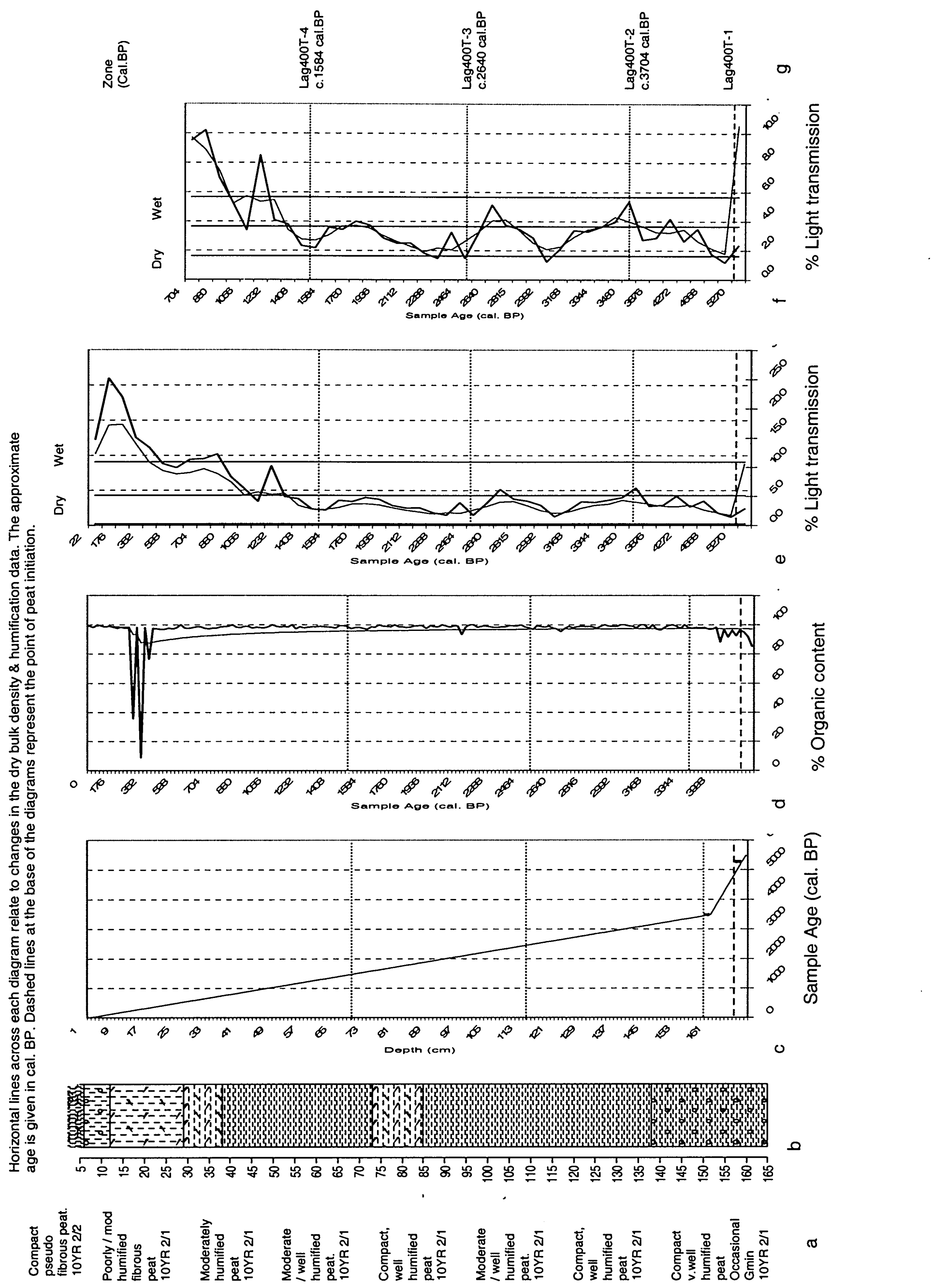
Figure 5.35 (c) suggests that an average peat accumulation rate of 32.5 years /cm can be calculated through the peat profile, although this rate will have varied through time. The well-humified nature of the deposits means there is little variation between the dry bulk density graph and the ash free dry bulk density graph (Figures 5.36 (c) and (e)). These suggest that the organic material sitting directly on bedrock has relatively low values of bulk density, between 0.15g/cm^3 and 0.20g/cm^3, but values rise sharply at c.3382 cal. BP to c.2584 cal. BP, demonstrated well in graph 5.36 (d), suggesting this was a period of increased decomposition and compaction. After this period, values fall but increase again at c.2122 cal. BP fluctuating either side of the plus one standard deviation. At c.1188 cal. BP and c.511 cal. BP, values gradually decrease and at c.264 cal. BP until the present day, bulk density declines sharply. The acrotelm / catotelm boundary is placed here in the upper 10-15cm at c.250 cal. BP.

5.3.10 Peat humification profile from Lag 400 MOS

Figures 5.36 (a) and (b) show minor fluctuations in percentage light transmission through the peat core at Lag 400 MOS. Figure 5.36 (b) shows more pronounced changes as a result of removing the values through the upper part of the core (through the acrotelm / catotelm boundary). This graph indicates a number of small shifts towards a wetter mire surface: in particular, at c.4262 cal BP and c.3998 cal. BP to c.3646 cal. BP in the lower part of the core. Conditions then appear to become dry for c.1200 years before a further wet shift is recorded at c.2374 cal. BP, and a sharp shift occurs at c.1089 cal.BP and at c.561 cal. BP. Figure 5.36 (b) then shows a reversal to drier conditions at c.891 cal. BP before values rise sharply at the current acrotelm / catotelm boundary.

5.3.11 Sediment sequence at Lag 400m TOS

The long core from Lag 400 TOS measured 165cm in length (Figure 5.38 (b)). At the base it contained a well-humified peat with occasional sand / silt particles. The organic content (Figure 5.38 (d)) through the basal 15cm shows minor fluctuations from 85% to 97%, after which values remain above 98%. The peat sequence throughout the core consisted of moderate to well-humified peats but, at c.286 cal. BP, an inwash band with decreasing organic content to 9% is found within the upper poor / moderate humified layers. The point of blanket peat initiation has been placed at 166cm and is dated to c.5270 cal. BP.



Horizontal lines across each diagram relate to changes in the dry bulk density & humification data. The approximate age is given in cal. BP. Dashed lines at the base of the diagrams represent the point of peat initiation.

Figure 5.38: LAG 400 TOS (a) Simplified sediment description, (b) depth and lithology, (c) time-depth graph, (d) organic content, (e) humification data, (f) humification data omitting the acrotelm / catotelm boundary and (g) the local pollen zonation

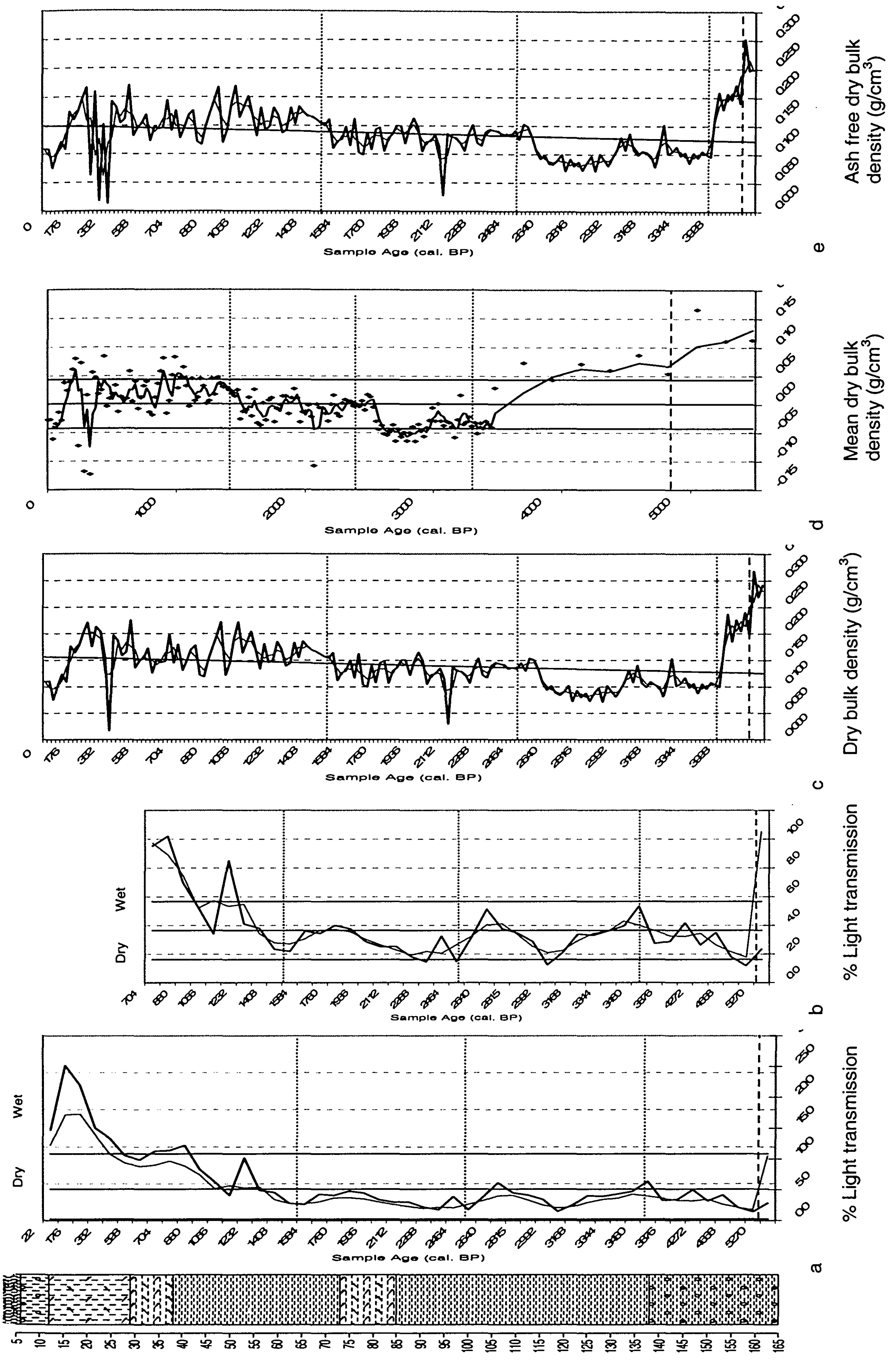


Figure 5.39: Lag 400 TOS (a) humification data, (b) humification data omitting the acrotelm / catotelm boundary, (c) dry bulk density (g/cm³), (d) mean ash free dry bulk density data (e) ash free dry bulk density data.

5.3.12 Sediment sequence & mean rates of sedimentation at 400m TOS Base

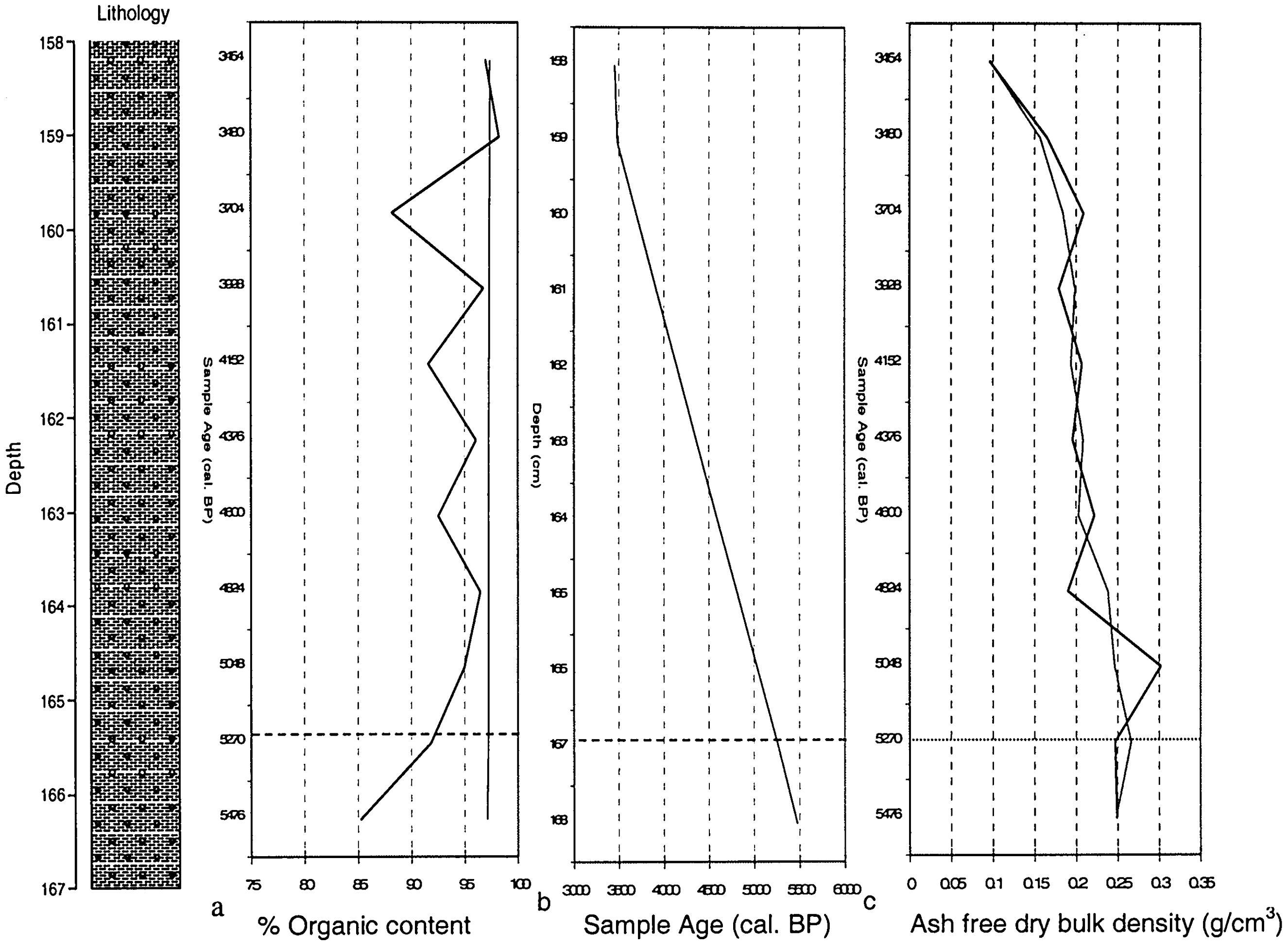


Figure 5.40: (a) organic content from Lag 400 TOS Base with cumulative average mean, (b) time-depth curve for Lag 400 TOS Base drawn on the basis of calibrated AMS dates (table 5.10) (c) ash free dry bulk density for Lag 400 TOS with a three term average running mean.

The basal sequence through Lag 400 TOS Base indicates a high level of organic content through the well-humified peat (with occasional gmin.), with values over 85% from an early stage. Figure 5.40 (b) suggest the mean accumulation rate of this early sequence is 224 years / cm and the bulk density data (Figure 5.40 (c)) shows highs values of bulk density from the base of the core, indicating rapid decay and compaction. No particle size analysis was undertaken through these basal layers due to their highly organic nature.

5.3.13 Mean rates of sedimentation at Lag 400 TOS

Two AMS radiocarbon dates were obtained from Lag 400 TOS (Table 5.10)

Altitude	Slope Position	Depth of sample	Material Dated	Lab code	14 C Age BP	δ13C	Cal. age BC / AD (± 2.0 σ)	Midpoint used (cal. Age BP)
400m OD	TOS	158-159cm	Humic Acid	SUERC-5997 GU-12904	3255±35	-28.3	1620-1430BC	c.3480
400m OD	TOS	166-167cm	Humic Acid	SUERC-2701 GU-11959	4600±35	-28.3	3510-3110BC	c.5270

Table 5.10: AMS radiocarbon dates from Lag 400 TOS.

The estimates of accumulation rates for Lag 400 TOS (Figure 5.38 (c)) are based on only two AMS radiocarbon dates and suggest that between c.5476 cal. BP and c.3480 cal. BP, peat was accumulating very slowly with an average vertical rate of 224 years / cm. The bulk density data (Figures 5.39 (c)), (d) and (e) also suggest that compaction and decomposition of the blanket peat was high at the base of the core, with values of up to 0.3g/cm^3. From c.3454 cal. BP to c.2530 cal. BP values decrease sharply to 0.055g/cm^3 before rising again. A further increase in values occurs at c.1474 cal. BP and deviate between the mean and plus one standard deviation (Figure 5.39 (d)). The acrotelm / catotelm boundary is placed at c.330 cal. BP, 20cm below the surface where % organic volume decreases.

5.3.14 Peat humification profile from Lag 400 TOS

Percentage light transmission for Lag 400 TOS is presented in Figures 5.39 (a) and (b). The graphs show that there are several minor shifts to possible wetter conditions. Figure 5.39 (b), for example, indicates a gradual increase in wet conditions from c.4376 cal. BP to c.3480 cal BP. A further more pronounced shift is then recorded at c.2618 cal. BP before values fall, suggesting a drier period. A minor shift is recorded at c.1760 cal. BP, followed by a more pronounced change to wet conditions at c.1122 cal. BP. The start of the acrotelm / catotelm boundary is placed at c.30cm (c.700 cal. BP) when values increase sharply (Figure 5.39 (a)).

5.4 *Fine resolution pollen diagrams at 230m OD*

The pollen analytical results in the form of percentage pollen diagrams of all terrestrial taxa, aquatic taxa and total terrestrial pollen concentration are presented in the next section. A total of nine fine resolution pollen diagrams have been produced through each of the basal profiles at the nine sites and three longer, complete sequences through the profiles at Lag 230 BOS, Lag 230 MOS and Lag 230 TOS. This will allow an analysis of the detailed vegetation change before, during and after blanket peat initiation. The longer sequences allow a more regional analysis over the last c.6000 yrs BP to be produced.

5.4.1 Fine-interval pollen diagram at Lag 230 BOS

Lag230B-1 *Alnus-Corylus (c.5200-5125 Cal.BP)*

Figure 5.42 covers the basal 20cm of the full percentage diagram (Figure 5.90-5.61). Pollen analyses begin at 211-216cm with zone Lag230B-1, which includes the transition into blanket peat with over 80% organic at depth 215cm. This zone suggests the area was partially wooded with areas of open grassland. It contains a high proportion of arboreal pollen types, with some shrubs and herbaceous species, representing relatively high levels of plant productivity before the encroachment of heathland communities. The total disappearance of *Pinus* and a decline in Pteridophyta from the very base of the core between c.5200 cal. BP to c.5185 cal.BP suggests a decline in shade intolerant herbs and a temporary drying of the ground surface during which time *Alnus* levels increase (a peak in *Alnus* is recorded at c.5190 cal.BP, the point of peat initiation), accompanied by fluctuating but gradually increasing values of *Betula*, *Quercus* and *Ulmus*, making arboreal pollen reach 60% tlp. Values for *Corylus* and *Poaceae* also rise and peak at c.5140cal.BP and a number of other grassland species, including *Urtica* and *Ranunculus,* are recorded along with comparatively rare *Calluna vulgaris.* Several Cerealia pollen grains were also identified through the basal layers (c.5190cal.BP) and accompanied by pollen types typical of disturbed ground (e.g.; *Artemesia*), suggesting some human activity in the area. Towards the close of this zone values for *Corylus* and *Poaceae* begin to decline whilst there is a small peak in *Myrica* values.

Lag 230B-2a Betula-Poaceae (c.5125-5030cal.BP)

Figure 5.41 shows charcoal analysis through the basal sequence at Lag 230 BOS Base and is compared with the % organic content in order to show the transition into well humified blanket peat and the point of blanket peat initiation. The pollen zones have also been demarcated by fine horizontal lines and sample ages begin after the point of peat initiation.

The end of the previous zone and beginning of Lag 230B-2a coincides with a single peak in charcoal at c.5130cal.BP (Figure 5.41) with a rise in the frequency of Cerealia grains. *Betula* values however, recover quickly and form distinct peaks at 210cm and 205cm whilst *Alnus* slowly declines through this zone following a slight peak at 209cm. The values for *Quercus* increase slightly whilst *Ulmus* remains fairly steady. *Corylus* levels also decline through this zone but greater numbers of other shrubs are present and growing around the site, in particular *Myrica* and *Salix*, and steady but low values of *Calluna vulgaris*. This zone is also distinguished by a peak in *Poaceae* levels and the development of a species rich grassland with *Apiaceae, Ranunculus type, Filipendula, Saxifraga* and *Urtica type* all increasing to 35%tlp at c5060cal.BP. Several Cerealia grains were also identified, particularly between c.5090 and 5060cal. BP, coinciding with a reduction in tree values, particularly *Betula,* suggesting this represents a period of anthropogenic activity and the establishment for a time of cereal cultivation. The numbers of Pteridophyta spores also decline slightly towards the end of this zone.

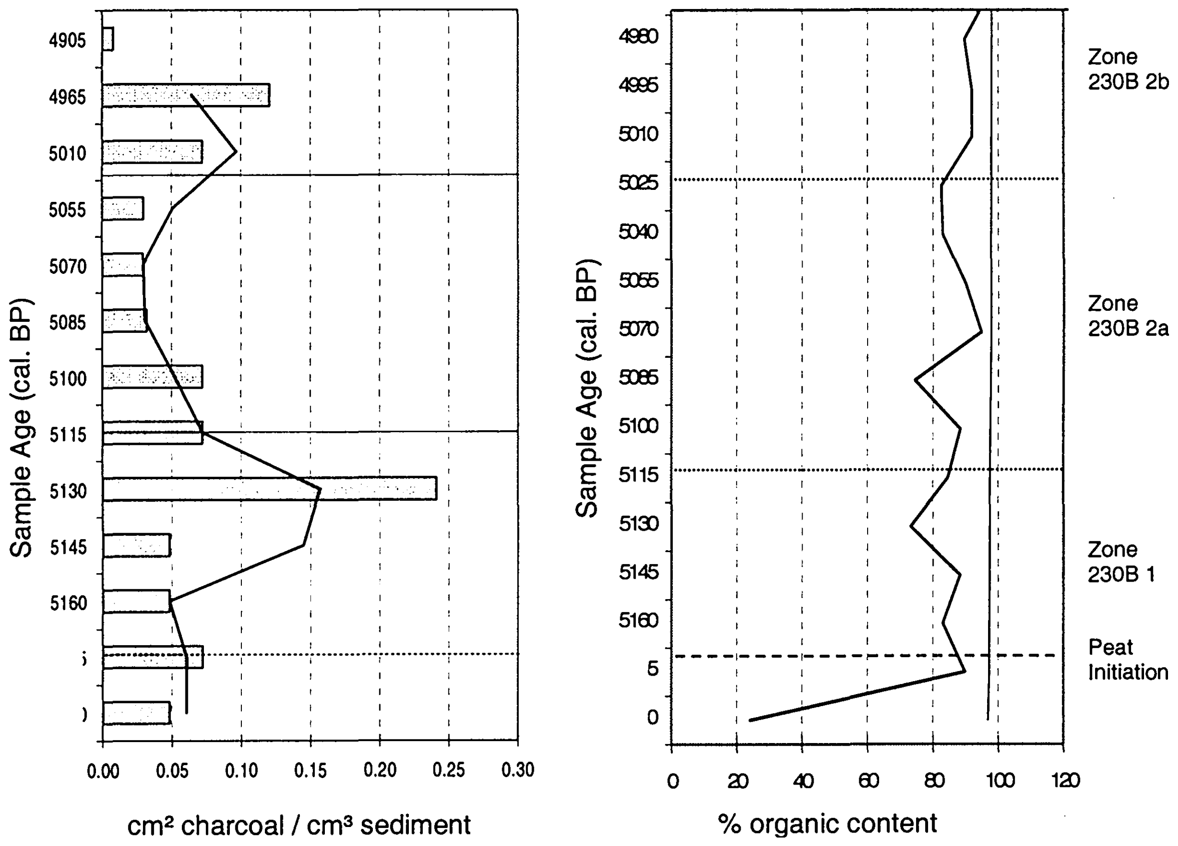


Figure 5.41 Fine interval charcoal analyses of Lag 230 BOS Base

Lag 230B-2b. Corylus-Poaceae (c.5030-4890 cal.BP)

The final zone through the basal sequence marks a gradual decline in arboreal pollen with decreasing values of *Betula* and *Alnus* and marks a rise in shrubs, herbs and Pteridophyta, suggesting that open ground cover increased slightly. In particular, higher values of *Saxifraga, Rumex acetosella* and *Corylus* are all recorded. Poaceae levels fall slightly at the opening of the zone but recover at c.4970cal.BP. A small peak in charcoal is recorded at c4965 cal. BP (Figure 5.41) which corresponds with the decline in *Alnus* and the slight increase in Poaceae, Cerealia and *Scilla* type, suggesting continued human activity.

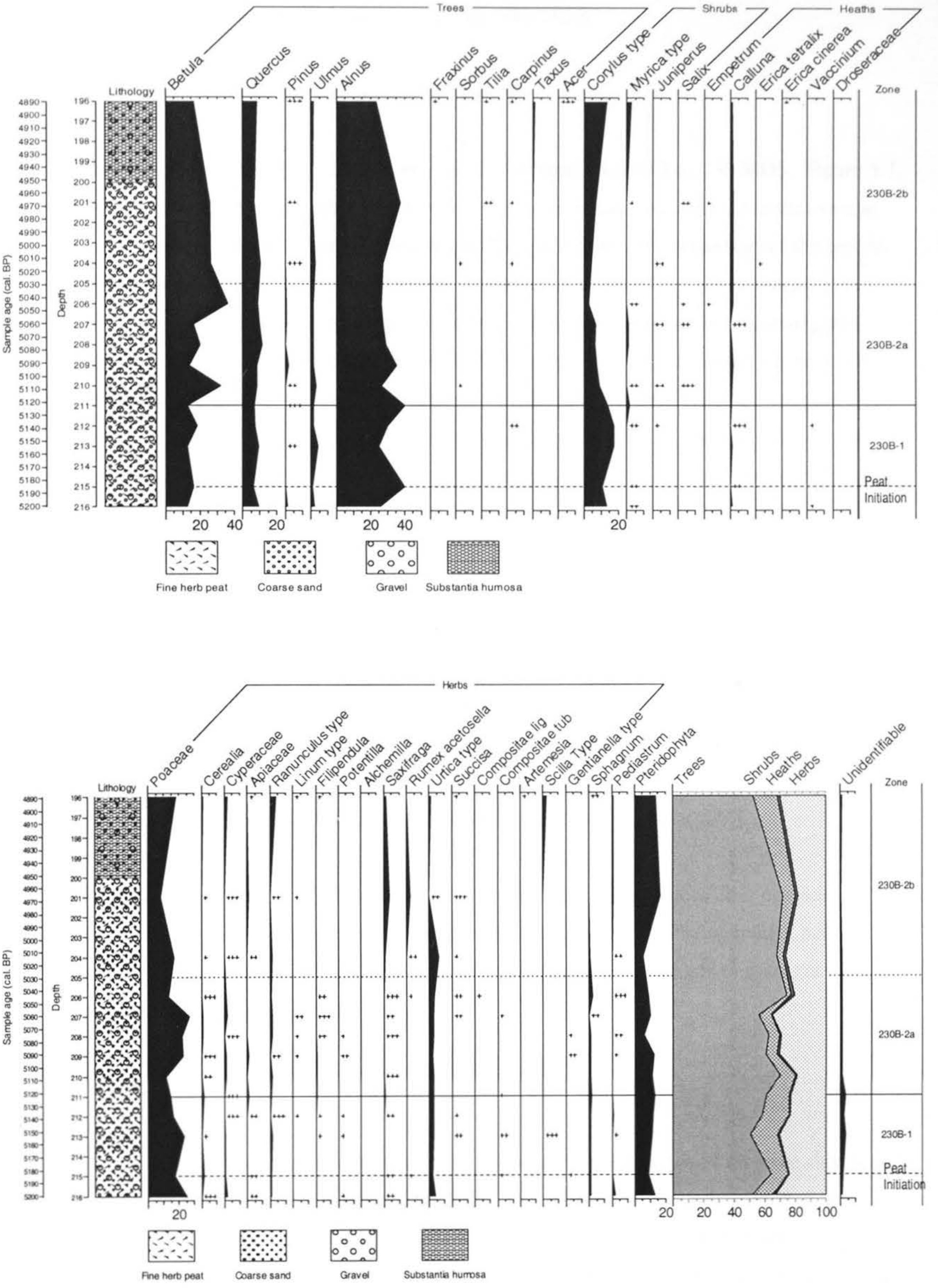


Figure 5.42 Lag 23O BOS Base Fine Interval Percentage Pollen Diagram

5.4.2 Fine-interval pollen diagram at Lag 230 MOS

Lag230M-1 Alnus-Corylus (pre.c.4675 cal.BP)

The fine-interval diagram (Figure 5.44), covers the basal 27cm of Lag 230 MOS. Figure 5.7, the loss-on-ignition graph (showing the curve for ignition residue compared to the average running mean), indicates that organic content fluctuated from 28% at the base of the core to 80% at the point of initiation (c.4675cal.BP), marked as a dashed line in the second zone (Figure 5.44). The earliest sequence is therefore situated within a matrix of minerogenic material. Figure 5.7 (a) suggests organic productivity prior to peat initiation was relatively low. There are greater values for *Pediastrum* and *Sphagnum* within this zone, suggesting waterlogged conditions were experienced with decreasing values of *Calluna vulgaris* and *Saxifraga*. Relatively high but fluctuating values of *Corylus* and Poaceae are recorded, with a slight decrease at c.5250cal.BP. The very base of the diagram is distinguished by decreasing values of *Betula*, *Ulmus* and *Quercus* as wetter conditions locally were experienced and possible signifies the *Ulmus* decline pre c.4675 cal. BP. These taxa then recover and peak before falling again, and *Betula* values continue to rise gently through this zone. *Alnus* values are high at the opening of the diagram and remain steady throughout, suggesting it is likely that the mineral substrate accumulated after the colonisation of this slope by *Alnus*, after c.6500 cal. BP. Some open ground taxa are also present including possible Cerealia (pre c.4675 cal.BP), Cyperaceae, Apiaceae and *Urtica* type. Two peaks in charcoal pre c.4675 cal. BP are also recorded (Figure 5.43).

The pollen evidence through this sequence suggests a trend from wet to drier conditions before c.4675 cal. BP. The mineral sequence shows no evidence of being mixed, but perhaps reflects a sequence of colluvial layers. A decrease in Pteridophyta spores at the end of this zone suggests drier conditions.

Lag 230M-2 Betula-Poaceae (pre c.4675-3650 cal.BP)

This zone is distinguished by a greater variety of arboreal pollen types, with some shrubs and herbaceous species present in the change from a fine herb peat into a well-humified peat. The most noticeable feature of this zone is the steady rise in values of *Betula* and the slow decline of *Alnus* towards the point of peat initiation at c.4675cal. BP, where organic content exceeds 80%. After this, values of *Betula* slowly decline and *Alnus* appears to slowly increase. There is a low but continued presence of *Quercus* and *Ulmus* and a greater variety of other tree species are recorded including *Fraxinus, Tilia* and *Taxus* which are often under-represented in pollen records and may have grown in open *Betula-Corylus* woodland. Overall, values of *Corylus* decline at the start of this zone but increase slightly towards the end. *Myrica* is present in greater quantities and the presence of *Juniperus* and *Salix* are also recorded. *Poaceae*, *Cyperaceae, Filipendula* and *Sphagnum* also remain relatively consistent and a greater number of open ground herbs are recorded within this zone, including Cerealia and *Plantago* sp., suggesting some human disturbance particularly between c.4300 cal. BP and c.3800cal.BP when there is a slight decline in trees and a rise in herbs. A small peak in Pteridophyta, *Corylus* and *Alnus* is recorded at c.3900 cal, BP. The largest charcoal peak is recorded at c.4993cal. BP within the mineral sediment, positioned at the tail end of a small peak in trees and a decrease in herbs.

Lag 230M-3a Calluna-Poaceae (c.3650-3360 cal.BP)

This zone is clearly distinguished by a gradual decline in the values of trees and shrubs, in particular *Alnus* and *Betula,* and the beginning of increased values of *Calluna vulgaris* and the continued presence of herbs, in particular Poaceae and *Filipendula.* A slight rise in *Sphagnum* is also recorded. No Cerealia pollen grains were found within this zone. This zone marks the beginning of heathland development. A small peak in charcoal is recorded at c.3361cal.BP.

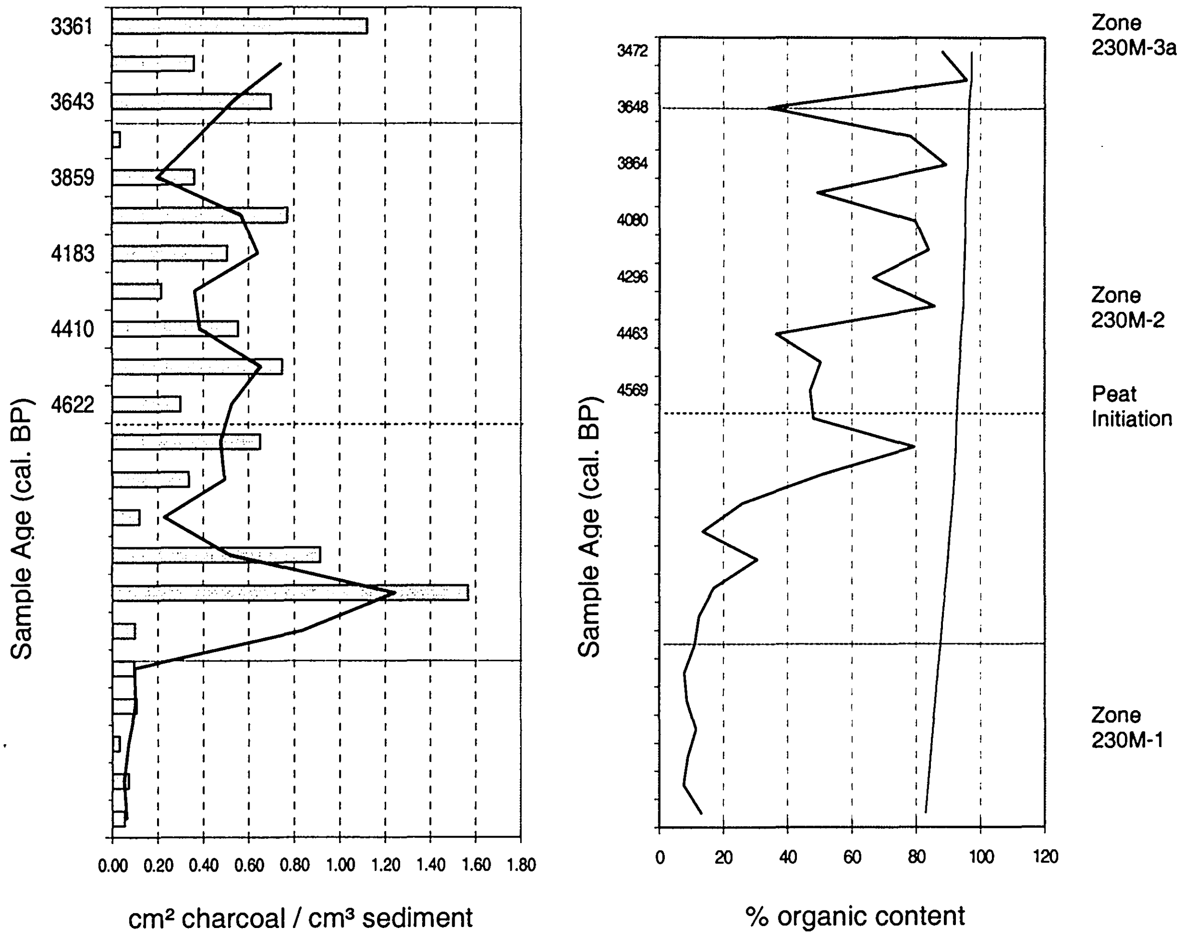


Figure 5.43 Fine interval charcoal analyses of Lag 230 MOS Base

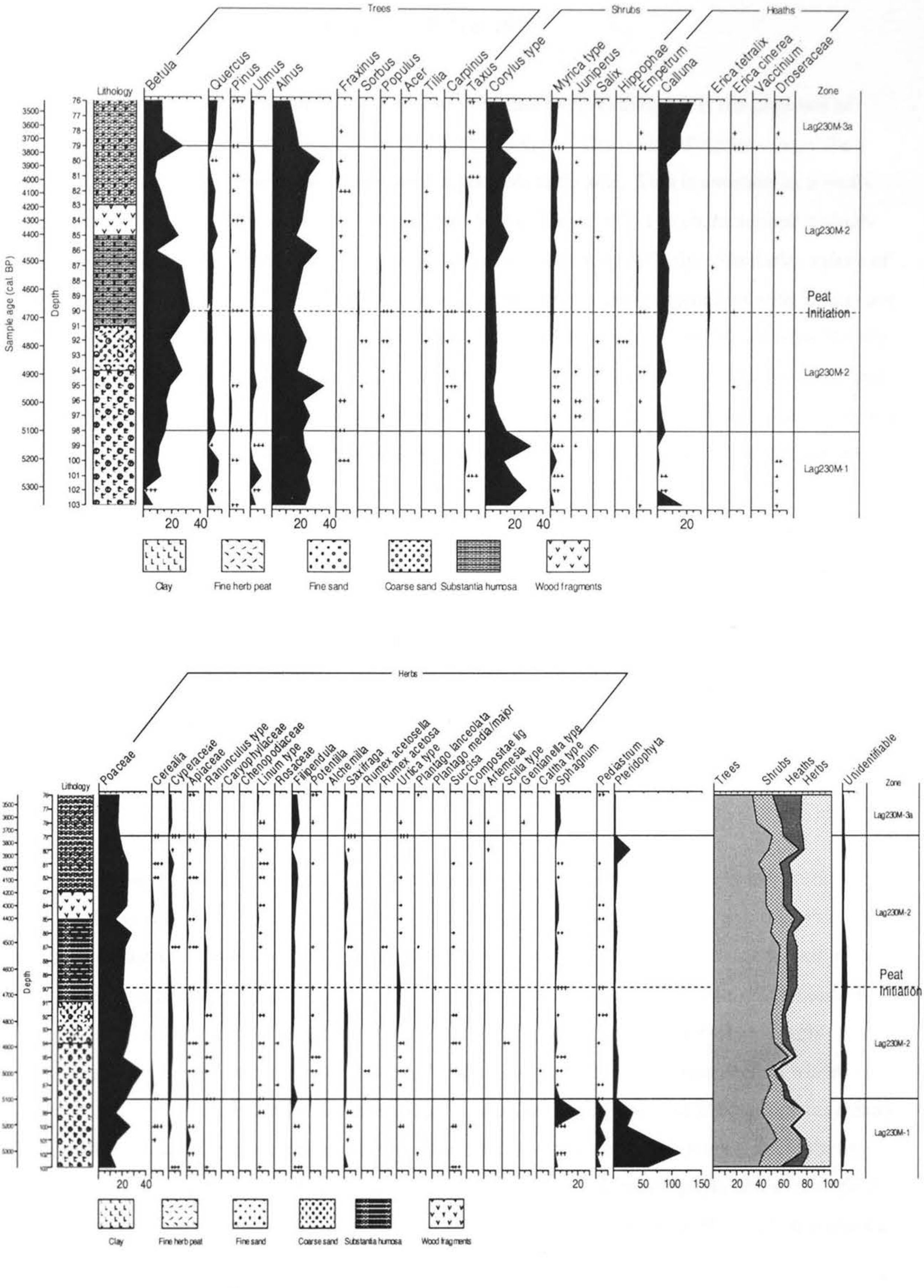


Figure 5.44 Lag 23O MOS Base Fine Interval Percentage Pollen Diagram

5.4.3 Fine-interval pollen diagram at Lag 230 TOS

Lag 230T-1 Alnus-Corylus (pre c. 6400 cal.BP)

The most noticeable feature of the Lag 230 TOS fine interval diagram is the presence of abundant *Calluna* pollen throughout the basal sequence. The pollen diagram covers the basal 20cm. The basal 8cm encompasses a possible early soil. This is overlain by a well-humified woody/herbaceous peat (see Figure 5.13). Zone 230T-1 is characterised by high values of shrubs, in particular *Corylus* and *Myrica*, making up 30% tlp. Similarly, values of *Calluna vulgaris* and Droseraceae are high, possibly growing in conjunction with *Sphagnum* and Pteridophyta in damp, acidic conditions. *Betula* values decrease at 187cm from 20%tlp to <10%tlp whilst *Alnus*, *Ulmus* and *Quercus* values increase, making up 35%tlp at the end of the zone (c.6500 cal.BP). This pollen sequence covers the earliest period at Lagafater and represents the earliest local vegetation at the site prior to peat initiation. It would suggest that from c.6600cal.BP, *Betula* stands were present along with some *Quercus*, *Pinus* and *Ulmus* although these may have been growing at some distance from the site. Pre c.6400 cal. BP, *Alnus* was introduced and competed with *Betula* to become the more dominant tree species. No Cerealia grains are recorded but rich grassland species such as Apiaceae, *Saxifraga* and *Succisa* are recorded along with low levels of *Poaceae*. Damp, increasingly acidic conditions with patches of *Betula-Corylus* woodland and areas of open ground typify this early zone.

Lag 230T-2a Calluna-Alnus (pre c.6400 cal. BP-6050 cal.BP)

This zone shows a steady increase in the number and diversity of heath species, particularly *Calluna vulgaris* where levels reach 40% tlp at c.6050cal.BP and *Empetrum*. The Poaceae curve shows a slight increase to 182cm (c.6250 cal.BP) and then values decrease but other grassland herbs persist throughout this zone, in particular *Ranunculus* type, *Filipendula* and *Saxifraga*. This pattern is mirrored with values for *Corylus* and *Myrica* where levels similarly rise and then fall at c.6150cal.BP and overall, herbs and shrubs decline whilst heathland species expand. The curves for *Betula*, *Quercus*, *Pinus* and *Ulmus* remains steady with relatively low levels of tlp. whilst values for *Alnus* fluctuate but remain at c.20% tlp. There is also a low but continued presence of *Sphagnum* and Pteridophyta and a small peak in charcoal (see Figure 5.45) at c.6109 cal.BP. The point of blanket peat initiation is placed at c.6375 cal.BP.

Lag 230T-2b Calluna-Betula (c.6050 cal.BP-5720cal.BP)

Calluna vulgaris values reach a peak at the boundary between zone 230T-2a and 230T-2b and then steadily fall, along with other heathland species in particular, *Empetrum*. Their fall to c.5800cal.BP within this zone is paralleled by a slight rise in *Betula* that peaks at this point, and increases in *Quercus*, *Ulmus* and *Alnus*. After this period, which coincides with a peak in charcoal at c.5893 cal.BP (see Figure 5.45), *Calluna vulgaris* declines markedly whilst Poaceae, *Saxifraga, Urtica* and *Ranunculus* increase. A number of Cerealia grains are also found after c.5800cal.BP along with the occasional *Plantago* sp. grain, suggesting human activity.

Lag 230T-2c Alnus-Poaceae (c.5720cal.BP-c.5500cal.BP)

The base of this zone only is covered in the fine-interval diagram (see section x for the complete description of this zone) and is distinguished by a rise in *Alnus* values and the continued presence of *Quercus*, *Betula* and *Pinus* although levels of *Ulmus* appear to fall slightly, possibly representing the *Ulmus* decline (c.5725 cal. BP). This zone is placed at the boundary of a small rise in charcoal and there is a decline in values of *Corylus*, whilst *Calluna vulgaris* values appear to stabilise and represent 25% tlp. There is also a rise in Poaceae at the beginning of this zone and a low but continued presence of *Sphagnum* and Pteridophyta.

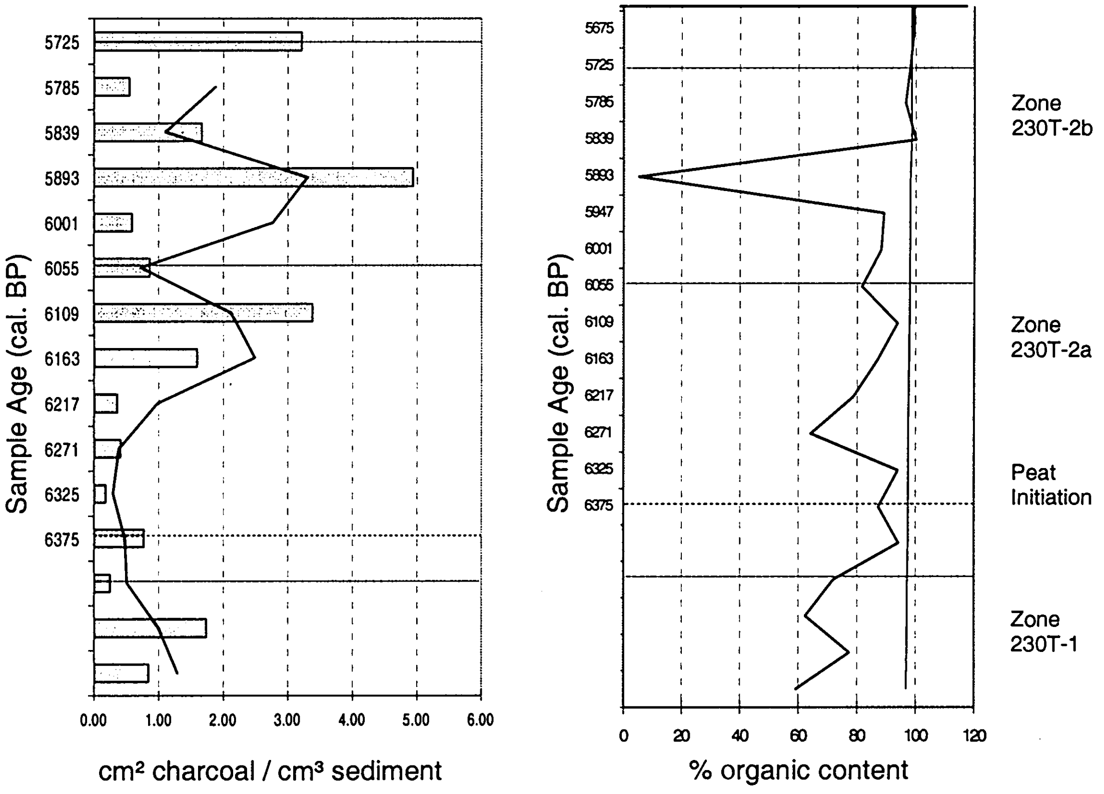


Figure 5.45 Fine interval charcoal analyses of Lag 230 TOS Base

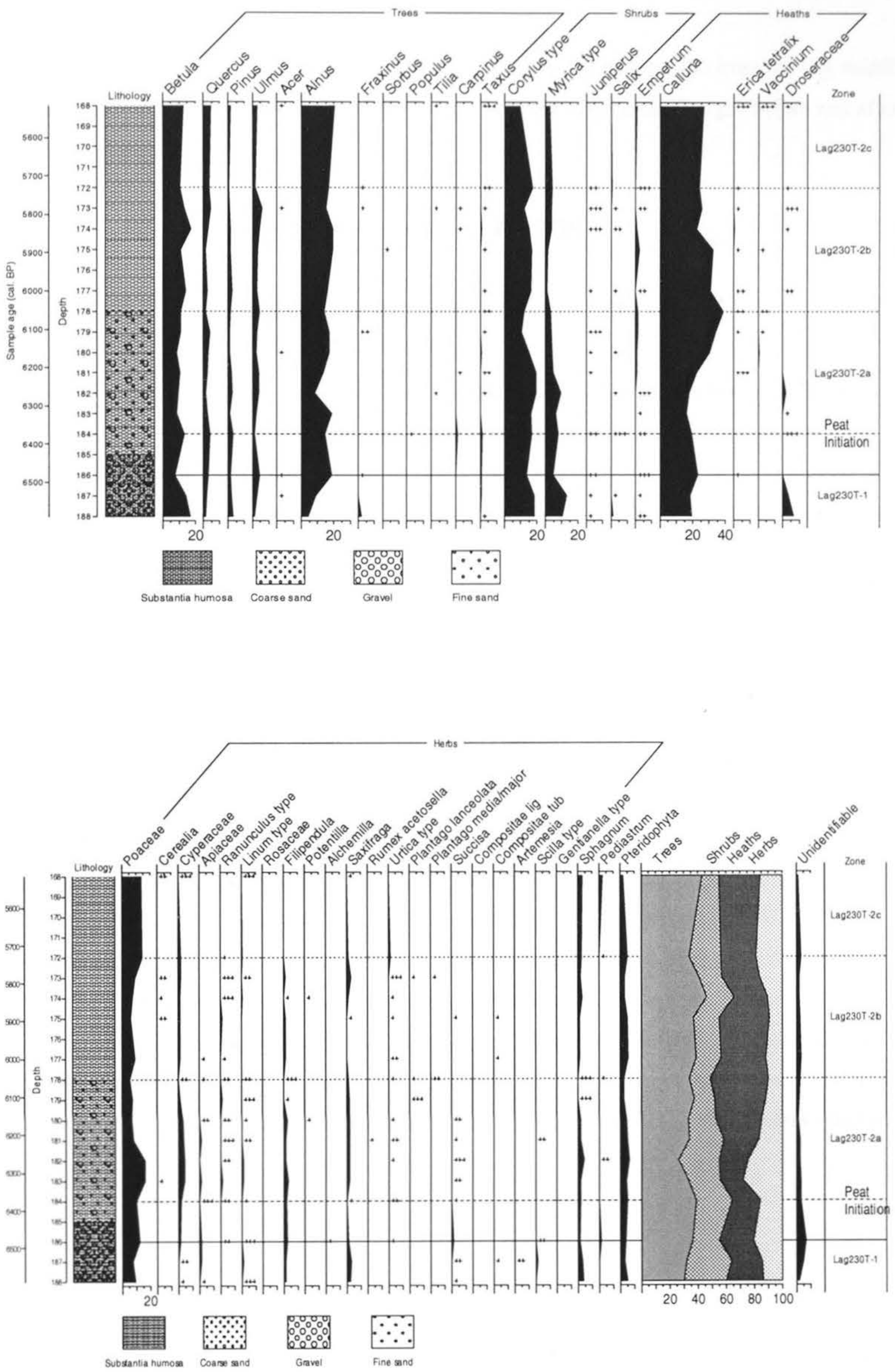


Figure 5.46 Lag 23O TOS Base Fine Interval Percentage Pollen Diagram

5.5 Fine resolution pollen diagrams at 300m OD

Fine resolution pollen diagrams at the base of each blanket peat profile from the top, middle and bottom of the slope at 300m OD were analysed for vegetation changes before and after blanket peat initiation.

5.5.1 Fine-interval pollen diagram at Lag 300 BOS

Lag300B-1 *Betula*-Poaceae *(c.4720 cal.BP-c.4650 cal.BP)*

Only one zone has been assigned to the basal 10cm at Lag 300 BOS, covering c.70 years. The pollen was analysed every one cm through the basal, well-humified blanket peat. Organic content values through this profile were consistently above 80% and the point of peat initiation has been placed at 173cm, dated to c.4710 cal.BP (dashed line). Figure 5.17 (b) suggest that this profile had a high mass rate but slow vertical growth rates indicating slow rates of decay but greater rates of plant productivity.

Trees dominate the pollen profile with *Betula* and *Alnus* curves fluctuating but remaining high containing over 60% TLP. Overall, *Alnus* levels decline towards the top of the zone whilst *Betula* levels remain relatively constant. *Quercus* is also present, with smaller values being recorded for *Pinus*, *Carpinus* and *Ulmus*. The pollen diagram shows the presence of Poaceae throughout. A peak in herbs such as *Ranunculus*, *Filipendula* and *Urtica* at c.4702 cal.BP, as well as of *Sphagnum* and the appearance of *Pediastrum* suggest conditions were wetter for a short time. Shrubs are present throughout in low numbers (<20% TLP), in particular *Corylus* and *Myrica*, although the latter disappears at c.4685 cal.BP. A peak in values of *Calluna vulgaris* and Poaceae and a decrease in Pteridophyta is recorded at c.4670 cal BP with a corresponding decline in values for *Alnus* and *Betula* and this also correlates with a peak in charcoal (Figure 5.48) at 167cm (c.4671 cal.BP) and the presence of Cerealia grains, suggesting some level of human impact between c.4680 cal.BP and c.4660 cal.BP.

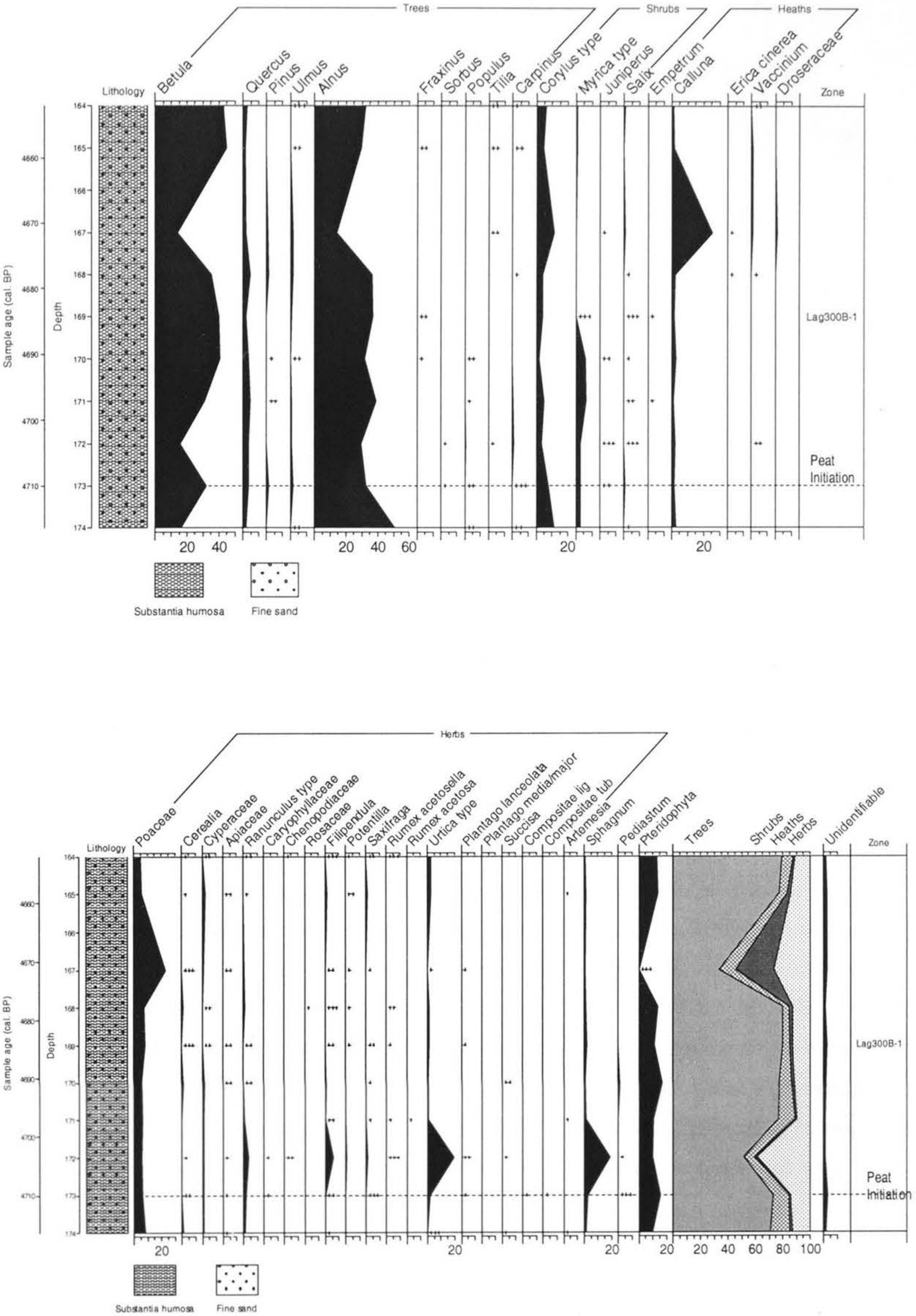


Figure 5.47 Lag 300 BOS Base Fine Interval Percentage Pollen Diagram

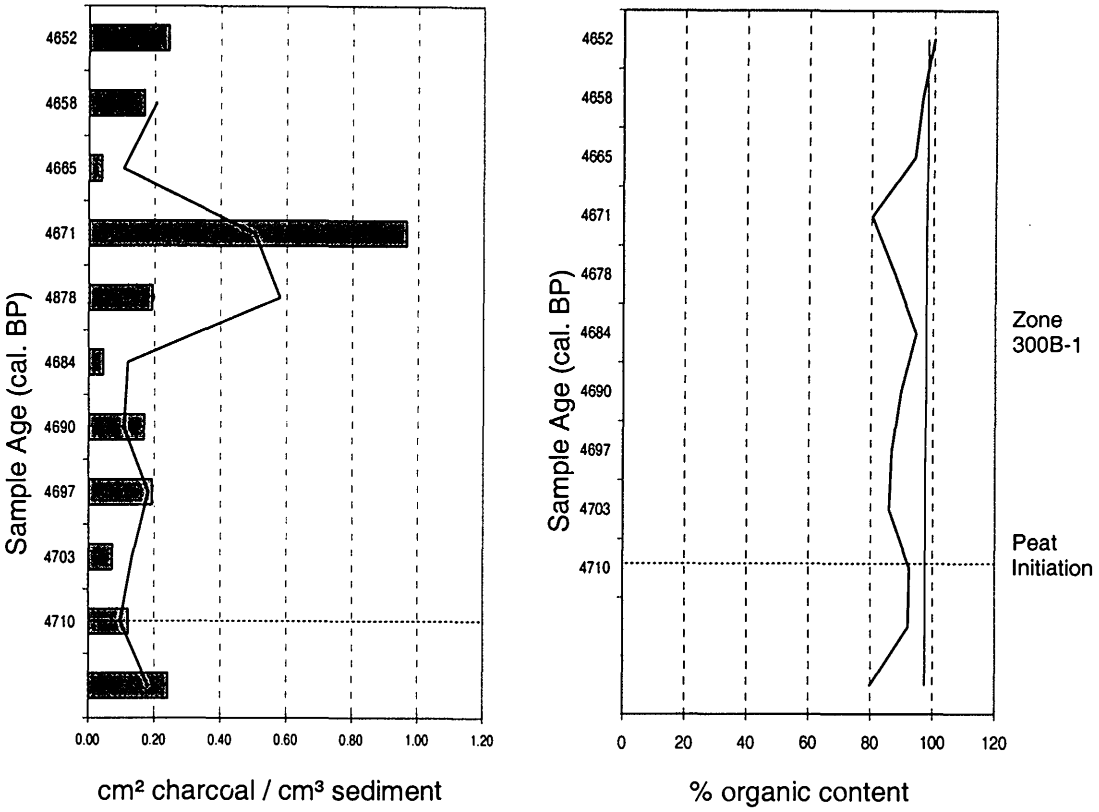


Figure 5.48 Fine interval charcoal analyses of Lag 300 BOS Base

5.5.2 Fine-interval pollen diagram at Lag 300 MOS

Lag 300M-1 Betula-Calluna (pre c.3600 cal.BP)

The fine interval pollen diagram at Lag 300M (Figure 5.50) covers the basal 18cm of the core. Zone 300m-1 covers 1 cm pre c. 3600 cal.BP, a well-humified peat with patches of sand and gravel throughout. *Calluna vulgaris*, *Erica cinerea* and Droseraceae were well established at the base of the diagram, making up almost 40% TLP. *Corylus*, *Myrica* type and *Juniperus* were also present although values fall at the end of the zone and *Betula*, *Quercus*, *Ulmus*, *Alnus* and *Fraxinus* are also represented with values increasing towards the end of this zone, up to 40% TLP. The opening of this pollen sequence therefore appears to be dominated by heaths and trees; very few herbs are present and a peak in Pteridophyta at c.3850 cal.BP suggests acidic soils with ferns and shrubs perhaps competing for open ground or may also suggest differential preservation. No cereals are recorded in this zone.

Lag 300M-2a Calluna-Poaceae (pre c.3600 cal.BP)

Betula and *Quercus* values decrease in this zone whilst values of *Alnus* remain constant at c. 15% TLP. A peak in *Calluna vulgaris* and Droseraceae is recorded at c.3800 cal.BP and there is a gradual increase in values of Poaceae towards the end of the zone.

Lag 300M-2b Betula-Corylus (pre c.3600 cal.BP)

This zone is characterised by an increase in *Betula* which peak at c.3700 cal.BP and a slight increase in values of *Quercus*, *Pinus* and *Ulmus* but a decrease in *Alnus* and a decrease in values for *Calluna vulgaris*. Poaceae levels also fall but other herb species appear in greater numbers (e.g.; Apiaceae, *Ranunculus* type and *Filipendula*), suggesting a more open landscape existed throughout zone 2a but the gradual establishment of *Betula* towards the end of zone 2b was to the detriment of *Calluna vulgaris*. The curve for Pteridophyta shows a decline but values of *Sphagnum* begin to increase.

Lag 300M-3 Alnus-Calluna (c.3700 cal.BP-c.3500 cal.BP)

The zone boundary is defined by the reduction in values of *Betula* and increased levels of *Calluna vulgaris* once more. The effect on tree taxa of decreased *Betula* from the pollen catchment is a slight increase in *Quercus*, *Pinus* and *Ulmus* percentages, and steady but fluctuating levels of *Alnus* and *Fraxinus*. *Corylus* pollen representation appears to decrease slightly but stabilises at around 12-15%TLP whilst other shrub types are also recorded (e.g. *Myrica*, *Salix* and *Juniperus*). Values for *Calluna* increase from approximately 20% TLP to 40% TLP at the end of the zone and other Ericaceae species are also recorded. Blanket peat initiation is placed at 101cm (c.3600 cal.BP). This also coincides with a peak in charcoal at 101cm –100cm dated to c.3600-3560 cal.BP (Figure 5.49). In total, the contribution of woodland taxa decline in relative and absolute values from this point and *Calluna* heath and grassland become well represented, although grazing indicator herbs do not increase. Cerealia grains appear towards the close of this zone (c.3520 cal.BP) along with disturbed ground herbs such as *Artemesia*, *Potentilla* and *Filipendula*, characteristic of crop growth and marking the first signs of human activity in the pollen diagram.

Lag 300M-4a Calluna -Poaceae (c.3500-3390 cal.BP)

Zone 300M-4a (98-95cm) is a less pronounced phase of human activity with a rise in Cyperaceae and *Sphagnum* suggesting increased wet conditions. The appearance of aquatic species, *Typha* and *Potamogeton* support this idea. Values for *Alnus* decrease at the start of the zone but then remain stable at c.10% TLP. Several tree species are no longer represented in this and the proceeding zone, and values for *Betula* and *Quercus* slowly decline along with *Corylus*. An increase in *Calluna vulgaris*, *Erica cinerea* and open grassland herbs (*Filipendula* & *Potentilla*) typify this zone suggesting there is a gradual decline in arboreal pollen and a change to a more open heathland and a flora more typical of acidic, nutrient poor blanket peat. No Cerealia grains were identified in this zone but a small peak in charcoal is recorded at c.3455 cal.BP (97cm) at a phase when *Alnus* declines and Poaceae increases.

Lag 300M-4b Calluna-Poaceae (c.3390-3200cal.BP)

This zone is similar to 300M-4a with *Calluna vulgaris* continuing to increase at the demise of *Corylus* and *Betula*. Open ground herbs also increase, Poaceae levels stabilise and together account for 30% TLP and *Sphagnum* increases, indicative of continued wet conditions. Two minor charcoal peaks are recognised in zone 300M-4 at 97cm (3455 cal.BP) and 91cm (3169 cal.BP) and the latter coincides with the appearance of Cerealia grains and increased values of *Plantago lanceolata*, suggesting renewed anthropogenic activity in the local area.

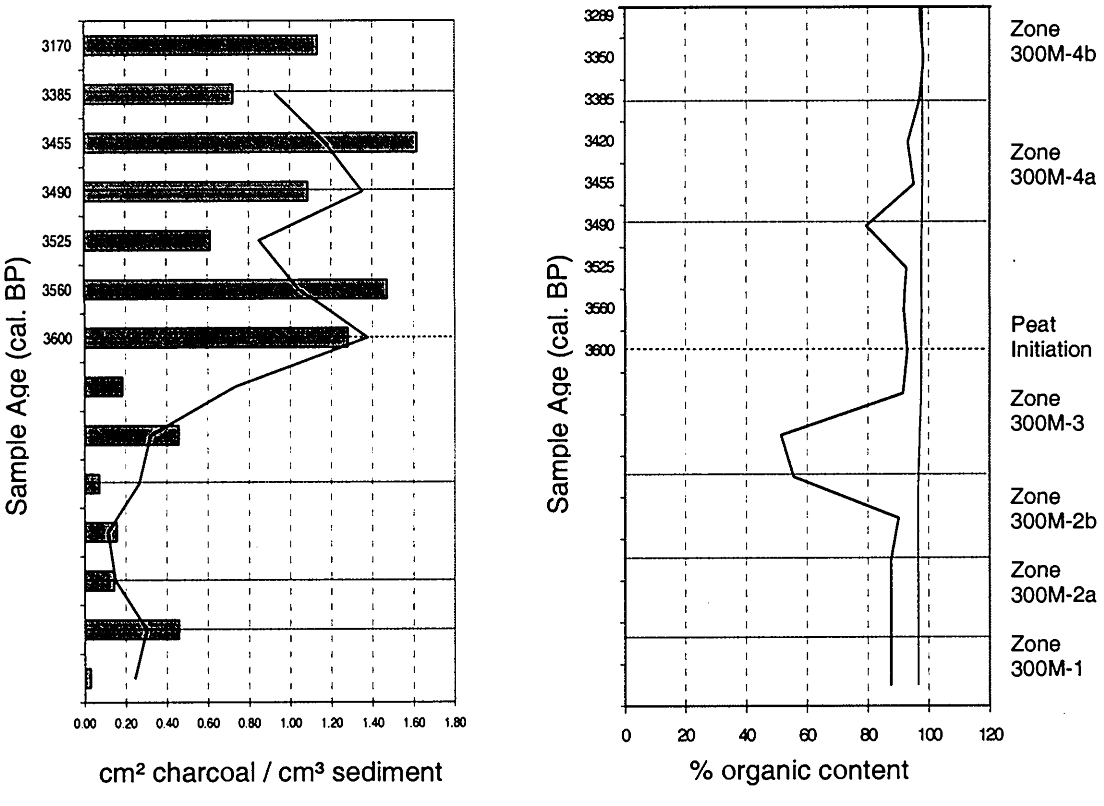


Figure 5.49 Fine interval charcoal analyses of Lag 300 MOS Base

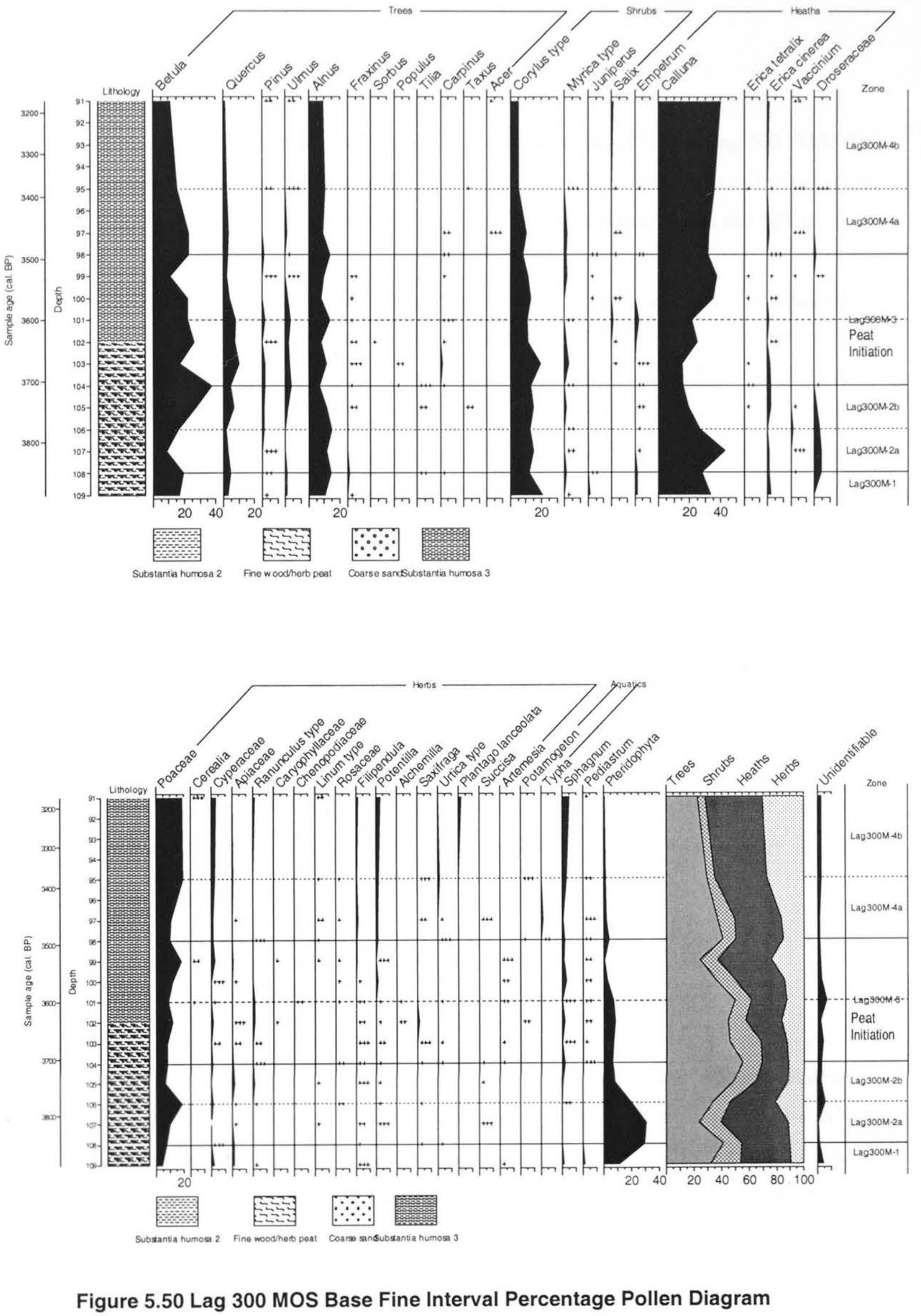


Figure 5.50 Lag 300 MOS Base Fine Interval Percentage Pollen Diagram

5.5.3 Fine-interval pollen diagram at Lag 300 TOS

Lag 300T-1 Calluna -Corylus (pre c.6135 cal. BP)

The fine interval pollen diagram (Figure 5.52) covers the basal 7cm of Lag 300 TOS. The sediment consists of a compact, well-humified peat with substantial sand and minerogenic particles; Figure 5.25 shows low organic content values between 121cm and 125cm.

The earliest zone at Lag 300 TOS sees a predominance of heaths, in particular *Calluna vulgaris*, *Vaccinium* and Droseraceae, making up over 50% TLP. *Corylus* values are also high whilst Poaceae levels and other herbs remain low. Some woodland is present within the landscape with values of *Alnus* slowly rising towards the end of the zone and *Betula*, *Quercus*, *Pinus*, *Carpinus* and *Ulmus* are also recorded but at low levels. Pteridophyta are consistently present throughout this zone but make up <5% TLP. The opening of this pollen sequence therefore appears to be dominated by heaths and shrubs; very few herbs are present and suggest acidic soils with ferns and shrubs perhaps competing for open ground. No cereals are recorded in this zone.

A decline in heathland species is later recorded and this is mirrored by an increase in Poaceae and the presence of more open grassland species such as *Filipendula*, *Saxifraga* and *Succisa*. Local woodland appears to remain stable with arboreal pollen making up only 20% TLP, and *Corylus* values also remain constant throughout this zone. Grassland species appear to be competing with heathland species with the latter declining towards the end of the zone.

Lag 300T-2 Calluna-Betula (pre c.6135 cal.BP)

Values of Poaceae and other herbs continue to rise at the start of this zone, with a greater variety of species being recorded, in particular Apiaceae, *Ranunculus,* Chenopodiaceae, *Filipendula* and *Potentilla*, particularly towards the end of the zone. This increase in herbs is marked by a continued decrease in values for heaths, in particular *Calluna vulgaris*. At c.6180 cal.BP however, levels of Poaceae fall although other herbs typical of disturbed ground persist and there is an increase in *Calluna vulgaris* and *Vaccinium.* Values for *Corylus* type also decrease at this point. Woodland species remain relatively stable through this zone with a slight increase in values for *Betula*, *Quercus* and *Ulmus* and a greater number of arboreal species appear for the first time including *Tilia* and *Fraxinus*. It is possible that this period through the mineral soil coincides with the first appearance of anthropogenic activity where shrubs and open grassland areas have been cultivated for the first time although microscopic charcoal is recorded only at low levels during this phase.

Lag 300T-3 Betula-Poaceae (c.6140cal.BP-6000cal.BP)

This zone is characterised by an increase in arboreal pollen with a rise in values for *Betula* and *Alnus*, and consistent levels of *Quercus*, *Pinus* and *Ulmus*. *Corylus* values continue to decline and the opening of the zone sees an increase in *Calluna* and *Vaccinium*, whilst Poaceae continues to decrease. At c.6080 cal.BP, *Calluna* values begin to decline once more and are replaced by higher percentages of Poaceae. No Cerealia grains were identified through this zone. A peak in charcoal appears at 118cm (c.5954 cal.BP) at the very top of this zone.

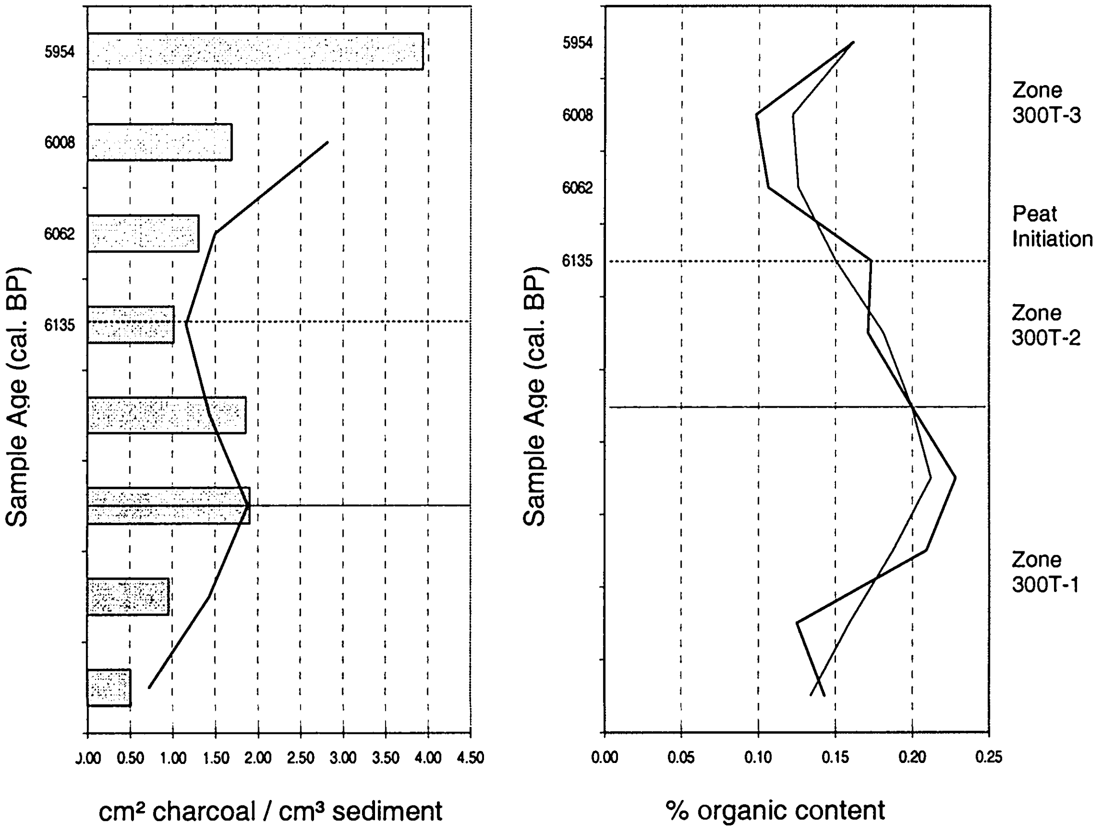
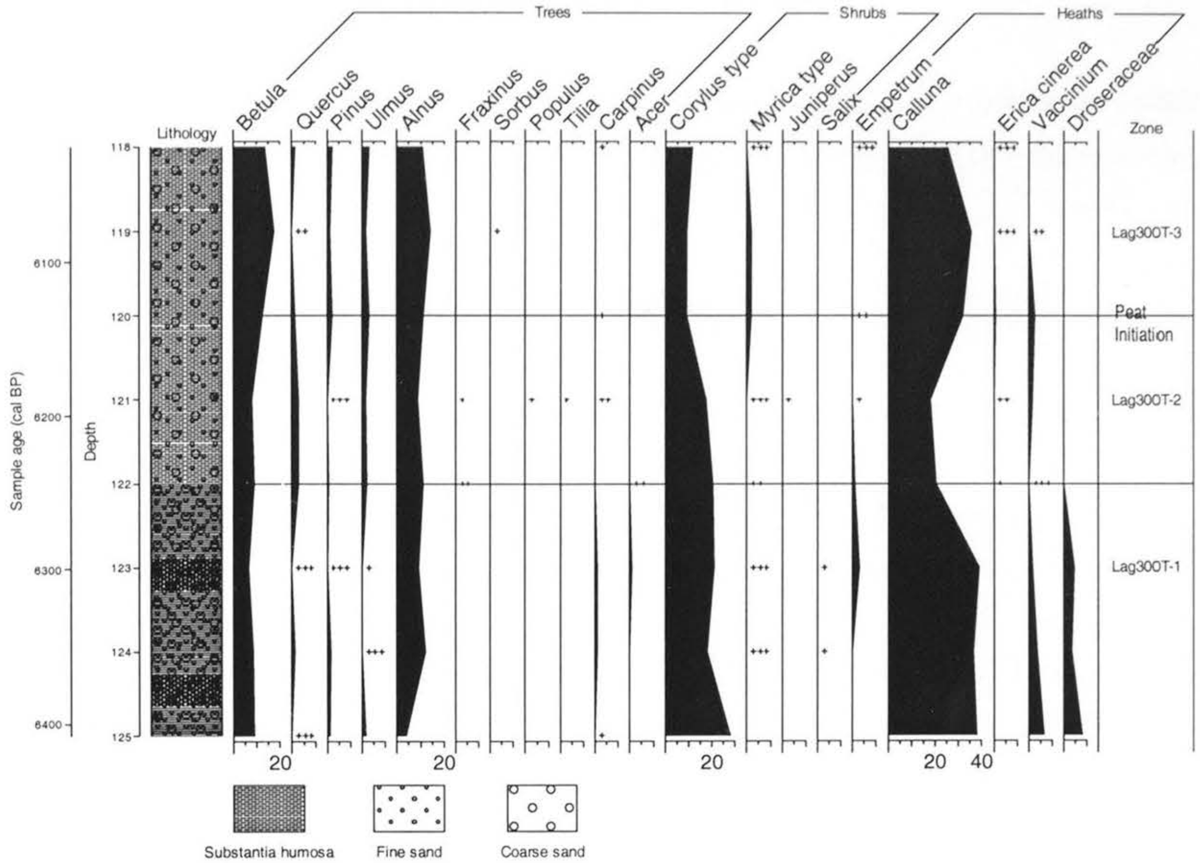


Figure 5.51 Fine interval charcoal analyses of Lag 300 TOS Base



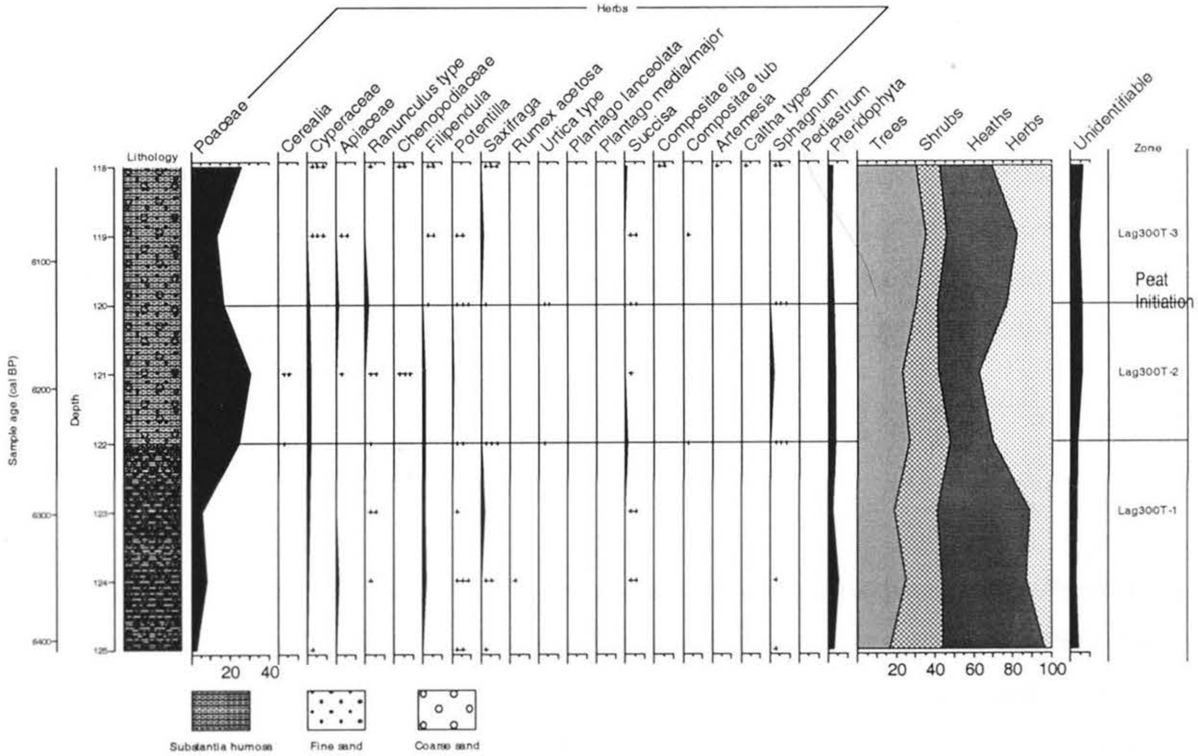


Figure 5.52 Lag 300 TOS Base Fine Interval Percentage Pollen Diagram

5.6 *Fine resolution pollen diagrams at 400m OD*

Fine resolution pollen diagrams at the base of each blanket peat profile from the top, middle and bottom of the slope at 400m OD were analysed for vegetation changes before and after blanket peat initiation.

5.6.1 Fine-interval pollen diagram at Lag 400 BOS

Lag400B-1 Corylus–Pinus (pre c.4935 cal.BP)

The fine interval pollen diagram at Lag 400BOS (Figure 5.54) covers the basal 21cm through the peat core and encompasses the transition through a possible early soil into true blanket peat. Figure 5.31 shows the change from an inorganic soil to an organic peat at c.4935 cal.BP, the point of peat initiation. The opening zone shows a high level of Pteridophyta and increasing levels of *Sphagnum. Corylus*, *Myrica* and *Salix* together comprise approximately 30% TLP. Several other woodland species are recorded, though at relatively low values; these include increasing values of *Betula* and gradually decreasing values of *Quercus, Pinus* and *Alnus.* Several open-ground herbs are also present with high values of Apiaceae, *Rumex acetosella* and Poaceae and low levels of heath species; in particular *Empetrum* and *Calluna* are recorded but contribute less then 10% TLP. The opening sequence suggests the landscape was possibly open prior to the development of blanket peat although interpretation through the minerogenic sequence is difficult with differential preservation of certain pollen grains and the redeposition of material and the pollen record (see section 4.6.8.3). Shrubs and herbs however, appear to dominate the flora with patches of trees, suited to upland areas (e.g. *Pinus*), and *Calluna*, confined to drier ground and the latter, to peaty hollows. Only low levels of charcoal are recorded during this phase.

Lag 400B-2a Corylus–Cyperaceae (pre c.4935 cal. BP)

Prior to the onset of blanket peat, *Corylus* and *Myrica* appear to replace *Alnus*, *Pinus* and *Quercus* in the pollen diagram, although values for *Betula* remain constant and there is a slight increase in *Pinus*. Cyperaceae and *Sphagnum* also peak at this point and fewer herbs are recorded with decreased values for *Rumex acetosella,* Apiaceae and Poaceae as well as

Calluna. This zone marks a period of increased waterlogged conditions with increased levels of Cyperaceae and *Sphagnum* as well as increased levels of Pteridophyta.

Lag400B-2b Corylus–Sphagnum (pre c.4935 cal. BP)

Lag 400B-2b appears to represent an overall decline in tree species with values for *Alnus* falling, and a slight increase in herbs with values for *Rumex acetosella, Urtica* and Apiaceae increasing while values for Poaceae remain relatively low but constant, suggesting conditions became progressively more open. Values for *Corylus* type increase once more following a small decline at the end of the previous zone and values for *Sphagnum* peak at c.5331 cal.BP and levels of Pteridophyta reach a maximum during the same period, perhaps as a result of fewer trees and increased waterlogged conditions. Levels of heaths remain relatively low but constant at <10% TLP.

Lag 400B-3 Alnus-Corylus (pre c.4935 cal. BP)

This zone is distinguished by the recovery and increased values of woodland species, in particular increased values of *Alnus*, *Pinus* and *Betula* which make up 40% TLP towards the end of the zone. There is also a marked decrease in *Sphagnum* and Pteridophyta, although the latter increases briefly at c.5194 cal.BP and values for *Corylus* type also decrease as woodland types compete. The area of open-ground appears to decrease slightly and initially waterlogged hollows and basins appear to have been slowly infilling and drying out as more species colonise. Values for heaths remain low but consistent and there is a slight decrease in values for herbs, in particular *Rumex acetosella* and Poaceae. A small peak in charcoal is also recorded within this zone between c.5194 and 5161 cal.BP but is recorded only at low levels. Few anthropogenic indicators are recorded at Lag 400 BOS base and it is likely that these low levels of charcoal represent activities elsewhere in the landscape.

Lag 400B-4 Alnus–Ulmus (pre c.4935 cal.BP)

Levels of Pteridophyta and *Sphagnum* continue to decrease in zone 400B-4 whilst trees continue to increase; in particular values for *Alnus, Ulmus, Quercus* and *Betula* fluctuate but slowly increase representing 50% TLP. *Calluna, Myrica, Juniperus, Salix* and *Ilex* are also recorded but levels of *Corylus* type slowly decrease through the zone. Similarly, values for herbs fluctuate with a slight increase in Poaceae, Apiaceae, and *Saxifraga.*

Lag 400B-5 Betula / Alnus – Poaceae (pre c.4935 – c.4862 cal.BP)

Blanket peat initiation is placed at c.4935 cal.BP within this zone and is represented by a dashed line. Trees remain present within the Lagafater landscape with greater values of *Quercus* and *Ulmus* being recorded at c.4935 cal.BP although values do fall slightly towards the end of the zone. A marked increase in herbs is recorded with values of Poaceae increasing along with *Ranunculus type, Saxifraga, Urtica* and *Compositae*. *Corylus* values also fall and levels of heaths, in particular *Calluna* type also decrease. Values of Pteridophyta continue to decrease and for a period of c.300 years, woodland appears to have been relatively stable with a slight reduction in cover being recorded towards the close of the zone. This also correlates with a rise in charcoal concentrations between c.4930 cal.BP-c.4862 cal.BP.

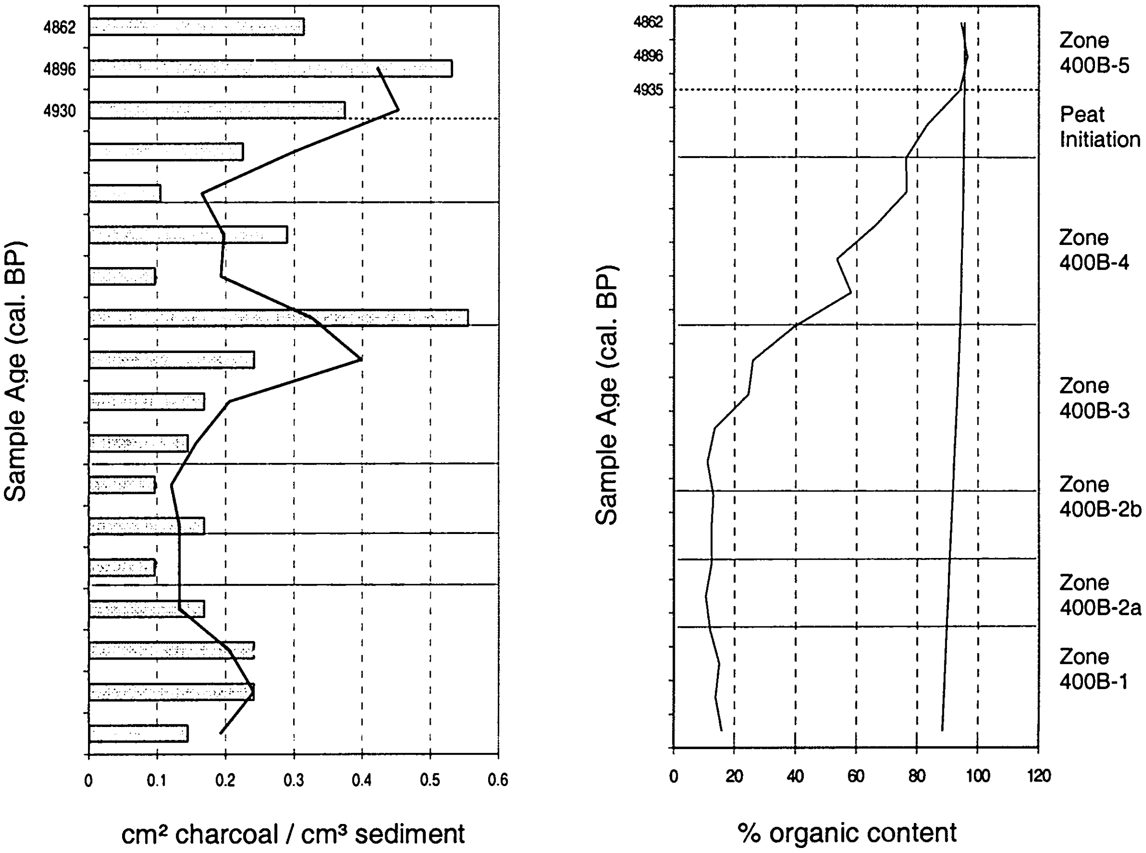


Figure 5.53: Fine interval charcoal analyses of Lag 400 BOS Base

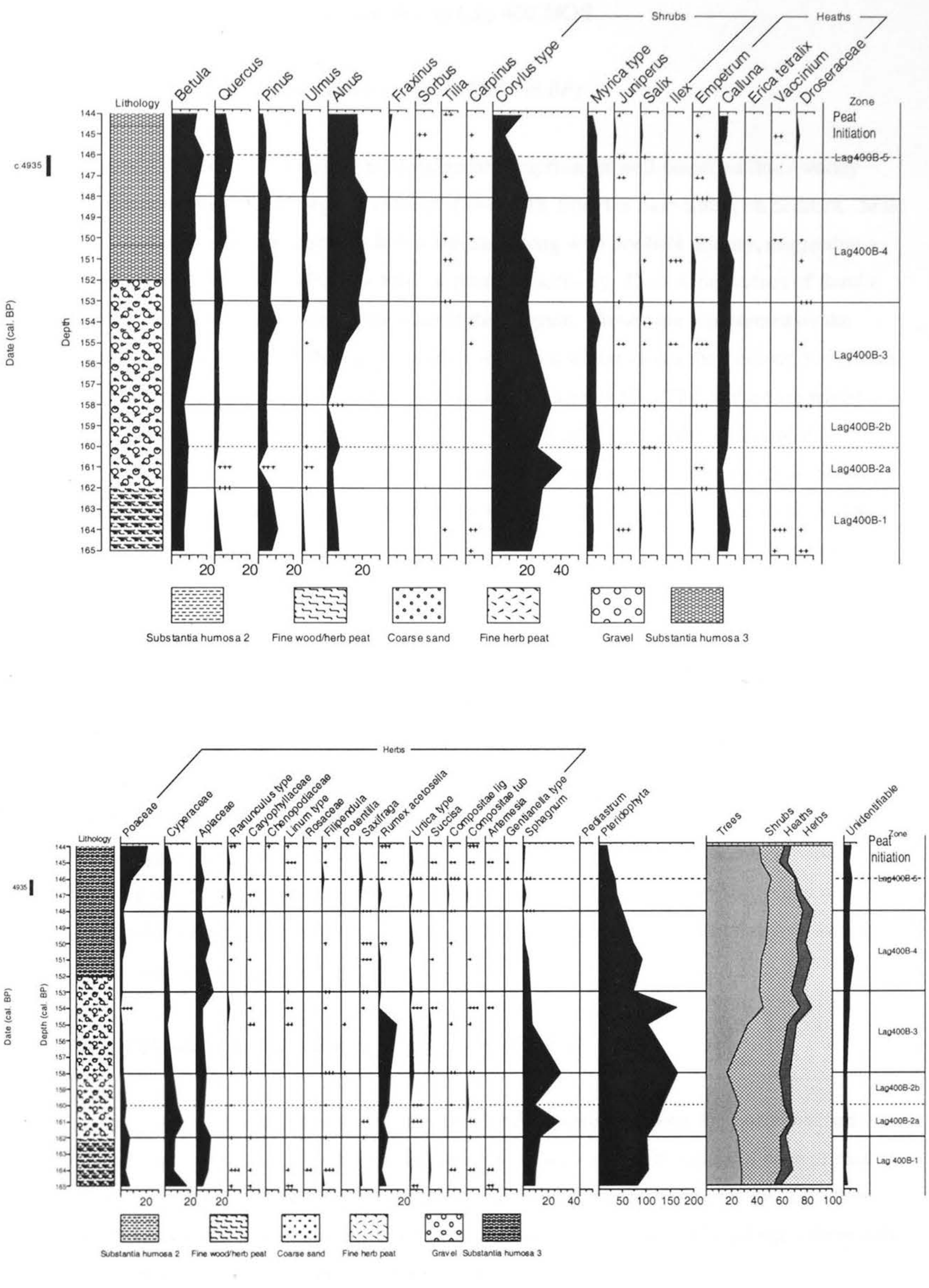


Figure 5.54 Lag 400 BOS Base Fine Interval Percentage Pollen Diagram

5.6.2 Fine-interval pollen diagram at Lag 400 MOS

Lag 400M-1 Poaceae–Calluna (c.4620-4280 cal.BP)

Figure 5.35 shows the basal 15cm of sediment comprising a well-humified fine / woody herbaceous peat with an organic content of over 80% from the base sitting on bedrock. Mass accumulation rates are relatively low at the base along with dry bulk density, suggesting a high level of compaction but low level of plant productivity. Decreasing values of *Betula*, *Alnus* and *Pinus* are recorded at the base of the diagram. Shrubs are represented by the presence of *Corylus* and *Myrica* but levels remain low whilst values for *Calluna*, *Vaccinium* and Droseraceae appear to increase. Herbs comprise almost 40% TLP at the base whilst *Sphagnum* and Pteridophyta values are very low as blanket peat is already established. Cerealia grains are also recorded at c.4620 cal.BP, suggesting some anthropogenic activity within the landscape during this period. Blanket peat encroached onto the middle of slope when a predominantly open landscape dominated with some early heath development. Blanket peat initiation is placed at c.4620 cal.BP within this zone.

An increase in the types and numbers of herbs, in particular, Cyperaceae, Apiaceae, *Ranunculus* type, *Filipendula, Potentilla* and *Urtica* is recorded towards the close of this zone suggesting a species-rich grassland developed along side the growth of cereals. A low number of shrubs, in particular *Corylus* type, allowed for the expansion of *Betula* and *Alnus* during this phase, and the presence of several other arboreal pollen types are recorded including *Pinus, Ulmus, Fraxinus, Tilia* and *Acer* indicating localised patches of woodland and a greater windblown component. *Calluna* values begin to rise towards the end of this zone whilst *Poaceae* levels decrease and a peak in *Cyperaceae* suggests relatively damp conditions were experienced.

Lag400M-2a Calluna-Betula–Alnus (c.4280-4000 cal. BP)

An expansion of heathland species, in particular *Empetrum, Calluna, Erica cinerea* and *Vaccinium* is recorded at c.4180 cal.BP and this impacts on the frequency of open ground herbs as levels fall at this point. Throughout this zone however, herbs recover and values *Calluna* type fall and a number of rich grassland species are recorded including, *Filipendula* and *Potentilla.* No cereal grains were recorded in this zone.

Lag 400M-2b Calluna–Betula (c.4000-3720cal.BP)

Empetrum and *Calluna vulgaris* increase to 40% TLP before declining slightly at the end of this zone. *Betula* values increase while levels of *Ulmus* and *Alnus* fall. Poaceae levels also decrease but grassland communities were maintained and *Plantago lanceolata* is recorded, found in open grassland or under light shade within local *Betula* stands. A small peak in *Myrica* is recorded at c.3800cal.BP whilst levels of *Empetrum* decline at the close of this zone. No cereal pollen grains were recorded although levels of charcoal begin to increase within this zone (see Figure 5.55) possibly signifying a level of human activity across the landscape. Towards the close of this zone, *Sphagnum* increases and shrubs play only a small part in the TLP.

Lag 400M-3 Calluna–Betula (c.3720-3382cal.BP)

The contribution of woodland taxa declines slightly as *Calluna* heathland and grassland become better represented although *Empetrum* declines. A slight decrease in values of Poaceae is replaced by increased levels of *Ranunculus,* Apiaceae and *Filipendula.* Low but consistent levels of *Corylus* and *Myrica* are recorded. A large peak in charcoal is recorded at c.3382cal.BP at the top of this diagram.

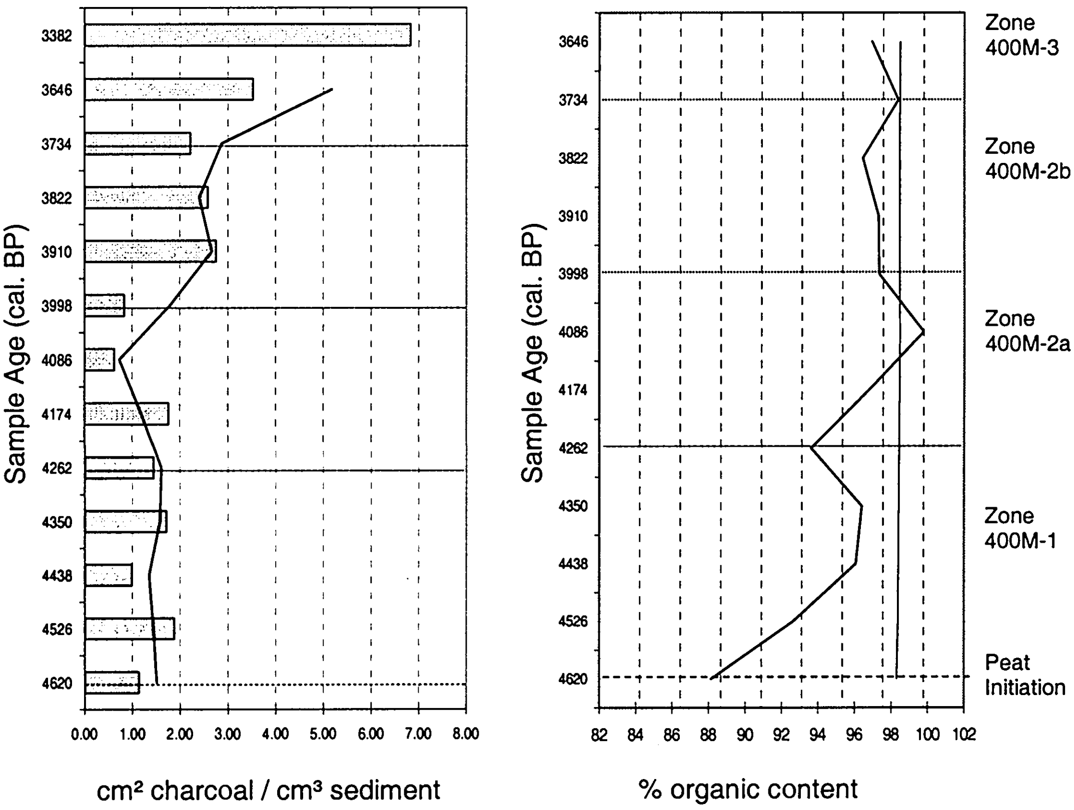


Figure 5.55 Fine interval charcoal analyses of Lag 400 MOS Base

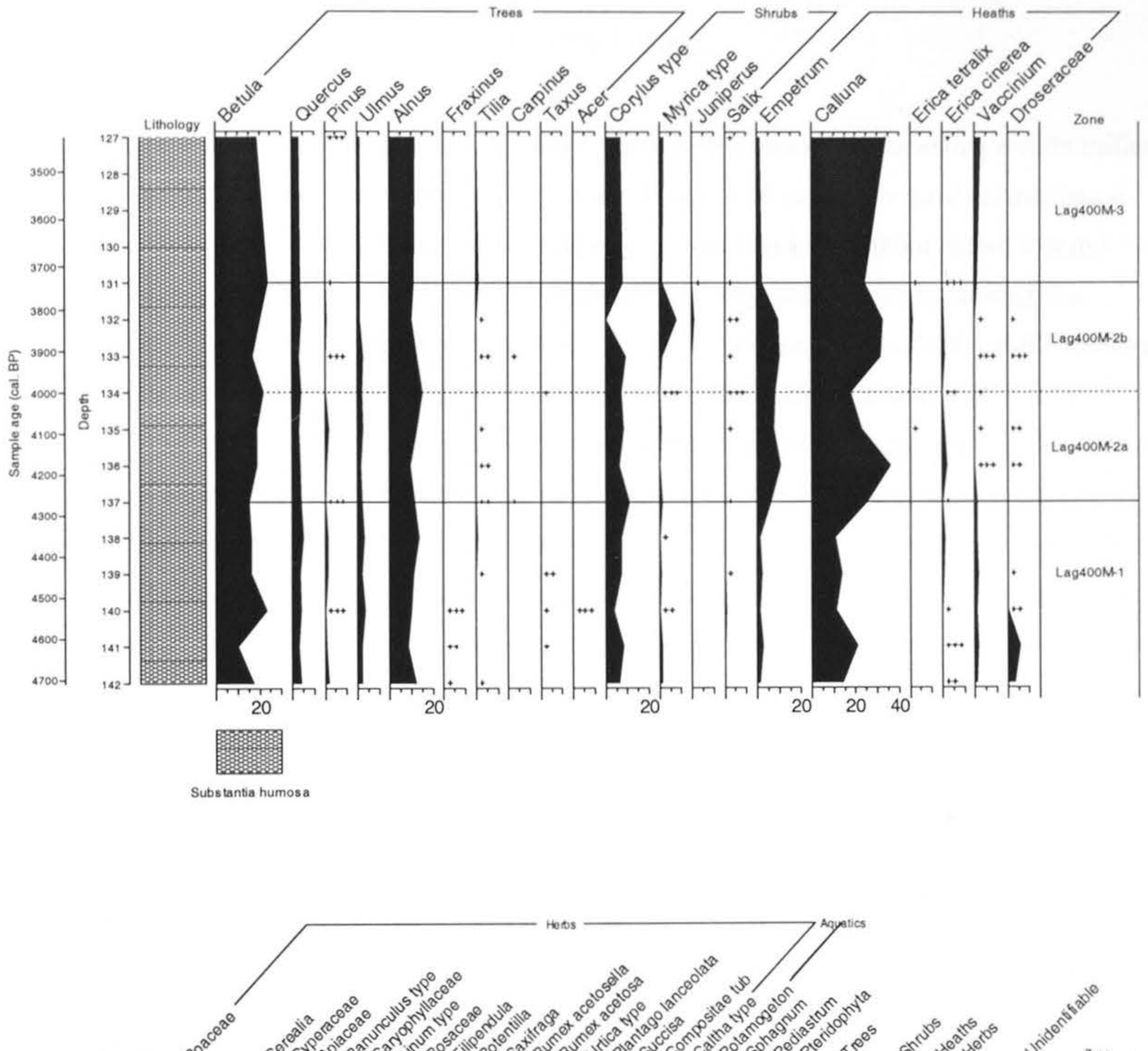


Figure 5.56 Lag 400 MOS Base Fine Interval Percentage Pollen Diagram

5.6.3 Fine-interval pollen diagram at Lag 400 TOS

Lag400T-1 Alnus–Calluna (c.5476-5280cal.BP)

The basal sequence through Lag 400 TOS (Figure 5.58) covers 9cm through a well-humified peat with occasional sand particles throughout. Figure 5.38 suggest vertical accumulation rates through the basal sequence were relatively slow (224years / cm) but record low dry bulk density readings, suggesting a very high rate of decay and compaction during this period. The opening pollen zone, Lag 400T-1, from c.5476 cal.BP to c.5280 cal.BP shows a decline in the percentage of trees, in particular *Alnus*, *Betula* and *Pinus* from 80% TLP to 20% TLP at the end of the zone as well as decreasing numbers of Pteridophyta pollen grains. These are replaced in the pollen record by increasing values of *Calluna vulgaris* and *Empetrum* as heathland developed at Lag 400 TOS. Low percentages of herbs are recorded whilst *Corylus* and *Myrica* values increase slightly but remain stable throughout the pollen sequence at 15% TLP. Increasing values of *Sphagnum* also suggest that conditions were wet.

Lag400T-2 Calluna–Poaceae (c.5280-3500cal.BP)

The pollen sequence over the following c.1780 years BP remains relatively stable. Heathland species fluctuate but continue to dominate the record whilst *Alnus*, *Quercus, Ulmus* and *Betula* values remain lower then the previous zone but fluctuate very little, making up 15-20% TLP. An increase in grassland herbs is recorded with values of Poaceae and Cyperaceae in particular, rising. A number of cereal gains are recorded at c.4800 cal.BP and from c.4400 cal.BP. Their appearance is also marked by increased values of grassland, cereal weeds and disturbed ground taxa including *Plantago lanceolata, Rumex acetosella, Ranunculus, Linum* type and *Saxifraga.* A peak in charcoal (see Figure 5.57) is similarly recorded at c.4600 cal.BP.

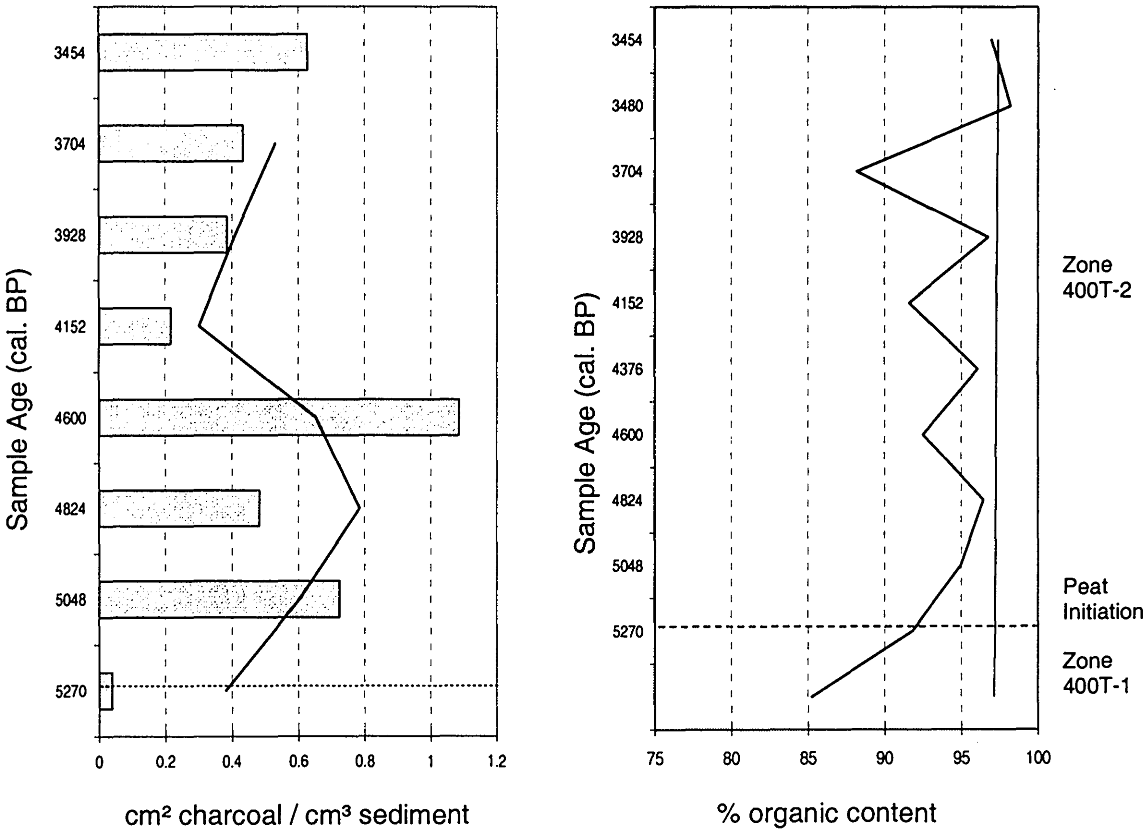


Figure 5.57 Fine interval charcoal analyses of Lag 400 TOS Base

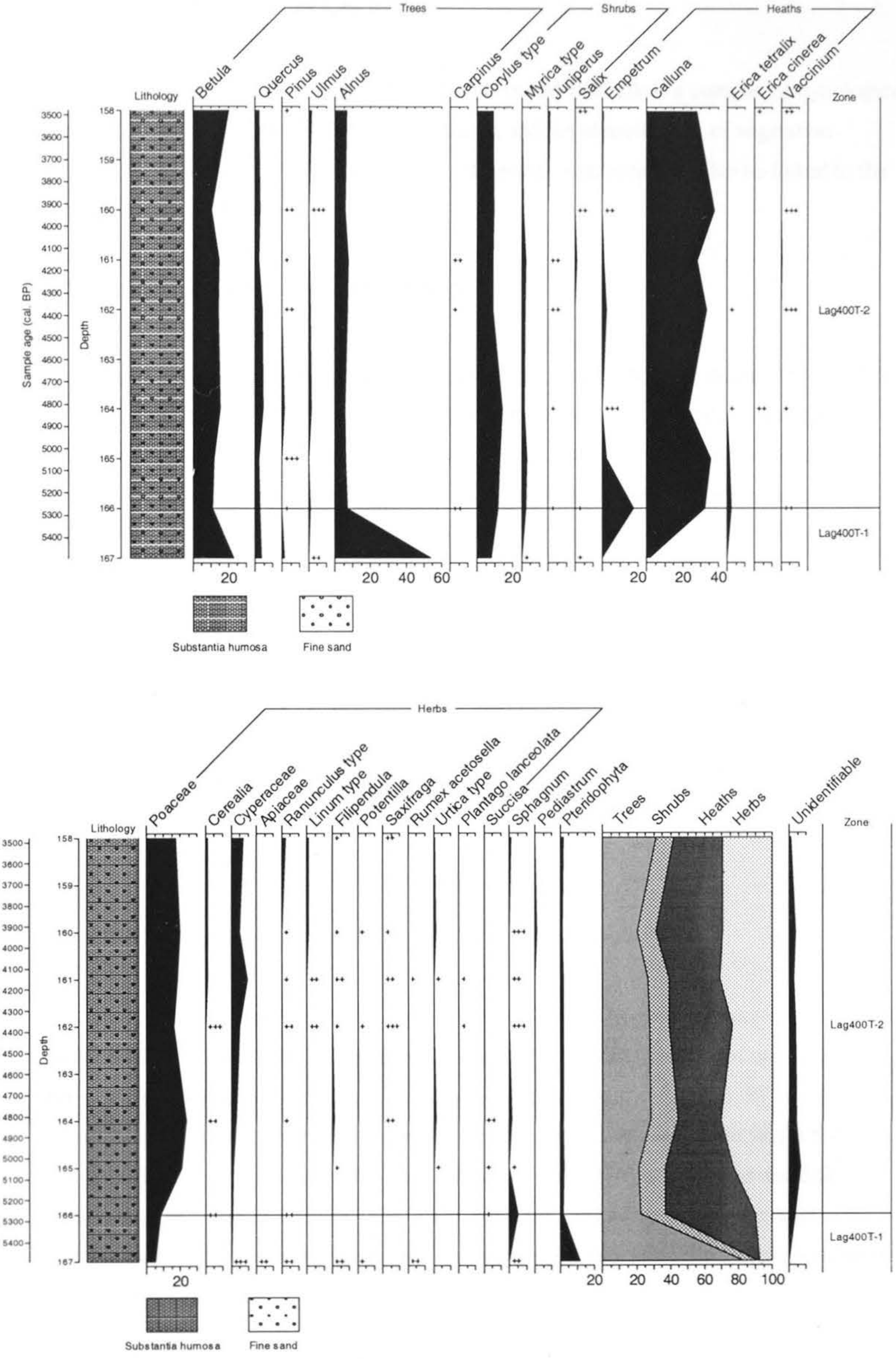


Figure 5.58 Lag 400 TOS Base Fine Interval Percentage Pollen Diagram

5.7 Pollen diagrams at Lag 230m

The full pollen profiles from Lag 230m BOS, MOS and TOS allow a complete palynological analysis of the last c.6000 yrs BP to be produced, and the identification of vegetation changes on the slope. Significant changes in the pollen sequence may also be linked to the local archaeological record.

5.7.1 Pollen diagram at Lag 230m BOS

The earliest pollen zones through the basal profile of Lag 230 BOS are discussed in section 5.4 and cover the period from c.5200 cal. BP to c.4542 cal. BP. The following section therefore begins with a discussion of the pollen record from c.4542 cal. BP to the present day. The pollen diagram has been split over two pages at the end of each section for ease of use.

Lag 230B-3a Betula-Poaceae (c.4542-4218 cal. BP)

Towards the close of the previous zone, values of *Pediastrum* and *Sphagnum* begin to rise. This pattern is continued in this zone, with a reduction in the variety and number of herbs and shrubs but a slight increase in Poaceae and *Filipendula*. This subzone is distinguished primarily on the basis of a rise in *Betula* values at c.4470 cal. BP before a marked decline, and a rise in *Alnus* and *Quercus*.

Lag 230B-3b Betula-Poaceae-Sphagnum (c.4218-3841 cal. BP)

The zone boundary is defined by the rise of *Sphagnum* and Cyperaceae, suggesting increased wet conditions. Values of Poaceae also rise along with a greater number of open ground herbs, including *Potentilla* and *Urtica*. Values of *Betula* rise at c.4017 cal. BP, displacing *Alnus*, before declining towards the close of the zone. A gradual decline in values for *Quercus* and *Ulmus* is similarly recorded, whilst *Corylus, Myrica, Juniperus* and *Salix* remain relatively stable at c.10% TLP. Zone 3 is distinguished by the first increase in *Calluna* and a reduction in the number of Cerealia grains, indicating more open, wet, heath conditions with reduced human activity.

Lag 230B-4 Poaceae-Betula-Calluna (c.3841 cal. BP-c.3378 cal. BP)

The development of an open grassland in which Poaceae, Apiaceae, Chenopodiaceae, *Filipendula* and *Plantago lanceolata* are all recorded, begins in Zone 4 after c.3841 cal. BP with herbs contributing c.50% TLP. A slight increase in *Calluna* and *Empetrum* levels are recorded, whilst values of *Corylus*, *Myrica, Juniperus* and *Salix* remain stable but contribute <20 % TLP. Within this zone there is an overall decrease in the number of trees present within the landscape. In particular, *Betula, Quercus* and *Alnus* all decline.

Lag 230B-5 Alnus-Calluna (c.3378 cal. BP- c.2205 cal.BP)

This zone is distinguished by the distinct and important increase in the number and variety of herb-rich grassland species, in which Poaceae, Cyperaceae, Apiaceae, *Ranunculus,* Chenopodiaceae, *Filipendula, Saxifraga* and *Plantago lanceolata* were important. This is accompanied by a rise in values of Cerealia indicating renewed agricultural and anthropogenic activity in the local area. The *Betula* curve fluctuates but continues to decline through the zone, whilst a peak in *Alnus* values is recorded at c.2777 cal. BP before levels also fall. Shrubs remain stable at c.10% TLP whilst a greater variety of heath species are recorded. Following an initial decline in levels of *Calluna* at the start of the zone, values increase markedly at c.2543 cal. BP, coinciding with a small peak in *Sphagnum* and *Cyperaceae* indicating the still damp nature of the local landscape as shown also by the peat itself.

Lag 230B-6 Calluna–Poaceae-Filipendula (c.2205 cal. BP-1483 cal. BP)

The expansion of heathland, in particular *Empetrum*, *Calluna, Erica tetralix* and Droseraceae, is recorded in this zone with a corresponding decline in values of trees, particularly at c.1481 cal. BP. *Betula, Quercus* and *Alnus* are all reduced and there is a slight fall in values of *Corylus* and *Myrica* type. In contrast, the *Poaceae* curve increases and peaks at c.1900 cal. BP, along with levels of *Filipendula*, Apiaceae, *Urtica* and the continued presence of *Plantago lanceolata* and *Plantago media / major*. The absence of Cerealia grains, however, perhaps suggests continued agricultural activity in the form of grazing but little or no arable agriculture occurred as the landscape became dominated by heather and blanket peat continued to develop.

Lag 230B-7a Calluna – Poaceae (c.1483 cal. BP-c.881 cal. BP).

The zone boundary is defined by an increase in *Sphagnum*, Cyperaceae and Pteridophyta. *Calluna* and *Empetrum* decline slightly within this zone at c.1204 cal. BP, before recovering and increasing in values once more. Heathland and herbs continue to dominate the pollen diagram whilst there is a decline in *Betula, Alnus*, and *Corylus* with trees and shrubs contributing only 20% TLP. A peak in Poaceae levels is recorded at c.1182 cal. BP before values decline, and the continued presence of taxa indicative of grassland / pasture, including Apiaceae, *Ranunculus, Filipendula* and *Plantago lanceolata,* are well represented. Cerealia pollen grains were also identified, suggesting renewed arable activity during this period.

Lag 230B-7b Calluna- Cyperaceae (c.881 cal. BP-0 BP)

The upper 42cm of Lag 230B typify a wet, open, heathland environment with an almost total absence of tree species, with the exception of small stands of *Alnus* and the more recent inclusion of *Pinus* pollen from modern plantations. Shrub species also disappear and are replaced by a dominance of *Empetrum, Calluna* and *Erica cinerea* making up 80% TLP. Higher values of Cyperaceae and *Pediastrum* suggest wet peaty ground with some standing water: an increase in these at 25cm possibly marks the acrotelm / catotelm boundary and this corresponds well with the bulk density data (Figure 5.4). Within the *Calluna* stands, some Poaceae and open herbs also exist, and the presence of *Plantago sp.* and some Cerealia pollen grains (e.g. *Hordeum Vulgare*) indicates continued agricultural activity.

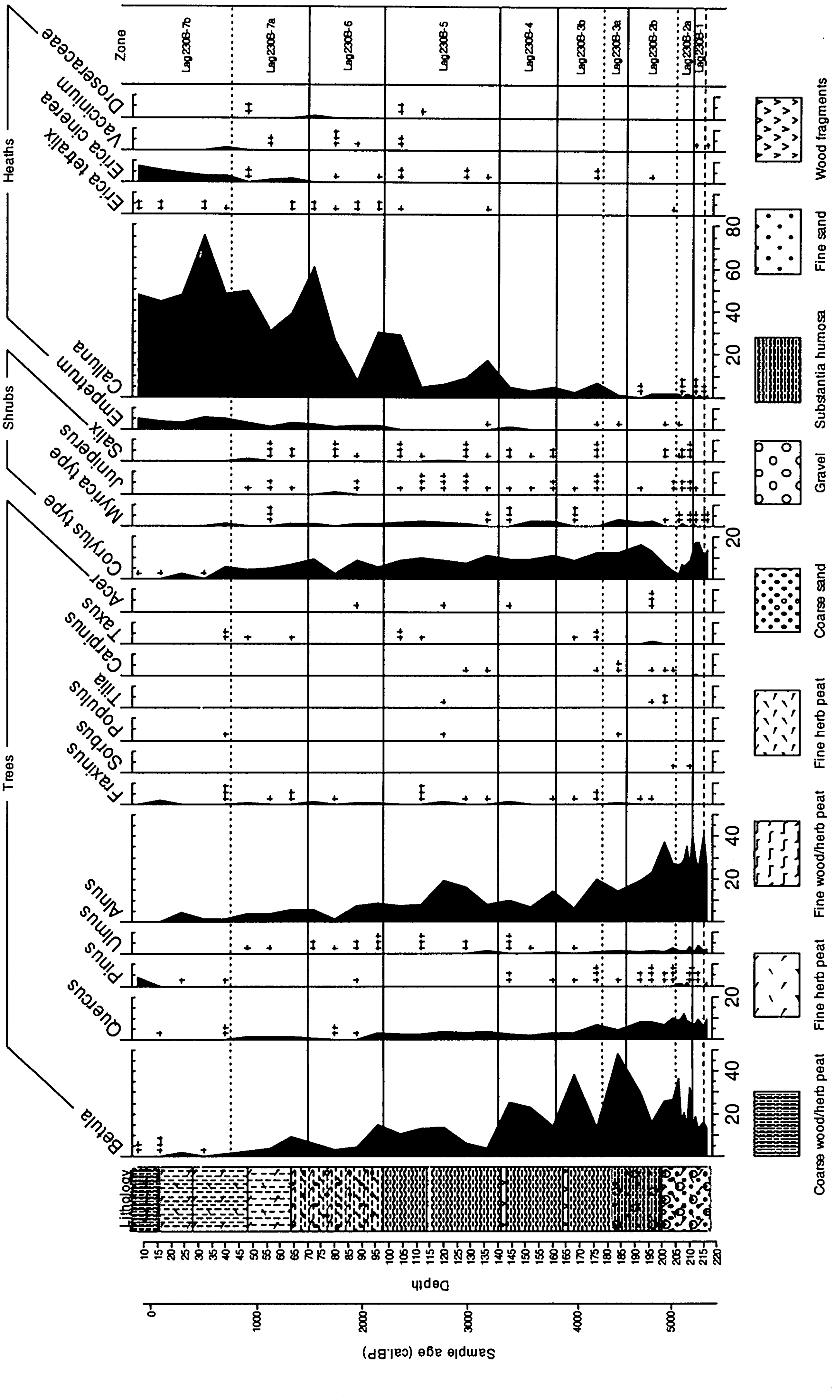
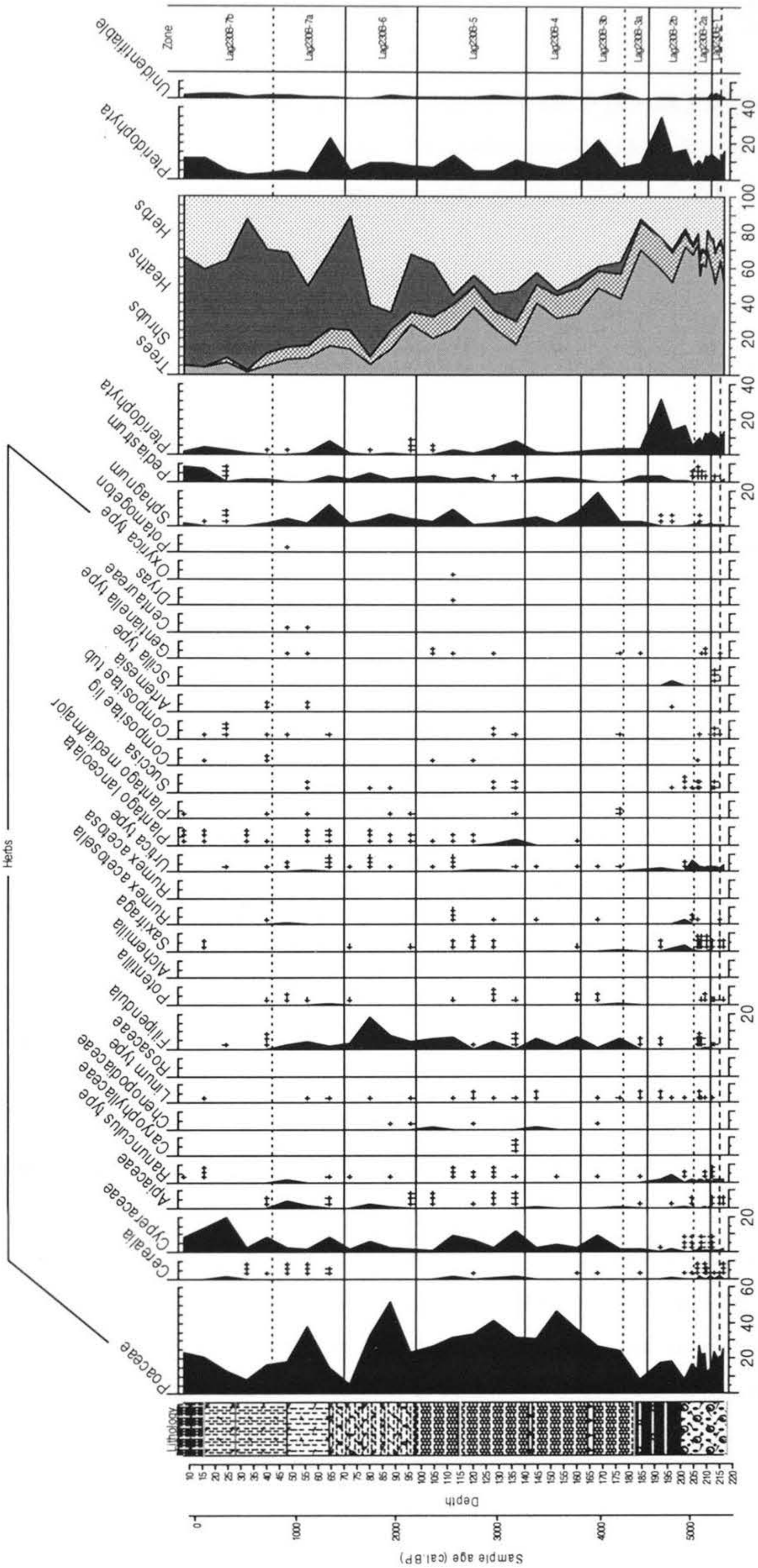


Figure 5.59: Lag 230 BOS Pollen Percentage Diagram


Sample age (cal.B.P)
Depth
Lithology
Herbs
Poaceae
Cerealia
Cyperaceae
Apiaceae
Ranunculus type
Caryophyllaceae
Chenopodiaceae
Linum type
Rosaceae
Filipendula
Potentilla
Alchemilla
Saxifraga
Rumex acetosella
Rumex acetosa
Urtica type
Plantago lanceolata
Plantago media/major
Succisa
Compositae lig
Compositae tub
Artemesia
Scilla type
Gentianella type
Centaurea
Dryas
Oxyrica type
Potamogeton
Sphagnum
Pediastrum
Pteridophyta
Trees
Shrubs
Heaths
Herbs
Pteridophyta
Unidentifiable
Zone
Lag2008-7b
Lag2008-7a
Lag2008-6
Lag2008-5
Lag2008-4
Lag2008-3b
Lag2008-3a
Lag2008-2b
Lag2008-2a
Coarse wood/herb peat
Fine herb peat
Fine wood/herb peat
Fine herb peat
Coarse sand
Gravel
Substantia humosa
Fine sand
Wood fragments

5.7.2 Pollen diagram at Lag 230m MOS

The pollen sequence through the basal layers of Lag 230 MOS is presented in section 5.4.2. Analysis through Lag 230M-3a began in the fine resolution pollen diagram but its full pollen record is presented here, spanning a greater period of time (to c.2459 cal. BP).

Lag 230M-3a Calluna-Poaceae (c.3967-2459 cal. BP)

This zone is distinguished by a gradual decline in the values of trees and shrubs, in particular *Alnus*, *Betula*, *Quercus*, *Ulmus*, *Corylus* and *Myrica* type, and the beginning of increased values of *Calluna vulgaris*, *Empetrum*, *Erica tetralix* and *Erica cinerea*, with a marked expansion of heathland at c.3751 cal. BP. Open ground herbs indicative of grassland / pasture are also present with Poaceae, *Ranunculus* type, *Linum* type, *Filipendula*, *Potentilla* and *Plantago lanceolata*. Several Cerealia pollen grains were identified at the base of the zone at c.3967-3859 cal. BP suggesting some arable activity. Figure 5.43 also shows a small peak in charcoal, recorded at c.3361 cal. BP.

Lag 230M-3b Calluna-Erica cinerea-Poaceae (c.2459 – 945 cal. BP)

Heathland continues to expand with *Calluna*, *Empetrum* and *Erica cinerea* making up 70% TLP, reaching their greatest percentage within the pollen diagram. *Betula*, *Quercus*, *Alnus* and *Corylus* continue to decline. Poaceae and open ground herbs make up c.15% TLP with disturbed ground taxa being recorded *(Ranunculus* and *Plantago lanceolata)* but only two Cerealia pollen grains were found. A slight rise in *Sphagnum*, Cyperaceae and *Pediastrum* also distinguishes this zone, suggesting some surface waterlogging occurred.

Lag 230M-3c Calluna –Poaceae (c 945 cal. BP-c.585 cal. BP)

This zone is distinguished by an increase in Poaceae, *Ranunculus*, *Filipendula* and *Potentilla* but the overall variety of open herbs decreases. A slight decline in *Calluna* and *Erica cinerea* occurs at c.900 cal. BP, with a corresponding gentle rise in *Betula*, but heath species recover towards the end of the zone and trees continue to decline. A slight peak in *Sphagnum* is also recorded suggesting wet, open heathland dominated the landscape.

Lag 230M-4 Calluna-Poaceae-Cyperaceae (c.585 cal. BP – c. 0 BP)

The upper 27cm of Lag 230 MOS are represented by a rise in Poaceae and Cerealia grains (the latter in the upper 14cm from c.292 cal. BP). *Calluna, Erica cinerea, Vaccinium* and Droseraceae fluctuate but continue to dominate the pollen record, with a slight decrease in *Calluna* being recorded at c.247 cal. BP. Shrubs are entirely absent from the percentage diagram, and tree species decline further with the disappearance of *Alnus* and *Ulmus* in the upper 12cm.

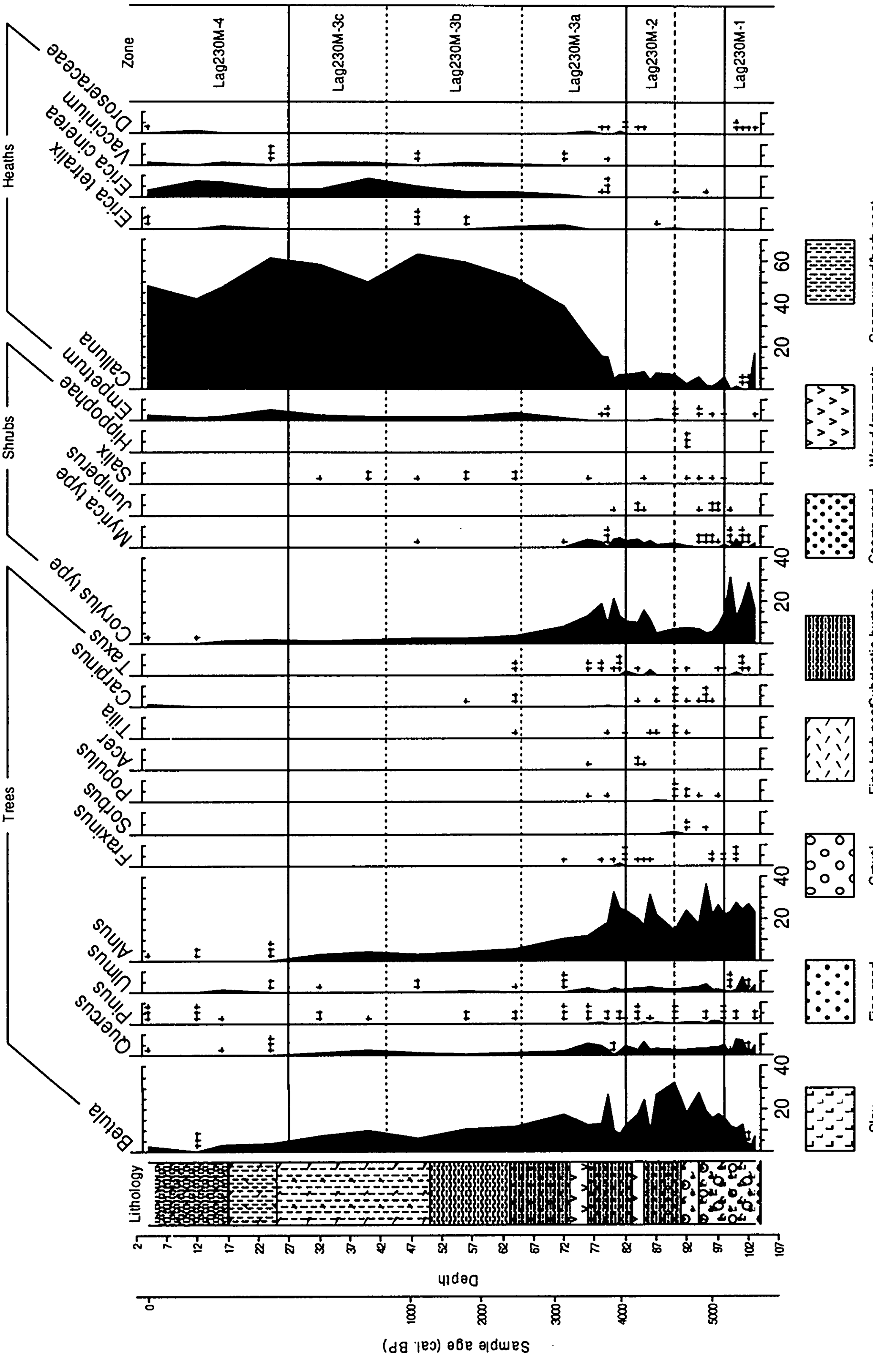
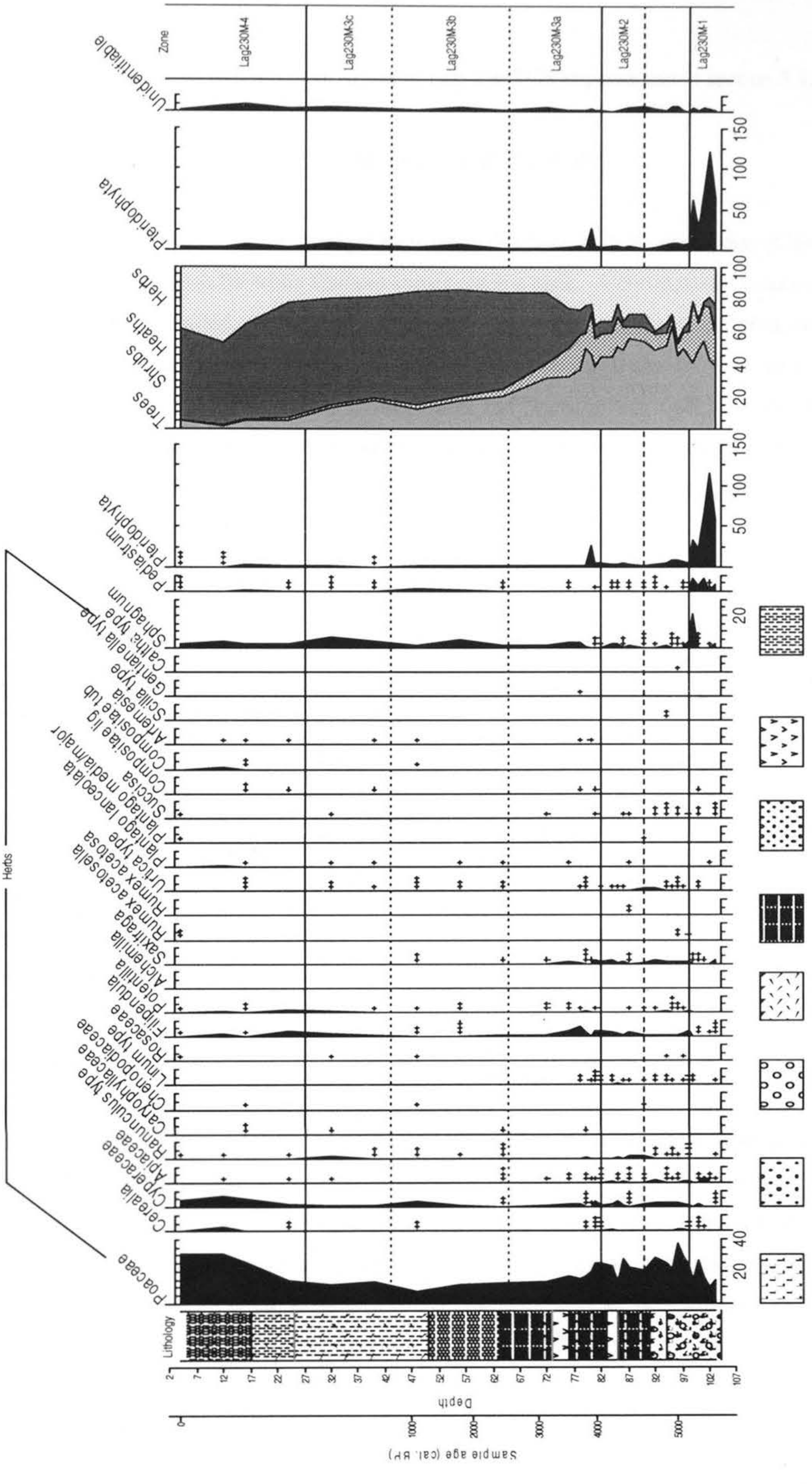


Figure 5.60: Lag 230 MOS Pollen Percentage Diagram


Sample age (cal. BP)
0
1000
2000
3000
4000
5000
Depth
2
7
12
17
22
27
32
37
42
47
52
57
62
67
72
77
82
87
92
97
102
107
Lithology
Poaceae
20
40
Herbs
Cerealia
Cyperaceae
Apiaceae
Ranunculus type
Caryophyllaceae
Chenopodiaceae
Linum type
Rosaceae
Filipendula
Potentilla
Alchemilla
Saxifraga
Rumex acetosella
Rumex acetosa
Urtica type
Plantago lanceolata
Plantago media/major
Succisa
Compositae lig
Compositae tub
Artemesia
Scilla type
Gentianella type
Caltha type
Sphagnum
20
Pediastrum
Pteridophyta
50
100
150
Trees
Shrubs
Heaths
Herbs
20
40
60
80
100
Pteridophyta
50
100
150
Unidentifiable
Zone
Lag230M-4
Lag230M-3c
Lag230M-3b
Lag230M-3a
Lag230M-2
Lag230M-1
Clay
Fine sand
Gravel
Fine herb peat
Substantia humosa
Coarse sand
Wood fragments
Coarse wood/herb peat

5.7.3 Pollen diagram at Lag 230m TOS

The pollen sequence through the basal layers of Lag 230 TOS is presented in section 5.4.3.

Lag 230T-3a Calluna–Corylus (c. 5500 cal. BP- c.4025 cal. BP)

Calluna and *Empetrum* pollen percentages increase in this zone with the expansion of heathland, particularly at c.4375 cal. BP when *Calluna* values reach a peak. A corresponding decrease in *Coryloid* pollen is recorded at this time (possibly *Myrica*), along with a peak in *Sphagnum*, suggesting conditions were wet. Overall the number and variety of herbs decrease, with falling values of Poaceae and *Filipendula*, and *Betula, Alnus* and *Quercus* values also decline. *Corlyus / Myrica* type values appear to fluctuate but remain relatively stable, accounting for 20% TLP. Two Cerealia grains were recorded in this zone but few other agricultural indicator species are present within the herb pollen.

Lag 230T-3b Calluna–Poaceae (c. 4025 cal. BP-2690 cal. BP)

A decline in *Calluna* marks the opening of this zone, with a corresponding increase in values of *Alnus*. This pattern, however, is short lived and *Calluna* recovers to the detriment of *Corylus,* whose values fall to <10% TLP by c.3250 cal. BP. The overall percentage of tree species, including *Betula, Alnus, Quercus* and *Ulmus,* all decline although *Taxus* is recorded within the pollen assemblage. A marked rise in the number and variety of herbs indicative of open grassland / pasture is recorded and distinguishes this zone. A rise in Poaceae, *Linum* type, Cyperaceae, *Filipendula, Saxifraga* and *Plantago lanceolata* suggest a wet but open mire surface with a reduction in possible grazing activities.

Lag 230T-4 Calluna –Poaceae– Sphagnum (c.2690 cal. BP-1685 cal. BP)

An expansion of *Calluna* at c.2315 cal. BP is recorded at the start of this zone, after which point values decrease slightly but remain stable, accounting for c. 50% TLP. *Poaceae* values rise steadily and, similar to zone 3b, open grassland species indicative of disturbance are present throughout. A peak in *Sphagnum* at c.2315 cal. BP, corresponding with the decline in heathland species and a rise in *Pediastrum,* suggests a wetter landscape with areas of standing water experienced for a time. Following this peak in *Sphagnum*, Cerealia grains are recorded and the curve for *Plantago lanceolata* also rises, suggesting renewed human activity. Values of *Betula, Quercus, Alnus* and *Corylus* continue to decline.

Lag 230T-5a   Calluna – Empetrum (c.1685 cal. BP–c.1298 cal. BP)

The *Calluna* curve shows an increase to a maximum level of c.60% TLP along with a peak in *Empetrum* values at c.1342 cal. BP. This expansion is mirrored by a decline in Poaceae and other herbs, and the continued decline of *Betula* and *Alnus*. Values of *Corylus* also decline but *Myrica* type levels appear to rise slightly. Lower values of *Sphagnum* and *Pediastrum* are recorded, suggesting conditions became drier for a period. Two Cerealia grains were also found but fewer open ground herbs, suggesting the landscape was dominated by heather.

Lag 230T–5b   Corylus – Calluna (c. 1298 cal. BP-c.528 cal. BP)

This zone is characterised by a fluctuating decline in *Calluna* and the disappearance of *Empetrum* from the record. A slight recovery in values of *Corylus* and *Alnus* are recorded, whilst increased values of herbs, including Chenopodiaceae, *Linum* type, *Saxifraga, Urtica, Plantago lanceolata,* and Cerealia grains are also present suggesting some anthropogenic activity. Values for *Poaceae* remain lower than in the previous zone but stabilise, and a marked rise in Cyperaceae, *Sphagnum, Pediastrum* together with Pteridophyta suggest increased waterlogging and competition from an acidophilous flora.

Lag 230T-6   Calluna–Poaceae (c.528 cal. BP-c.0 BP)

The uppermost 25cm are distinguished by an increase in Poaceae, *Ranunculus, Plantago lanceolata, Sphagnum* and *Pediastrum,* reflecting the current acrotelm / catotelm boundary and waterlogged conditions as well as more recent agricultural practices over the last c.300 years. *Calluna* values appear to have declined during this period although still contribute c.50% TLP, and the disappearance of *Corylus, Myrica, Empetrum* and *Alnus* is apparent.

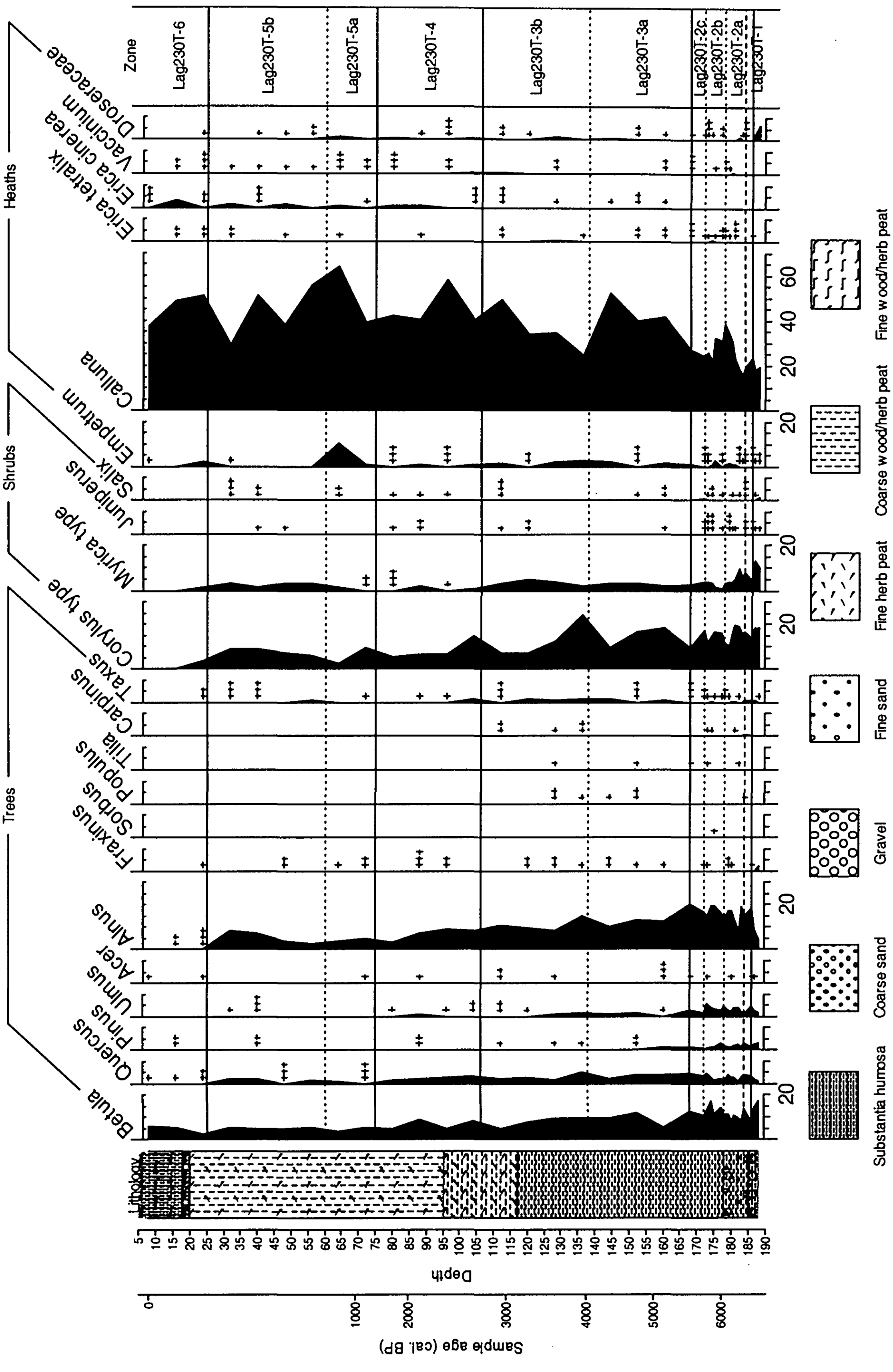
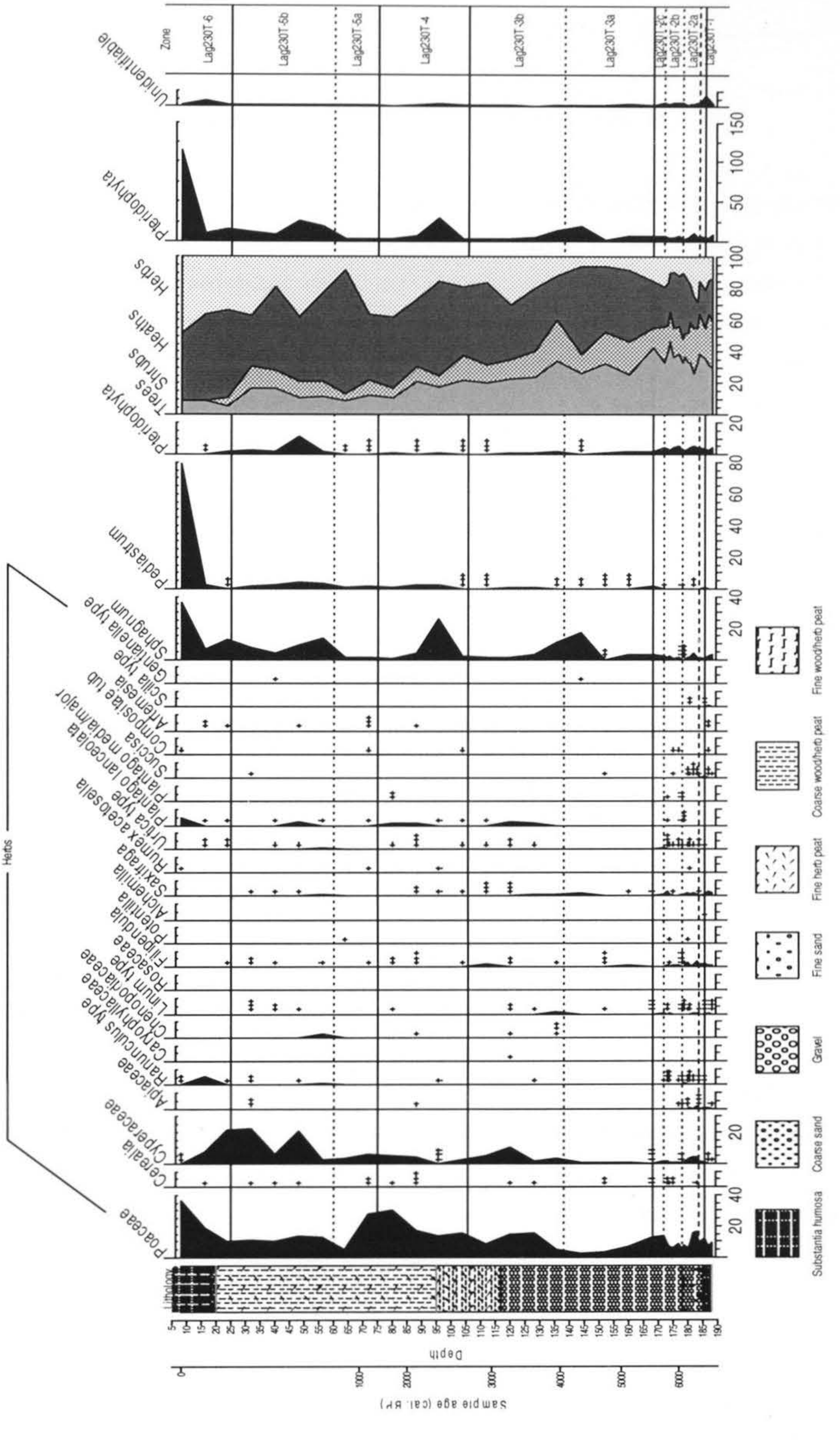


Figure 5.61: Lag 230 TOS Pollen Percentage Diagram



Sample age (cal. BP)
0
1000
2000
3000
4000
5000
6000
Depth
5
10
15
20
25
30
35
40
45
50
55
60
65
70
75
80
85
90
95
100
105
110
115
120
125
130
135
140
145
150
155
160
165
170
175
180
185
190
Lithology
Poaceae
Cerealia
Cyperaceae
Apiaceae
Ranunculus type
Caryophyllaceae
Chenopodiaceae
Linum type
Rosaceae
Filipendula
Potentilla
Alchemilla
Saxifraga
Rumex acetosella
Urtica type
Plantago lanceolata
Plantago media/major
Succisa
Compositae tub
Artemisia
Scilla type
Gentianella type
Sphagnum
Pediastrum
Pteridophyta
Trees
Shrubs
Heaths
Herbs
Pteridophyta
Unidentifiable
Herbs
Zone
Lag230T-6
Lag230T-5b
Lag230T-5a
Lag230T-4
Lag230T-3b
Lag230T-3a
Lag230T-3c
Lag230T-2b
Lag230T-2a
Lag230T-1
20
40
60
80
100
50
150
Substantia humosa
Coarse sand
Gravel
Fine sand
Fine herb peat
Coarse wood/herb peat
Fine wood/herb peat

Chapter 6 Discussion

6.1 Interpretation of the palynological and sedimentological record

The key aim of this thesis was to examine the physical and vegetational factors at the time of blanket peat initiation. This chapter integrates the palynological and sedimentological evidence for past human activity and climate change and the impact these have had on the initiation of blanket peat at each altitude, set within the AMS chronological framework. The details of these changes are described below. Detailed correlation between the different pollen assemblage zone and wet / dry shifts across each site is also presented in Table 6.2 at the end of the chapter (page 257).

6.1.1 Blanket Bog development at Lagafater and vegetational history

c.6500-6300 cal. BP

The AMS radiocarbon dating programme indicates that the earliest blanket peat formation began at Lag 230m TOS at c.6375 cal. BP (Table 5.1). A well-humified peat with some sand / silt particles at the base of the sequence is replaced by a well-humified blanket peat (Figure 5.11). The loss-on-ignition (LOI) results (Figure 5.11) show two abrupt increases through the basal minerogenic layers (c.5cm deep): the first through the point of peat initiation at 185cm (c.6375 cal. BP), and the second following a possible inwash band at c.5893 cal. BP, although little erosion or translocation of material is indicated through the particle size analysis results (Figure 5.14). The humification data (Figure 5.12) suggest that conditions were wet at the point of peat initiation but following this the mire surface became dry for a brief period, coinciding with the second decrease in organic content values. The stratigraphic profile (Figure 5.1) indicates that peat began accumulating in a shallow hollow where paludification occurred over a period of c.570 years. The top of the slope at 230m OD, therefore, began accumulating peat over a period of c.570 years, during which time conditions were wet enough for groundwater gleying and paludification. Particle size analyses, however, show only low proportions of clay particles and no downward translocation of finer material (Figure 5.14), and the grey mottling present through the basal soil layers across all of the profiles may not be contemporary with peat formation. Pedogenic changes were therefore probably not responsible for the development of blanket peat at this earliest site.

Sediments prior to c.6375 cal. BP have a high minerogenic component. Evidence for vegetation changes was sought through pollen analysis, although the problems associated with soil palynology have been well documented (Anderson 1986; Dimbleby 1957) and are appreciated here. The pollen record through this sequence must, therefore, be interpreted with caution, but nevertheless the pollen sequence indicates some stratification through these pre-peat layers. The basal sediments through Lag 230 TOS (230T-1) show a broad spectrum of plant species. The overall % of tree species is well represented, with increasing values of *Alnus*. Shrubs such as *Corlyus* and *Myrica* were present, and heaths including *Calluna* and Droseraceae were also growing, with some Poaceae. The presence of *Sphagnum* suggests damp, increasingly acidic conditions prior to peat initiation, with patches of *Betula-Corylus* woodland growing in the nearby landscape. While it is likely that these taxa were present in the area before peat initiation, there are problems associated with attempting to decipher a stratigraphic record. A greater number of corroded and unidentifiable grains were identified through this and the start of the succeeding zone.

c.6375-6050 cal. BP

At the soil / peat interface of Lag 230 TOS, the vegetation appears to have consisted of a *Corylus* scrub, with *Calluna* and Poaceae suggesting a relatively open, wet mire community as peat began to accumulate. Following initiation, a small rise in *Sphagnum*, Cyperaceae and *Filipendula* is recorded, suggesting increased surface water supply, perhaps as a result of a high water table (Figure 5.46). The humification results from Lag 230 TOS support this view of a brief period of increased wetness following peat initiation, as a wet phase is recorded at c.6271 cal. BP and bulk density values fall at c.6100 cal. BP (Figure 5.12)

The steady presence of *Alnus*, *Betula* and *Corylus* throughout the basal pollen sequence at Lag 230 TOS (25-30% TLP) suggest this was the dominant woodland type, but it is likely that the coring site did not support a dense alder carr: values are too low for this but they suggest *Alnus* was growing locally, close to the margins of this initial foci for peat growth.

A similar early pollen sequence is recorded through Lag 300 TOS-1 (Section 5.52), where the transition from mineral soil to blanket peat occurred a little later, at c.6135 cal. BP. This site is situated approximately 200m from Lag 230 TOS (see Figure 4.3). Its earliest pollen zone, set within a matrix of well-humified peat with some minerogenic material (Figure 5.25), is characterised by high values of *Corylus*, *Calluna* and *Alnus* growing alongside wet-loving species such as *Saxifraga* and *Filipendula.* An early peak in surface wetness is also recorded through the humification records between c.6135 to c.6008 cal. BP (Figure 5.26).

This may have been a local feature because at Lag 230 TOS at c.6150 cal. BP (230T-2a and 300T-2), an expansion in Poaceae <8um diameter, a decline in *Corylus,* and increased values of *Calluna*, may represent drier conditions, particularly when *Empetrum* appears in the pollen record at greater values. This agrees with the dry bulk density and humification records from both Lag 230 TOS and Lag 300 TOS (Figure 5.12 & 5.25), which both indicate that drier conditions persisted at both sites from c. 6150 cal. BP to c.3500 cal. BP. A small peak in charcoal is recorded at Lag 230T at c.6109 cal. BP but no anthropogenic indicators within the pollen record are seen, suggesting this was a natural, perhaps local disturbance.

c.6050-5500 cal. BP

Zones 230T-2b and 300T-3 mark a change in stratigraphy to a well-humified blanket peat. *Calluna* reached peak values during this period before declining after c.6080 cal. BP. Values of *Corylus* also decline and are replaced by increased numbers of *Betula*, *Quercus*, *Pinus* and *Ulmus* pollen. These species were probably present in regional woodlands across the Lagafater region with the more thermophilous taxa like *Quercus* and *Ulmus* growing in sheltered areas, and their pollen may have become more 'visible' as the local plant canopy opened. A sharp decline in values of *Ulmus* in 230T-2b at c.5725 cal. BP occurs at a time which matches other radiocarbon age estimates for the *Ulmus* decline in the region (Parker *et al* 2002).

At c.5893 cal. BP (230T-2b) an increase in Poaceae is recorded at 230 TOS and 300 TOS, and a rise in the number of rich grassland herbs also coincides with a peak in charcoal at c.5954 cal. BP (300T-3). Humification and dry bulk density records suggest a continued phase of dry ground conditions, and the age/depth models from both sites suggest steady peat accumulation rates of c.54 years / cm. The continued presence of *Myrica* type pollen may reflect its growth on the dry peat surface in areas not occupied by *Alnus* or *Betula.*

The first appearance of Cerealia grains, although in small numbers, is recorded within 230T-2b after c.5800 cal. BP. There are few other anthropogenic indicators (few grazing indicators or weed species) within the pollen record at this altitude to suggest that agriculture was being carried out adjacent to the coring sites, but the presence of charcoal may indicate a level of human activity and landscape management elsewhere in the landscape. The majority of archaeological sites around 230m OD are Neolithic in date (e.g. Marklach Cairn, NX 175 729; Figure 3.3) and it is perhaps that this relatively open landscape offered nomadic, farming activities to small groups within the Lagafater region.

c.5500-5000 cal. BP

The pollen evidence from Lag 400 BOS (Figure 5.54) prior to peat initiation at c.4935 cal. BP is difficult to define as the sediment is a compact, organic sandy silt soil (Figure 5.31). The taxa presented within this horizon, however, display strong correlations with similarly dated horizons from other, contemporary peat-derived pollen assemblages at sites at Lagafater (e.g. zone 230T-2c) and therefore some comparison may be made. For example, Lag 400B-1 and Lag 400B-2 show increased levels of *Sphagnum*, Pteridophyta, *Corylus* and *Rumex acetosella*, indicative of open, wet and acid conditions at this site prior to peat initiation. Lower values of tree species (for example *Quercus*, *Pinus* and *Alnus*) are recorded than in the earlier zones of 230T-2b and 300T-3, and peaks in *Sphagnum* and Cyperaceae values in zone 400B-2a correlate with declines in *Pinus* and *Quercus*. These might be linked to higher groundwater levels. Humification analyses through these basal layers were not undertaken given the minerogenic content of the samples, and therefore wet shifts could not be independently identified at this site. The dry bulk density data, however, are interpreted as showing high levels of decomposition at this stage, suggesting slightly drier conditions. Age-depth relations (Figure 5.31) indicate an accumulation rate of c.34 years / cm. It is likely, however, that compaction of the underlying peat has affected the dry bulk density results, and whilst conditions at 400 BOS were clearly wet during this period, elsewhere the pollen evidence, particularly on slopes at 230m OD, suggests conditions across Lagafater were dry, with the expansion of *Calluna*. The early pollen record from Lag 400 BOS may reflect the waterlogged nature of the soil at this site and site-specific autogenic hydrological changes. The fine sorting of mineral particles within the soil beneath the peat (Figure 5.34) indicate no downward translocation of clay minerals. Blanket peat, therefore, began to develop as a result of localised waterlogging, accelerated by the natural hollow of the underlying topography (Figure 5.29) and its topographic situation at the base of a slope.

Between c.5476 cal. BP and c.5280 cal. BP, locally wet conditions may be reflected at Lag 400 TOS with decreasing values of tree taxa, in particular *Betula* and *Pinus,* and a slight peak in *Sphagnum* (400 T-1), which correlates well with zone 400B-2b. This decrease, however, is also accompanied by a rise in *Rumex acetosella* and Compositeae herbs, often associated with increased grazing pressure. The decrease in tree taxa, therefore, may well be associated with small-scale grazing pressure at this altitude, suggesting an early, small-scale Neolithic agricultural landscape existed at Lagafater and may have accelerated the process of peat initiation at Lag 400 BOS. A more open landscape is presented, but with *Corylus* scrub now dominating the pollen record (Figure 5.54). Blanket peat initiation at Lag 400 TOS is placed at c.5270 cal. BP (Table 5.1) with an estimated accumulation rate of 225 years / cm. High values of bulk density (Figure 5.39) suggest that some structural collapse and compaction of the basal peat layers has occurred, though when this happened is hard to define. No particle size analysis was undertaken at this site given the highly organic nature of the basal sediments. A climatic driving force may be implicated for the initiation of peat at this site in the absence of evidence for soil change or small-scale human vegetation disturbance. Small hollows across an otherwise well-drained landscape acted as foci for the development of groundwater gleys and, ultimately, blanket peat, at Lag 400m OD. Towards the end of this period however, conditions become drier and *Calluna* and *Empetrum* increase in values, particularly at Lag 400 TOS.

At c.5185 cal. BP, blanket peat had developed at Lag 230 BOS and probably also at Lag 230 MOS (Figure 5.44), before c.4675 cal.BP. There is close correlation between the pollen assemblages at these sites (Figures 5.42 & 5.44). At both sites high values of Pteridophyta, *Pediastrum* (particularly at Lag 230 MOS), *Sphagnum* and a number of herb taxa are all recorded, indicating high groundwater levels. High values of *Corylus* and *Alnus* are also recorded. Particle size analysis suggests the development of a groundwater gley at Lag 230 BOS (Figure 5.6) but a slow accumulation rate of 15 years / cm. A peak in fine sand, grading upwards to finer material, at Lag 230 MOS, however, suggests some sorting of mineral sediment by flowing water (Figure 5.10), and the introduction of eroded sediment suggests some soil disturbance upslope prior to peat inception as well as the alteration of hydrological properties at the site itself. A slower accumulation rate of 53 years / cm is recorded.

A similar pollen assemblage is seen in zone Lag 400B-3 between c.5300 cal. BP and c.5100 cal. BP, reflecting an increase from Lag 400B-2 in woodland cover, particularly *Alnus* and *Betula* (Figure 5.54). The presence of woodland, making up 60% TLP at this time at Lag 230 BOS (Figure 5.42), indicates increasing scrub cover here, and this is suggested to a lesser degree by a rise in arboreal pollen values from <20% to over 40% TLP at Lag 400 BOS (Figure 5.54). It is possible that this re-growth of local woodland species represents reduced grazing pressure across the region and a change in the intensity of agricultural practices. These increases in tree cover seem, however, to coincide with a change across the hillside to drier conditions, so that trees may have been able to colonise previously wet heath. This change to drier conditions is clearly seen in the humification and dry bulk density figures at Lag 230 BOS, 230 TOS, Lag 300 TOS and Lag 400 BOS with increasing values for both at c.5100 cal. BP. Similar results from the humification data at Lag 230 BOS and Lag 230 MOS (Figures 5.4 & 5.8), already discussed also show this trend. Across all three sites, charcoal peaks are recorded dated most securely to c.5130 cal. BP at Lag 230 BOS (Figure 5.41). High values of Cerealia are also recorded at both Lag 230 MOS and Lag 230 BOS (Figures 5.44 & 5.42), indicating continued human activity at this altitude. Very few anthropogenic indicators are evident in the pollen diagram from higher altitudes, at Lag 400 BOS (Figure 5.54).

It is likely from the evidence so far presented that an increase in groundwater levels and therefore a worsening climate was responsible for the initiation of blanket peat at Lag 400m TOS and BOS. Fewer tree taxa, the absence of anthropogenic indicators, and fewer pollen types in general, are presented within the early pollen zones at this altitude, suggesting an open, predominantly acidophilous flora existed prior to peat growth. An increase in wet conditions at c.6500-5300 cal. BP tipped this sensitive balance, encouraging widespread blanket peat development at this altitude. At Lag 230m TOS and Lag 300m TOS, a similar picture of an already established acidophilous flora is presented before c.6375 cal. BP. An increase in wet conditions during this period may have been responsible for the development of blanket peat in small pockets of undulating topography where water levels locally increased. Between c.5500 and c.5000 cal. BP, however, the widespread encroachment of blanket peat at Lag 230m appears to be closely related to drier conditions within a wooded, rich grassland landscape (with a noticeable absence of heath species), and an increase in the number and distribution of Cerealia and charcoal horizons. It is therefore suggested that initiation of blanket peat at Lag 230 BOS and Lag 230 MOS was accelerated by continued human activity within the local area as the data indicate that climatic and pedogenic forcing were not responsible for the development of blanket peat. The pollen diagrams show the removal of *Corylus* scrub (particularly at Lag 230 MOS), an increase in open-ground vegetation synonymous with disturbance (e.g. *Artemesia*), the occurrence of some Cerealia (at c.5190 cal. BP) and the appearance of peaks in charcoal coincident with the onset of peat accumulation. Peat formation ensued at Lag 230 MOS and Lag 230 BOS when the forest and scrub cover growing on non peat covered areas were removed by controlled burning. The consequent reduction in the interception of rain water led to acidification and ground water gleying of the soil (shown in the Particle Size Analysis of Lag 230 MOS) enhanced by the incorporation of fine particulate matter produced by burning (Mallik *et al* 1984).

Between c.5000 cal. BP and c.5100 cal. BP drier conditions continued, with increased values of *Quercus*, *Ulmus* and *Alnus* at Lag 400 BOS (400B-4) and a decline in *Corylus* and *Calluna* (Figure 5.54). At Lag 230 BOS (230B-2a), the expansion of Poaceae and a decrease in *Corylus* and *Betula* are recorded (Figure 5.42). Cerealia grains are also present between c.5090 cal. BP and c.5060 cal. BP. Taxa such as *Plantago lanceolata* and Chenopodiaceae are also present, indicating a continued phase of Neolithic arable farming across Lag 230m OD and Lag 300m OD at Lagafater.

c.5000-c.4500 cal. BP

The next c.1000 years sees the expansion of human activity across the Lagafater landscape, particularly focussed on the hillside at 230m OD. Zone 230B-2b (Section 5.4.1) marks the decline in a number of tree taxa, including *Betula* and *Alnus*, and sees a rise in values of Poaceae and herb taxa, Cerealia grains, and a charcoal peak at c.4970 cal. BP. Similarly, at Lag 400B-5 (Section 5.6.1), Poaceae and some grassland herbs increase in value, possibly replacing *Calluna* (Figure 5.54). Although no Cerealia grains are recorded at this altitude, a charcoal layer is recorded between c.4930 and c.4862 cal. BP. Together with a reduction in the number and variety of tree taxa, these data suggest some management of the local landscape, marking a slight increase in erosion as more minerogenic material is recorded within the peat profile between c.4624 cal. BP and c.4352 cal. BP. The number of herb taxa present that are particularly sensitive to grazing (e.g. *Saxifraga* and *Filipendula*) suggest this was predominantly an arable landscape with little pastoral activity occurring during the Neolithic.

A phase of blanket peat initiation occurs between c.4620 cal. BP and c.4700 cal. BP, and it is thought that this was caused by accelerated human activity across the landscape. The initiation phase at c. 4710 cal. BP, for example, at Lag 300 BOS (300 BOS-1) (Section 5.5.1) marks the beginning of a decline in *Betula*, *Pinus*, *Ulmus* and *Alnus*, followed by a rise in herb taxa and *Sphagnum*. A peak in charcoal at c.4671 cal. BP also correlates well with the presence of Cerealia grains between c.4680 cal. BP and c. 4660 cal. BP in suggesting either local agricultural activity or the application of burning to modify vegetation. Particle size analysis through the basal layers (Figure 5.20) also suggests some soil disturbance upslope during this period, with the transport of higher energy sand grains to the site at c.4690 cal. BP. This is also paralleled by a slight decrease in organic content upslope at Lag 300 TOS between c.4712 cal. BP and c.4334 cal. BP. The delayed response in the appearance of wet loving taxa following peat initiation at Lag 300 BOS may well implicate human activity in the initiation process here as there are few climatic or pedogenic indictors to suggest increased surface wetness prior to peat initiation.

Similarly, at Lag 230 MOS (Section 5.4.2), peat initiation is placed at c.4675 cal. BP, corresponding with a peak in charcoal, and a period of soil instability is recorded through loss on ignition from c.4675 cal. BP to c. 3648 cal. BP. At c.4620 cal. BP, a peak in charcoal and increased values of Cerealia at Lag 400 TOS (400T-2) (Section 5.6.3) also correspond with the development of blanket peat down slope at Lag 400 MOS. These correlations suggest human activity on the slope accelerated the spread of blanket peat to the MOS site. A number of Cerealia grains are also recorded from both 400m OD sites during this period (400T-2 and 400M-1; Sections 5.6.3 & 5.6.2), along with *Plantago lanceolata* indicating the expansion of grazing pressures to higher altitudes.

c.4500-c.3800 cal. BP

The majority of pollen indicators across the sites at Lagafater suggest that slightly wetter conditions prevailed for the period between c.4500 cal. BP and c.3800 cal. BP, becoming gradually drier towards the end of this period. Relatively low values of dry bulk density are recorded (e.g. at Lag 300 BOS, Figure 5.18) although they are slightly higher near the initiation horizon as a result of compaction. Records of humification across the sites show that percentage transmission values are close to the mean of 10%, suggesting the bog surface was neither very wet nor very dry. An increase in *Sphagnum* at 230 TOS and 230 BOS (230T-3a and 230B-3b; Section 5.7.2 & 5.7.3), however, and a decrease in values of tree taxa such as *Betula* and *Pinus*, coupled with a rise in values of *Calluna* and Cyperaceae (e.g. 400M-1) and fluctuating levels of *Corylus*, suggest conditions were slightly wetter. However, the numbers of open ground herbs also increase, and Cerealia grains are continually recorded throughout this period, particularly between c.4400 cal. BP and c.3900 cal. BP at Lag 230 MOS (Section 5.7.2) and Lag 230 TOS (Section 5.7.3), and at c.4600 cal. BP at Lag 400 MOS (400M-1; Section 5.6.2). It is therefore suggested that accelerated human activity from c.4700 cal. BP, combined with deterioration in the climate, accelerated the process of blanket peat initiation. The hillside at Lagafater was effectively covered in blanket peat by c.3800 cal. BP.

c.3800-c.3500 cal. BP

This period across Lagafater marks increased dry conditions (Table 6.2), the expansion of *Calluna* heath across the landscape (recorded at c.3751 cal. BP at Lag 230 MOS, Section 5.7.2, and across the hillside at 300m OD; Section 5.5.2), and a reduction for a short period of the evidence for human activity. For example, no Cerealia grains and fewer herbs are recorded during this period (e.g. 300M-1; Figure 5.50), possibly as a reaction to increased *Calluna* growth and the expansion of blanket peat. *Calluna* heath was dominant, together with *Empetrum* (400M-2a, 400M-2b, 300M-2a; Figures 5.56 & 5.50) (cf. Tallis 1997). Slight increases in values for *Betula*, *Alnus* and *Quercus* were also recorded. Strong evidence for a period of drier conditions across Lagafater is provided by these data, together with the results of the humification analysis at all sites where low values are consistently recorded and fall below mean values (Sections 5.1 – 5.3) and higher dry bulk density values suggesting the increased decomposition of plant material.

c.3500-c.3000 cal. BP

Calluna and other Ericaceae remain important components of the bog vegetation from c.3800 cal. BP, seemingly at the expense of *Corylus* and tree taxa. Around c.3500 cal. BP, conditions once more appear to have become increasingly wet, but this period also marks an increase in the palynological evidence for human activity. Lag 300M-3, for example (Figure 5.50), records Cerealia at c.3520 cal. BP and a peak in charcoal at c.3600 cal. BP. These data, and evidence for a reduction in the number and variety of tree taxa with a rise in values for Poaceae and herbs, suggest that increased human activity relates to the late transition to blanket mire at this site. A similar pollen assemblage is recorded from Lag 400M-3 (Figure 5.56) with a peak in charcoal at c.3382 cal. BP. A decrease in organic matter at Lag 400 BOS between c.3468 cal. BP and c.2924 cal. BP suggests increased erosion upslope. Other charcoal peaks are recorded at c.3361 cal. BP (230M-3a) and at c.3455 cal. BP and c.3169 cal. BP (300M-4b).

Within this period, a number of discrete wood fragments were recorded within the blanket peat, particularly from Lag 230m BOS (c.3900 cal. BP and c.3412 cal. BP), at Lag 230 MOS (c.3115 cal. BP) and at Lag 300 BOS (c.3066 cal. BP-c.3416 cal. BP), suggesting better conditions suitable for tree growth and better preservation within the blanket peat during increasingly wetter conditions.

The expansion of *Calluna* is recorded across all altitudes at Lagafater during this period, along with a decline in tree taxa. Several bands of charcoal also parallel this decrease in woodland, but little evidence within the stratigraphic sequences or dry bulk density records (sections 5.1-5.3) hint at increased soil erosion during this period. Woodland destruction during the Bronze Age was probably therefore minimal at these sites, and heath spread across an already open landscape. The impact of human activity on woods at this time may have been limited to small-scale clearings across discrete areas of Lagafater, particularly as much of the evidence for burning from microscopic charcoal records in this period is situated within the MOS profiles. Within the study area a number of hut circles, buried walls, small cairns and enclosures pertaining to the Bronze Age have been recorded (Figure 3.4): the presence of numerous small cairns of Neolithic origin also within this area suggest local continuity of a human presence within the landscape.

A further shift to wetter conditions from c.3100 cal. BP to c.3400 cal. BP is recorded across the region in humification analyses (Sections 5.1-5.3). There is good agreement with this in the dry bulk density data with reductions in bulk volume suggesting reduced decomposition of plant material. The pollen record at Lag 230 TOS (Figure 5.61) sees a slight decline in *Calluna* (230T-3b) and an expansion of open grass herbs and Poaceae, whilst *Calluna* appears to dominate the percentage diagram at Lag 230 MOS (230M-3a) and Lag 230 BOS (230B-4) (Figures 5.60 & 5.59). An increase in *Sphagnum* and Cyperaceae is also recorded, particularly at Lag 300 MOS (300m-4a and 4b; Figure 5.50). Despite these wetter conditions, anthropogenic activity appears to have continued across Lagafater. A decrease in the percentages of Ericaceae across the top of slopes (Lag 230 m OD and Lag 300m OD) suggests that these locations were the foci for small-scale land management and arable activity. An increase in the number of herbs sensitive to grazing pressure (e.g. *Saxifraga* and *Filipendula*) suggests, however, that little pastoral activity occurred or that some localities were protected from grazing.

c.3000-c.1500 cal. BP

The interpretation of the palynological record covering the last c.3000 years is based on the analysis of pollen through the cores at Lag 230m OD (Section 5.4). Palaeoclimatic data from humification and dry bulk density data, however, continue to be derived from analyses of peat at all nine profiles.

A further wet shift between c.2800 cal. BP and c.2500 cal. BP is recorded across all sites (e.g. decreased humification values at Lag 230m OD, Lag 300m OD and Lag 400m OD). This shift correlates well with an increase in values of *Alnus* at Lag 230B-5 (Figure 5.59) and a rise in *Sphagnum* at 230M-3b and 230T-4 (Sections 5.7.2 & 5.7.3). *Calluna* and other Ericaceae dominate the pollen records from all three Lag 230m OD sites, and the expansion of heath species is particularly clear within the pollen record: at c.2543 cal. BP at Lag 230 BOS, and at c.2315 cal. BP at Lag 230 TOS (Figure 5.61). The number and variety of grassland taxa, including Poaceae, *Saxifraga* and *Plantago lanceolata* also increase, however, at Lag 230B-5 and Lag 230T-4 (Figures 5.61 & 5.59), accompanied by a rise in values of Cerealia, indicating renewed agricultural and anthropogenic activity in the area. Few charcoal horizons are identified, and this increase in activity is perhaps representative of arable agriculture near to the coring sites where blanket peat had not encroached or where blanket peat was actively being removed or ploughed under.

A drier phase is then recorded at c.2200 cal. BP across Lagafater at Lag 230m OD (see section 7.2) and elsewhere (e.g. Lag 400m BOS and Lag 400m TOS), suggesting this may have been a wider regional change. Humification data and dry bulk density data also record a decline in values (e.g. at Lag 400m BOS, Figure 5.33), supporting the view that drier conditions were experienced. The expansion of *Calluna* and *Empetrum* in zones 230B-6, 230M-3b and 230T-5a (Sections 5.59-5.61) relates to a further decline in trees. Few Cerealia grains are recorded for this period, although herbs continue to have been important: Poaceae values peak at c.1900 cal. BP at Lag 230 BOS.

c.1500–c. 500 cal. BP

The last c.1500 years are distinguished by an increase in Poaceae and a gradual decline in *Calluna,* along with the disappearance of *Corylus.* A further two wet phases are also recorded across the region, from c.1100 cal. BP to c.1030 cal. BP and from c.550 cal. BP to c.450 cal. BP. The pollen record shows increasingly high values of *Sphagnum* (230B-7a, 230M-3c and 230T-5b; Sections 5.59-5.61) along with an increase in grassland herbs indicative of pastoral activities (e.g. a reduction in values of *Filipendula* and *Saxifraga* and increased values of *Plantago lanceolata*, *Ranunculus* and Apiaceae). Some Cerealia grains are also recorded through this period e.g. at Lag 230 BOS (Figure 5.59)

c.500-c.0 cal. BP

The upper layers of the cores from Lag 230m OD contain a poorly humified *Sphagnum* peat with increasing levels of Cyperaceae and Poaceae, with a marked decline in the values of trees and shrubs. These upper layers typify a wet, open heathland environment (with *Calluna* dominating at over 50% TLP) and mark the transition into the acrotelm / catotelm boundary with higher water tables. Pastoral and arable agricultural activities are also indicated by the presence of some Cerealia grains within the upper layers and an increase in *Plantago lanceolata* and *Ranunculus* (e.g. 230T-6).

6.1.2 Blanket peat initiation and spread across Lagafater

Radiocarbon dates for the initiation of blanket peat range over almost 2800 years from the oldest initiation phase (c.6375 cal. BP) at Lag 230 TOS to the youngest peat initiation date of c.3600 cal. BP at Lag 300 MOS. In view of the age range, the initiation of blanket peat cannot be attributed to a single climatic event across the landscape, although climate change may have been an influencing factor. The onset of climatic cooling between c.6500 cal. BP and c.6000 cal. BP most likely led to changes in the regional moisture balance which allowed the development of shallow, waterlogged areas in isolated topographic situations at Lag 230 TOS and Lag 300 TOS. The palynological record from the earliest deposits at these sites indicates the already well-established presence of *Calluna* within an open landscape, with patches of *Corylus* and *Betula* scrub. The interpretation of vegetation through the earliest mineral deposits may not be a true ecological picture but it does indicate the early establishment of heath in an exposed, relatively open landscape with naturally occurring acidic soils. Although early Mesolithic sites have been recorded in the area (e.g. Affleck 1996), there is little palynological evidence here to suggest any anthropogenic influence over the initiation of blanket peat at these TOS sites (herb taxa are sparse in the pollen percentage diagrams).

By c.5280 cal. BP, the top of slopes across the three different altitudes had begun to develop blanket peat. The pollen assemblages from these areas all contain *Calluna*, *Corylus* and *Sphagnum,* with a gradual expansion of herbs and decline in tree taxa (with the exception of *Alnus*). From the generally high *Corylus* values it appears that hazel had strong representation in this early woodland, and the expansion of *Alnus* at the TOS sites may also have a climatic explanation (see Birks 1975). The majority of trees were growing at Lag 230m OD, possibly as a result of warmer, more sheltered conditions.

Following the development of 'climatic' blanket peat on the tops of slopes, downward seepage of water as overland flow (demonstrated through particle size analysis at Lag 230 MOS) and as seepage from the drainage system, may have been responsible for the development of waterlogged conditions at the bottom of slopes, particularly at Lag 230m BOS. The variation in stratigraphy across Lagafater reflects the control topography has exerted over the development of blanket peat, with sites that have limited capability of absorbing increased moisture and those sitting in shallow basins being the next to form groundwater gleys and ombrogenous conditions.

At Lag 230m OD, peat appears to have expanded outwards from initial foci at the top of slope and upslope from the BOS site and this pattern is paralleled across all sites, with the MOS sites being the last to be covered with blanket peat. Similarly, ombrogenous peat across the MOS sites appears to sit directly on bedrock or directly on mineral soil (Lag 230 MOS) containing charcoal at the soil / peat interface. This evidence, coupled with the appearance of Cerealia pollen and associated weed species during the early Neolithic period, is taken to suggest human activity accelerated the process of blanket peat initiation at Lag 230 BOS and Lag 230 MOS. Lag 230m OD was, therefore, effectively covered in blanket peat by c.4675 cal. BP as a result of intense and localised agricultural activity. Human activity appears to have been a more influential factor in the development of blanket peat than a climatic driving force. The latter may have been anticipated to be more effective at the higher altitude sites of Lag 400m OD, where it is likely to have been slightly cooler but these were covered in blanket peat later in the Neolithic / Bronze Age.

An anthropogenic cause for blanket peat initiation is also put forward at Lag 300 BOS and Lag 300 MOS over a period of c.1110 years, following the initial establishment of 'climatic peat' at Lag 300 TOS. Although conditions appear to have become wetter, peaks in charcoal at both sites, and a reduction in the number and variety of tree species during peat initiation, suggest that human activity accelerated this process. The development of blanket peat at Lag 230m TOS and Lag 300 TOS is similar in date (between c.6375 cal. BP and c.6135 cal. BP) and is also similar at the bottom of slopes (between c.5185 cal. BP and c.4710 cal. BP). These dates suggest that peat developed across similar topographical situations with parallel influencing factors and during roughly the same time period.

There are fewer anthropogenic indicators across Lag 400m OD. This altitude may have been too exposed and cool to sustain continued arable agriculture. The development of blanket peat at Lag 400m BOS shows little evidence for an anthropogenic cause and was perhaps the result of a rise in water table with a climatic and hydrological influence. The development of blanket peat at Lag 400 MOS, however, at c.4620 cal. BP, is linked (i.e. it occurs during the same period) with a peak in charcoal at the TOS site and an increase in Cerealia grains and associated weed species. This suggests agricultural activity expanded to this altitude during a phase of warmer climate conditions and effectively accelerated the encroachment of blanket peat at this site.

6.1.3 Evidence for anthropogenic activity at Lagafater

The earliest clear palynological evidence for human activity is dated to c.5800 cal. BP at Lag 230T-2b where a number of Cerealia grains were identified, although with few accompanying disturbed ground species. It might be suggested that this represents a low level of anthropogenic activity or it was some distance from the site. Increased anthropogenic activity, however, occurs from c. 5100 cal. BP to c.3800 cal. BP with the continued presence of a number of Cerealia grains and associated arable weed species such as *Linum bienne*, *Artemisia* and *Urtica.* Throughout the vegetation history of all the sites at Lagafater, there are fewer pollen indicators to suggest a period of intense pastoral activity, although low levels of grazing may have occurred at higher altitudes (for example, at Lag 400 m OD).

The link between fire history and vegetation change is less clear. Initial charcoal peaks are recorded at Lag 230m OD at c.5130 cal. BP, paralleling an increase in values of Cerealia, but also occurs during a general period of Neolithic woodland regeneration. It is possible that burning removed scrub vegetation from around the site and, although direct evidence for this is not strong, this may have added to the local increase in soil moisture to encourage the accelerated spread of blanket peat at this altitude. More direct effects of burning are seen between c.5000 cal. BP and c.4500 cal. BP: a decline in tree taxa correlates well with the appearance of several charcoal layers (e.g. at Lag 300 BOS, Lag 230 MOS and Lag 400 MOS), the continued presence of Cerealia grains, and the initiation of blanket peat across several areas. The radiocarbon dates suggest that this clearance episode was more or less synchronous across all three altitudes and marks the first phase of more intense disturbance to woodland and shrub cover. In addition to the pollen analytical evidence, the archaeological record from Lagafater indicates the presence of people during the Neolithic, demonstrating the importance of place through a number of burial monuments, but domestic structures and evidence for occupation sites are still lacking (Figure 3.3).

A second, renewed phase of anthropogenic activity occurs in the Bronze Age between c.3500 cal. BP and c.3000 cal. BP. A number of charcoal layers are recorded from across Lag 230m OD, Lag 300m OD and Lag 400m OD (e.g. c.3382 cal. BP), particularly from the middle of slopes where peat encroachment was perhaps not so developed compared to the tops and bottoms of slopes. These are once again associated with a number of Cerealia grains and decreases in woodland cover, but little evidence of increased erosion in the sediment and lithological records suggests this was a small-scale disturbance. A number of Bronze Age hut circles, burnt mounds, settlements and field systems are associated with this period at Lagafater, e.g. at Maurs Carin (NX 165 742) and at Glenwhilly (NX 161 724), perhaps representing a continuation of early Neolithic agricultural practices, supporting the palynological evidence for local anthropogenic activity at a similar scale. The reliability of the Bronze Age dates given to these features is however, poor. Extensive field survey was carried out by the RCAHMS in 1997 but dating of these features is based on similar architectural styles from hut circles elsewhere in Scotland e.g. the hut circles of south Perthshire (Harris 1984). No excavation of these features has occurred in the study area. If we accept the Bronze Age date however, it would appear that the spread of blanket peat in the area did not deter Bronze Age settlers but they in fact continued their agricultural practises, presumably on the better draining MOS slopes and further south from the coring sites where a cluster of Bronze Age monuments (e.g. hut circles and field systems) can be found (Figure 3.4).

In the upper part of the Lag 230m pollen diagrams (c.3000 cal. BP to c.1500 cal. BP), *Calluna* heath continues to dominate the pollen percentage diagram but fewer charcoal horizons are recorded. A slight shift to more pastoral herb indicators is recorded (e.g. *Rumex acetosella* type and *Plantago lanceolata*) suggesting grazing was introduced to the now peat-covered landscape. Fewer archaeological remains covering the Iron Age and post-Iron Age period are present in the area indicating a possible shift in settlement, but Cerealia grains continue to be recorded, possibly originating from areas to the south of Lag 230m OD away from the main area of blanket peat. The last c.1500 years are distinguished by a gradual decline in *Calluna* and an increase in *Sphagnum*, wet meadow herbs and grassland species indicative of continued and intense pastoral activities.

6.1.4 Comparison of the degree of humification with dry bulk density data

Percentage dry weight of peat is closely related to its dry bulk density (Clymo 1984). Therefore, higher percentages of dry weight should represent sections where the peat structure has collapsed and/or more decomposition has occurred, and should indicate periods of dry mire surface. Humification measures the degree of peat decay calorimetrically, as the proportion of humic acid increases when decomposition is greater. Assessment of the decay of peat in blanket mires is primarily determined by surface wetness and temperature at the time of peat deposition: it is greatest in dry conditions when aerobic conditions are experienced. The two methods, therefore, should be an effective measure of the same decay process and of the same mire surface conditions, although factors such as post-depositional compaction, accumulation rates and autogenic processes may also have had an effect. Dry bulk density measures structural collapse and humification measures rates of decomposition. The relationship between the two was therefore explored and values were used as proxy data for dry and wet shifts. Figures 6.1 to 6.3 provide a summary of the surface conditions indicated from the data, and the degree of comparability. Horizontal lines across the data sets suggest a high degree of comparability between the humification and dry bulk density records, indicating clear periods of wet / dry conditions. By comparing these records, more regional changes in surface wetness can be separated from local autogenic changes in mire hydrology. Comparison of the degree of humification and dry bulk density was also made with the accumulation rates extrapolated from the AMS radiocarbon framework (Table 6.1)

Site	Depth (cm)	Calibrated Age (cal. BP)	Accumulation rate
230 TOS	0-68	0-1510	22 yr /cm
	69-102	1510-2530	31 yr /cm
	102-121	2530-3295	40 yr /cm
	121-138	3295-4025	43 yr /cm
	138-173	4025-5785	50 yr /cm
	173-184	5785-6375	54 yr /cm
230 MOS	0-48	0-1065	22.5 yr /cm
	48-78	1065-3535	82 yr /cm
	78-86	3535-4410	108 yr /cm
	86-91	4410-4675	53 yr /cm
230 BOS	0-73	0-1555	21.5 yr /cm
	73-128	1555-2970	26 yr /cm
	128-144	2970-3510	34 yr /cm
	144-175	3510-4110	19 yr /cm
	175-197	4110-4905	36 yr /cm
	197-215	4905-5185	15 yr /cm
300 TOS	0-87	0-4280	50 yr /cm
	87-121	4280-6135	54 yr /cm
300 MOS	0-50	0-730	15 yr /cm
	50-94	730-3350	59 yr /cm
	94-101	3350-3600	35 yr /cm
300 BOS	0-159	0-4620	29 yr /cm
	159-173	4620-4710	6 yr /cm
400 TOS	0-159	0-3480	22 yr /cm
	159-167	3480-5270	225 yr /cm
400 MOS	0-76	0-1240	16.5 yr /cm
	76-129	1240-3470	42 yr /cm
	129-142	3470-4620	88 yr /cm
400 BOS	0-146	0-4935	34 yr /cm

Table 6.1: Accumulation rates at Lag 230m, Lag 300m and Lag 400m OD based on AMS radiocarbon dates

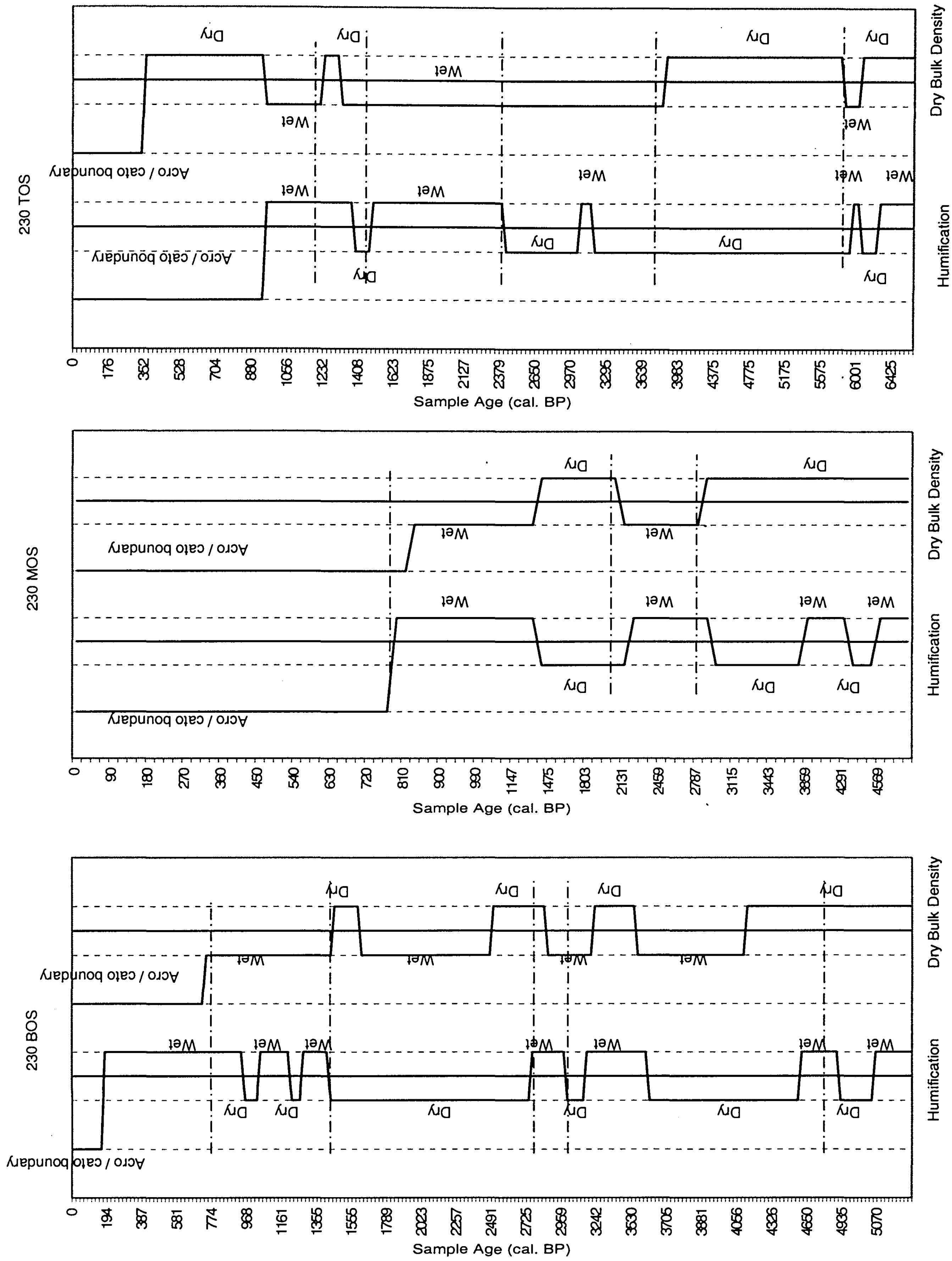


Figure 6.1: Inferred wet / dry shifts at Lag 230m OD based on humification & dry bulk density data. Horizontal lines indicate periods when both proxy records show similar mire surface conditions.

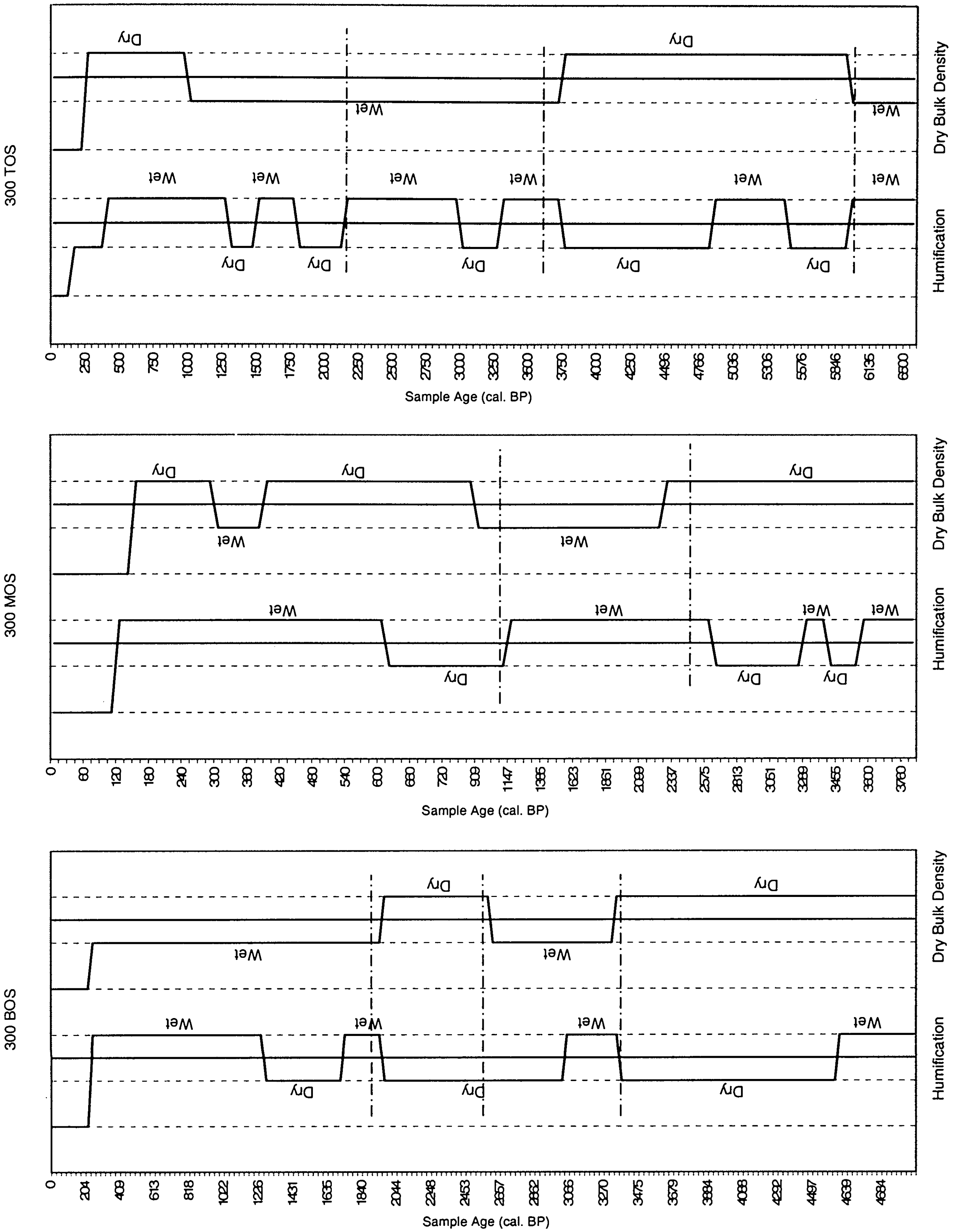


Figure 6.2: Inferred wet / dry shifts at Lag 300m OD based on humification & dry bulk density data. Horizontal lines indicate periods when both proxy records show similar mire surface conditions.

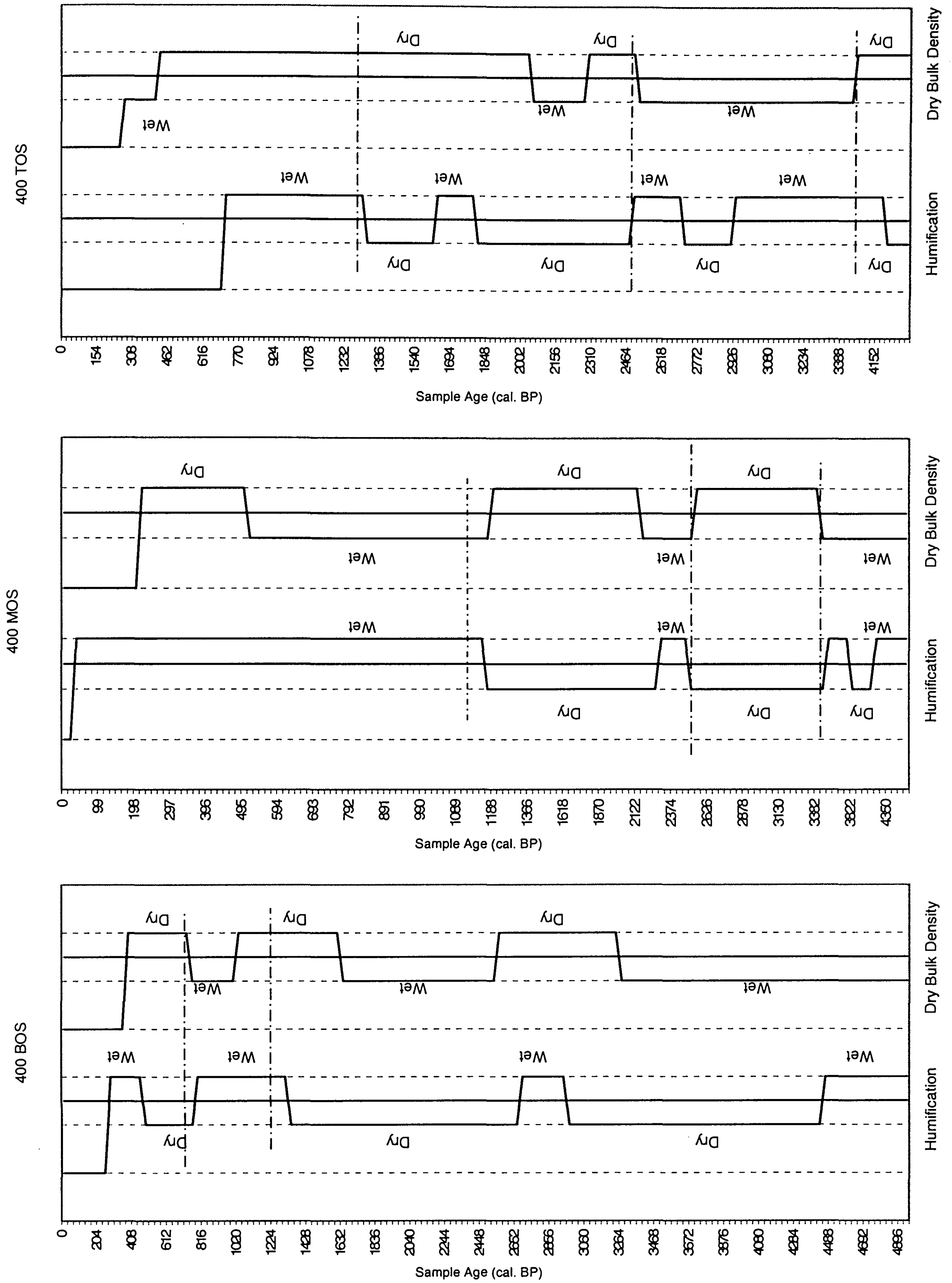


Figure 6.3: Inferred wet / dry shifts at Lag 400m OD based on humification & dry bulk density data. Horizontal lines indicate periods when both proxy records show similar mire surface conditions.

All of the MOS sites show a high degree of comparability between the palaeohydrological curves. It is possible that the lack of a groundwater gley across the middle of slopes, and the balance between moisture shedding and receiving, effectively gives a more accurate reflection of regional climatic changes. The BOS sites, however, appear to reflect more wet phases and more autogenic changes, particularly at Lag 230 BOS, as a result of greater throughflow and greater disturbance to the hydrological network upslope. The TOS sites may therefore represent more allogenic changes and they appear to have higher accumulation rates at the base of their profiles, suggesting these were the initial foci for waterlogging and peat accumulation and represent older, more compact samples. Separating changes in climate across the area from local autogenic changes was possible when there was a high degree of comparability across all nine sites and across all three proxy methods, particularly within the palynological record. These regional changes are discussed in more detail in chapter 7.

Comparison of the two data sets across the nine sites also show periods when the results do not match indicating the highly variable and influential nature of autogenic changes and the plant communities involved. It appears that the humification data show more changes to dry / wet episodes and dry bulk density data remain constant over longer periods of time. Humification is more sensitive to small scale changes and demonstrates a quicker response to changes in mire surface wetness suggesting decomposition of plant matter is a more accurate approach to measuring local hydrological change and precedes the process of compaction as blanket peat develops. A greater number of differences are recorded at Lag 230m where human impact was greatest. Brief changes recorded in the humification record highlight periods of disturbance to the vegetation, soil and local hydrological system following anthropogenic activity.

The relationship between bulk density (g/cm3), humification (percentage light transmission), and vertical accumulation rates (cm/yr) over the entire peat core is approximately linear with a tendency towards decreasing values with age. It has been suggested that decay is inconsequential over the age range of the peat (Gorham *et al* 2003) but clearly compaction has had an influence on the overall trend of bulk density readings, particularly towards the base of the cores. Aaby & Tauber (1975) and Rowell & Turner (1985), on work at Draved Moss and Quick Moss respectively, recognised an upper peat zone with a negative correlation between humification and pollen accumulation rates but a positive correlation in the lower zone as a result of compaction within the peat. Rowell & Turner (1985) explained the variable and inverse relationship between humification and accumulation rates in the upper layers as a result of short term climatic fluctuations about the long term mean, and results from Lagafater suggest a more sensitive record of wet / dry shifts over the last c. 1500 years. It is possible that the greater proportion and variety of plant taxa between c.6500 cal. BP and c.3000 cal. BP, with higher values of *Betula, Alnus* and *Corylus,* imply different plant communities, different bog surface conditions, greater areas of nutrient-rich soil, and a greater uptake of water, making the palaeoenvironmental record less sensitive to change. It is also interesting to note that accumulation rates at the base of Lag 230 m BOS and Lag 300m BOS are considerably higher than rates from other sites (15 years / cm and 6 years / cm respectively). These two sites contained a charcoal lens close to or at their initiation horizon suggesting *in situ* burning and disturbance of local vegetation which may have affected 'peat addition rates' and aerobic decomposition.

Table 6.2 provides a summary of the main vegetation changes and pollen assemblage zones across all nine sites at Lagafater from the present day through to the early Mesolithic period. Changes in regional climate (when there is agreement in the records across all of the sites) are indicated by shading with lighter grey areas representing periods of increased climatic wetness and darker grey areas representing periods when the climate was drier.

6.1.5 Summary

- Blanket peat initiation at the three TOS sites (Lag 230m TOS, Lag 300m TOS and Lag 400m TOS) has a climatic origin. Between c.6500 cal. BP and c.5400 cal. BP increased wetness was instrumental in determining the timing of peat initiation.
- Early peat initiation appears to have been confined to isolated hollows at the tops of slopes, and increased surface and throughflow collecting at the bottom of slopes encouraged the subsequent development of blanket peat at these locations.
- With the exception of Lag 400 BOS, anthropogenic activity accelerated the process of blanket peat initiation across Lagafater (the MOS and BOS sites).
- This initial development of blanket peat occurred within a relatively open landscape, where small stands of *Alnus / Betula / Corylus* woodland existed with more open areas dominated by *Calluna* and Poaceae, particularly on hill-top locations where conditions were more exposed and cooler. The transitional vegetation communities involved are relatively gradual within the pollen percentage diagrams and *Sphagnum* / wet mire communities form only a small component of the transition into blanket peat.
- A period of low intensity Neolithic and Bronze Age arable agricultural activities is identified across Lagafater.
- Humification and dry bulk density data can be used to identify regional shifts to wetter / drier bog surface conditions but site selection is paramount in separating allogenic changes from autogenic changes.

Age	230 BOS	230 MOS	230 TOS	300 MOS	400 MOS	400 TOS
0 Cereal	**230B-7b *Calluna* /** **Cyperaceae** **Open, wet heathland**	**230M-4 Poaceae / *Calluna*** Shrubs absent Rise in Poaceae and	**230T-6 *Calluna* / Poaceae** Increase in Poaceae, disturbance herbs.			
528 585	Cyperaceae and Poaceae **Some cereals**	**Some cereals** *Heath dominates* **230M-3c *Calluna* / Poaceae** Increase in Poaceae and	*Calluna* begins to decline			Wet
881 945 1298 1483 1500 1685 1800 No cereal 2000 2205	**230B-7a *Calluna* / Poaceae** Increase in *Sphagnum*. Peak in Poaceae at c.1182 cal. BP Rich grassland. **Some cereals** *Heath & herbs dominate* **230B-6 *Calluna* / Poaceae / *Filipendula*** *Heathland expands* Decline in trees at c.1481 cal.BP Poaceae increases and herbs **No cereals**	herbs. Rise in *Sphagnum* **230M-3b *Calluna* / *Erica Cinerea* / Poaceae** Heathland dominates Trees decline Some disturbed ground taxa Rise in Sphagnum. **Wet**	**230T-5b *Corylus* / *Calluna*** Decline in Calluna. Recovery of *Corylus*. Increased herbs. **Some Cereal.** Increase in **wet** loving species. **230T-5a *Calluna* / *Empetrum*** *Calluna* increases. Decline in Poaceae and herbs. Lower *Sphagnum*. Trees decline **230T-4 *Calluna* / Poaceae / *Sphagnum*** *Heath expansion* at c.2315 cal. BP Poaceae rises Peak in ***Sphagnum*** at c.2315			Wet Mediaeval
2300 2459 2500 2600 2690	**230B-5 *Alnus* / *Calluna*** Expansion of rich grassland **Some Cereals** Peak in *Alnus* at c.2777 cal.BP before decline *Calluna* / *heath expansion* at		cal. BP. **Cereal** grains and *Plantago lanceolata*. Trees decline			Iron Age Wet
2800 3200	c.2543 cal. BP					

Table 6.2: Summary pollen and climatic events across Lagafater. Lighter shaded areas indicate periods of wetter bog surface and darker shaded areas indicated drier periods (age in cal. BP)

Age	230 BOS	230 MOS	230 TOS	300 MOS	400 MOS	400 TOS
3200 Cereal				**300M-4b** ***Calluna* / Poaceae** *Calluna* increases, *Betula* decreases. *Sphagnum* increases.		Wet
3360 3382 3390		**230M-3a** ***Calluna* / Poaceae** *Calluna* increases *Alnus* & *Betula* decrease **Charcoal** at c.3361 cal.BP <u>Heath expands at c.3751</u> Grassland and some **cereals**	**230T-3b** ***Calluna* / Poaceae** Decline in *Calluna* & increase in *Alnus*. Trees decline. Rise in Poaceae and herbs.	2 **charcoal** peaks at c.3455 & c.3169 cal.BP **Cereal** grains & *Plantago lanceolata* increase.		Charcoal
No Cereal No Cereal	**230B-4 Poaceae / *Betula* / *Calluna*** Trees increase along with *Calluna*. <u>Some heath</u> Development of open grassland One cereal grain			**300M-4a** ***Calluna* / Poaceae** Aquatics appear (Typha & Potamogeton). Increase in *Sphagnum*. **Wet** Decrease in *Betula* & *Quercus*. Increase in *Calluna* & Poaceae. **Charcoal** peak at c.3455cal.BP <u>*Heath*</u> **No cereal** **300M-3** ***Alnus* / *Calluna*** Steady rise in *Calluna*.	**Lag400M-3** ***Calluna* / Betula** Increase in *Calluna*. / *Empetrum* declines. Decrease in woodland species. Sphagnum increases. **Wet. No Cereal** Peak in **charcoal** at c.3382cal.BP <u>*Heath*</u>	Late Bronze Age
3500 Cereal 3650 3700 3720 3750				Decrease in *Corylus*. Fall in *Quercus* & *Betula*. Rise in Poaceae & herbs. **Cereals** at c.3520cal.BP. Peak in **charcoal** at .3600cal.BP <u>*Heath*</u> (9) **Peat initiation at c.3600cal.BP**		Mid Bronze Age Dry

Age	230 BOS	230 MOS	230 TOS	300 MOS	400 MOS	400 TOS
3750 No Cereal 3780 No Cereal 3850 No Cereal 3900 4000	**23B-3b *Betula / Poaceae / Sphagnum*** Increased **wet** conditions Open ground herbs increase. **No cereal** Reduced trees	**230M-2 *Betula* / Poaceae** *Betula* rises / *Alnus* decreases. Fluctuating arboreal pollen values *Corylus* declines & then increases. Poaceae & grassland species increase. **Cereals at c.4400-c3900 cal.BP** Charcoal peak pre c.4675 cal.BP <u>*No heath*</u> (to c.5100)		**300M-2b *Betula / Corylus*** Increase in *Betula & Quercus*. Decrease in *Alnus & Calluna* *Sphagnum* <u>*Decrease in heath*</u> **No cereal** **300M-2a *Calluna* / Poaceae** Decline in *Betula & Quercus*. Increase in Poaceae & *Calluna* / ***Empetrum*** at c.3800cal.BP <u>*Heath*</u> **No cereal** **300M-1 *Betula / Calluna*** *Calluna* present. *Betula & Alnus* increase. Slight decline in *Corylus*. Increase in Pteridophyta **No cereal** <u>*Heath*</u>	**400M-2b *Calluna / Betula Empetrum*** *Calluna* increase. *Betula* increases. Poaceae decreases. *Plantago lanceolata* present. **No Cereals** **400M-2a *Calluna / Betula / Alnus*** *Betula, Quercus, Ulmus & Alnus* increase. <u>*Expansion of heathland*</u> at c.4180cal. BP & then decreases. **No Cereal**	Dry Early Bronze Age
4280 Cereal 4600	**230B-3a *Betula* / Poaceae** Reduction in herbs Sphagnum rises. Rise in *Betula* at c.4470 cal.BP. **One cereal** grain **Wet** <u>*No heath*</u>		**Lag 230T-3a *Calluna / Corylus*** *Calluna / Empetrum* increase. ***<u>Heath</u>***. Peak in *Sphagnum*. **Wet** Herbs decrease. 2 **cereal** grains, few anthrop indicators		**400M-1 Poaceae / *Calluna*** Decreasing values of *Betula, Alnus & Pinus*. *Calluna & Vaccinium* increase. <u>*Heath*</u> **Cereals** present at c.4620 cal. BP & herbs **Wet**	Late Neolithic

Age	230 BOS	230 MOS	230 TOS	300 BOS	400 MOS	400 TOS
4600						
Cereal					(8) **Peat initiation at c.4620 cal. BP**	**400T-2** ***Calluna*** **/ Poaceae** Increase in Poaceae, Cyperaceae & *Plantago lanceolata.* **Cereals** present. 4800-4400 cal. BP
4650		(7) **Peat Initiation at c.4675 cal. BP**		**300Bos-1** ***Betula*** **/ Poaceae** Woodland present. High levels of *Betula & Alnus.* Peak in *Calluna*, Poaceae. Decline in *Alnus & Betula* Peak in **charcoal** at c.4671cal BP		
4700						**Charcoal** peak at c.4600cal.BP Low but stable values of trees & <u>*heaths*</u>.(toc.5280 BP) Charcoal
Cereal				**Cereal** present between c.4680-4660cal.BP Fairly wet. <u>*Heath*</u>		Late Neolithic
4720				(6) **Peat initiation at c.4710cal.BP**		
4862					**400 BOS Little anthrop activity**	
4890	**230B-2b** ***Corylus*** **/ Poaceae** *Betula & Alnus* decline Rise in *Corylus* & shrubs. Increase in Poaceae & herbs **Cereal** grains. Charcoal peak at c.4970cal.BP <u>*No heath*</u>				**Lag400B-5** ***Betula / Alnus*** **/ Poaceae** Poaceae increases & *Ranunculus, Saxifraga*, & Compositeae increase. **herbs** *Calluna* decreases **Charcoal** at c.4930-4862 cal. BP **No cereals**	Late Neolithic
Cereal						Charcoal
5001						
5030					(5) **Peat initiation at c.4935 cal. BP**	

Age	230 BOS	230 MOS	230 TOS	300 BOS	400 BOS	400 TOS
5001 5030 Cereal	**230B-2a *Betula* / Poaceae** *Betula* percentages increase, *Alnus* declines Poaceae and grassland increase. *Corylus* declines **Cereal** grains c.5090-5060cal.BP No grazing indicators <u>*No heath*</u>				**Lag400B-4 *Alnus / Ulmus*** *Alnus, Ulmus, Quercus & Betula* increase. **Trees** *Corylus* & Calluna decrease **No cereals** <u>*Heath*</u>	Mid Neolithic
5100 5125 5166 Cereal	**230B-1 *Alnus/Corylus*** *Alnus* increases & peaks at c.5190cal.BP Partially wooded (60%tlp) *Corylus* increases. Poaceae increases & decreases. **Cereal** grains from c.5190cal.BP Charcoal peak at c5130cal BP **Relatively Dry** <u>*No heath*</u>	**230M-1 *Alnus / Corylus*** Peak in Pteridophyta, *Sphagnum & Pediastrum* (waterlogged conditions). *Corylus* increase *Alnus* values high and stable. Woodland = 40-50% TLP. 2 x charcoal peaks **Cereal** grains pre c.4675 cal.BP **Wet to dry** <u>*No heath*</u>			**Lag400B-3 *Alnus / Corylus*** Increase in woodland: *Alnus, Pinus & Betula* increase. *Corylus* decreases **Peak in herbs** e.g., *Rumex acetosella*. **Charcoal** peak at c.5194-5161cal.BP **No cereal**	Charcoal
5200 5280 5300 5331 5397 No Cereal 5463 5476	(4) **Peat initiation at c.5185cal.BP**				**Lag400B-2b *Corylus / Sphagnum*** Decline in woodland. *Corylus* increases. *Sphagnum* peaks c.53331cal.BP **Wet/ open** Pteridophyta reach a maximum <u>*Little heath*</u> **Lag400B-2a Corylus / Cyperaceae** Peak in Corylus and Myrica. Peak in Cyperaceae & Sphagnum. **Wet / open** Decrease in herbs. Decrease in Quercus, Pinus & Alnus. **No cereal**	(3) **Peat initiation at c.5270 cal. BP** **400T-1 *Alnus / Calluna*** Decline in woodland e.g.; *Alnus, Betula & Pinus*. Increase in *Calluna & Empetrum*. Sphagnum **Wet** **No Cereals** <u>*Heathland develops*</u> Early Neolithic

Age	230 BOS	230 MOS	230 TOS	300 TOS	400 BOS	400 TOS
5463						
5500			**230T-2c *Alnus* / Poaceae** Slight rise in *Alnus*, decline in *Corylus & Sphagnum*. *Calluna* stabilizes ***Ulmus* decline** c.5725 cal. BP) **Cereal** grains <u>*Heath*</u>		**400B-1 *Corylus / Pinus*** High level of Pteridophyta & *Sphagnum.* **Wet / open** Open ground herbs & *Corylus* increasing **No Cereal** <u>*Little heath*</u>	
5562						
5720						
6000			**230T-2b *Calluna / Betula*** Decrease in *Calluna* Increase in *Betula, Quercus, Alnus.* **Charcoal** peak at c.5893cal.BP Poaceae & **Cereal grains after C.5800cal.BP.** Slight decline in woodland species. <u>*Heath*</u>			
Cereal				**300T-3 *Betula* / Poaceae** Increase in *Betula & Alnus* Decline in *Calluna* Increase in Poaceae **Charcoal** peat at c.5954 cal.BP **No Cereal** <u>*Heath*</u>		Charcoal Early Neolithic
6050 6135						

Age	230 BOS	230 MOS	230 TOS	300 TOS	400 BOS	400 TOS
6050 6135 6200 No Cereal			**230T-2a *Calluna / Alnus*** *Calluna* & *Empetrum* increase (40% TLP at c.6050cal.BP). **Small peak in charcoal** at c.6109cal.BP Herbs begin to increase Low intensity grazing *Heath*	**300T-2 *Calluna / Betula*** Poaceae rises & then declines. Some grazing herbs *Corylus* decreases **Heath** *Calluna* & *Vaccinium* increase (2) **Peat initiation at c.6135 cal.BP**	Wet Mesolithic
6250 No Cereal 6360			(1) **Peat initiation at c.6375 cal.BP**	**300T-1 *Calluna/ Corylus*** *Calluna* & heaths= 50%TLP *Corylus* declines, Alnus increases. Very few herbs Decrease in *Calluna* at c.6300cal.BP Increase in Poaceae **No cereals** *Heath*		
6400 6500 No Cereal 6600			**230T-1 *Alnus / Corylus*** *Corylus* & *Myrica* make up 30% TLP. Shrubs *Calluna* & Droseraceae levels high. *Alnus* increases, *Betula* decreases. **No cereals** *Heath*			

Chapter 7 Interpretation

7.1 *Climate and vegetation change in the south-west of Scotland*

The accumulation of organic matter and the initiation of blanket peat is a result of waterlogging through local hydrological change (chapter 2). Using a multi-proxy approach, including palynology, humification and dry bulk density tests, as well as employing twenty-nine AMS radiocarbon dates, nine sites on a single hillside in south-west Scotland were examined for evidence of causal factors in such hydrological change (chapter 5). The results of these investigations (chapter 6) have highlighted a number of factors that are responsible for changes in hydrology and thus the initiation of blanket peat. The timing and subsequent spread of blanket peat across Lagafater have also been examined, and shown to have varied altitudinally and with micro-topography, with the tops of slopes acting as primary foci for peat accumulation (chapters 5 and 6). Cross-correlation of the pollen records spanning peat initiation between the sites has shown a high level of comparability. The full pollen percentage diagrams from Lag 230m TOS also display similarities (chapter 6). This environmental record can now, therefore, be compared with regional evidence for vegetation and climatic changes, placing Lagafater within the wider landscape. This chapter will also review the factors that have contributed to peat initiation in the south-west of Scotland and assess the contribution this study will make to our understanding of peat initiation processes and to the palaeoenvironmental record for Scotland.

7.1.1 The palynological records from south-west Scotland

The record of climate and vegetation change from blanket peat is necessarily constrained by the depth, age and availability of suitable deposits. The pollen sequence from Lagafater, therefore, covering the last c.6500 cal. years, contains important evidence principally for the development of early agricultural practices, closely related to the archaeological remains in the area.

The earliest palynological record at Lagafater records the presence of *Corylus, Myrica, Betula* and *Alnus* growing locally, along with heathland taxa such as *Calluna* growing on the more exposed top of slope sites. The pattern of colonisation and migration by the main tree taxa across Scotland is reasonably well established (e.g. Tipping 1994) and the data at Lagafater do not add to this. The exact timing of the colonisation of this woodland at Lagafater is difficult to discern, although by c.6000 cal. BP woodlands were probably at their maximum extent in the region (Tipping 1994). The creation of a *Calluna* heath landscape during the Mesolithic period has often been considered, and regarded as having close associations with Mesolithic human activity (e.g. Caseldine & Hatton 1993, Moore 1993, Simmons 1969), in which Mesolithic groups are seen as operating small-scale land-use systems for food production (Simmons 1996). Fire has been seen as fundamental to this management (Simmons 1996). The number of charcoal fragments in the Moffat Hills at Rotten Bottom between c.7000 and c.6000 cal. BP was high (Tipping & Milburn 2000), possibly associated with Mesolithic hunting activities high in the hills. Mesolithic anthropogenic woodland disturbances have been recorded from Burnfoothill Moss (Tipping 1995, 1999), at Loch Doon and Loch Dungeon (Edwards 1999) and at Ballachrink, Isle of Man (Innes *et al* 2003). This evidence, however, remains circumstantial across many parts of Scotland, including the south-west. Climatic stress and natural fire incidences might themselves have led to vegetation change and the replacement of woodland by heath (Tipping 1996, 2004).

Only one early charcoal layer is recorded at Lagafater, from Lag 230 TOS, and is dated to c.6050 cal. BP. It is possible that this is associated with late Mesolithic activity as it coincides with an increase in *Calluna* and *Empetrum* and the appearance of a possible cereal grain, at Lag 300 TOS, although there are few other palynological or sedimentological indications to suggest anthropogenic activity (see section 3.2.1 on pre-*Ulmus* decline Cereal pollen). The early and well-established presence of *Calluna* in some areas of the Lagafater landscape (i.e. on the tops of slopes) may have more of an edaphic cause. Increasingly acid substrates, typical of the Silurian Llandovery and Wenlock series, may have supported heathland from early in the Holocene. This is perhaps the earliest recorded heathland development for the south-west of Scotland. At higher altitudes before c.6000 cal. BP, a predominance of open-ground species with stands of *Betula* and *Corylus* suggest a largely treeless and exposed landscape across the south-west of Scotland (Birks 1972; Tipping 1999).

The impact of late Mesolithic activity at Lagafater is unclear from the palynological record. The end of the Mesolithic is distinguished by climatic dryness (e.g. at Burnfoothill Moss), centred on c.6100 cal. BP, and is well reported across other areas of Scotland and northern England (Barber *et al* 1994, Hughes *et al* 2000, Tipping 1995). A brief period of wetter conditions, however, is then recorded from sites across the south-west of Scotland, in particular at Rotten Bottom after c.6500 cal. BP and at Pict's Knowe from c.6040 cal. BP. It was perhaps during this period that increased waterlogging began in isolated hollows at the top of slopes across Lagafater. *Pinus,* for example, played no major role in the mid-Holocene woodlands of Lagafater, but probably had done earlier; Birks (1975) argues that its poor representation and disappearance from the Galloway Hills at c.7000 cal. BP was a result of increased wetness. At Pict's Knowe, values of *Pinus* decline abruptly between c.6410 and c.6190 cal. BP, possibly as a result of an increase in groundwater levels (Milburn & Tipping 1999). A similar picture is suggested at the base of Lag 300 TOS, where a slight decline in *Pinus* is recorded prior to c.6135 cal. BP, and at Lag 400 BOS, prior to c.4935 cal.BP; at this latter site coinciding with the initiation of blanket peat.

Following a brief period of increased precipitation, when blanket peat began to develop at Lag 230 TOS, Lag 300 TOS and Lag 400 BOS, mire records from the south-west of Scotland suggest conditions became drier for a sustained period (Milburn & Tipping 1999; Tipping & Tisdall 2004), interspersed with minor wet phases. It was during the early Neolithic that the earliest cereal grains are recorded from Lagafater, dated to c.5800 cal BP at Lag 230 TOS where the climate and location were most suitable for cereal cultivation. Bonsall *et al* (2002) and Tipping (1994) suggest that drier soils, particularly during the earliest Neolithic period, facilitated the adoption of cereal cultivation. At Lagafater, Neolithic human activity appears to have been only small-scale, with minor changes in values of woodland taxa recorded. The beginning of clear anthropogenic activity, however, does coincide with a possible *Ulmus* decline recorded at Lag 230 TOS and dated to c.5725 cal. BP. Elsewhere in south-west Scotland, temporary small-scale woodland disturbances in an already relatively open environment, and the appearance of cereal grains, have been recorded at Snibe Bog (Birks 1972), Aros Moss (Nichols 1967) and Torrs Warren, Luce Sands (Durno 1996), along with an increase in open ground taxa such as *Plantago lanceolata.* It is possible that natural disturbance mechanisms may have been responsible for the appearance of these weed species across south-west Scotland (Petts 1998), and low pollen frequencies from comparatively well-dispersed taxa across large areas need to be interpreted with care (Davies & Tipping 2004). However, the consistency with which herbaceous taxa such as *Plantago lanceolata*, Asteraceae and Chenopodiaceae are recorded from across the south-west of Scotland, and the close correlation of plant taxa from the nine sites at

Lagafater, suggest an intensive period of early Neolithic agriculture. The poorer representation of pastoral palynological indicators within the pollen diagrams from Lagafater is perhaps a reflection of the geographical location of the pollen sampling sites (below 450m OD), reflecting economic separation between lowland and highland regions. Archaeological evidence (although undated) may also support the idea of lowland settlement at Lagafater (see section 3.3) reflecting a long tradition of arable agriculture, with early field systems being recorded from across the region.

Between c.5476 and c.5280 cal. BP at Lagafater, a period of wetter conditions are recorded. By c.5185 cal. BP blanket peat had spread across much of the lower altitudes (230m TOS). Following the period of expansion of blanket peat, a rise in the numbers and pollen frequencies of tree taxa is also recorded, particularly increased values of *Alnus, Quercus* and *Ulmus* at c.5100 cal. BP. This may correlate with the more widespread period of later Neolithic woodland regeneration, where increases in the spread of woodland are also recorded at Brighouse Bay (Wells & Mighall 1999), Auld Wives Lifts (Dickson, 1981), Airds Moss (Durno, 1956), Bigholm Burn and Nick of Curleywee (Moar 1969), and Snibe Bog (Birks 1972). The synchronicity and reasons for this regeneration of woodland taxa across south-west Scotland, however, remain little understood (Tipping 1999). A period of drier conditions, for example, is recorded at Lagafater shortly after this woodland regeneration, associated with the expansion of *Calluna* and a number of charcoal peaks and increased values of cereal type pollen. Intensive anthropogenic activity at Lagafater is implicated in the initiation of blanket peat during this period, with associated declines in values of tree taxa, increased levels of charcoal and low peat accumulation rates particularly at the middle and bottom of slopes. A wet phase at c.4400 cal. BP is then recorded across Scotland during this period (see section 7.1.2 below), and a marked deterioration in climate is recorded at Burnfoothill Moss (with decreased humification levels) and also seen at Lagafater, with increased levels of *Sphagnum* and *Pediastrum* and an increase in the number of open ground herbs.

Early Bronze Age agricultural activity has been recorded across northern England and Scotland, particularly along the west coast. These sites can be linked with more extensive deforestation between c.4000 cal. BP and c.3800 cal. BP (e.g. Hodgkinson *et al* 2000; Macklin *et al* 2000), and with an increase in non-arboreal pollen such as Chenopodiaceae, Poaceae and *Plantago lanceolata* (e.g. at Snibe bog and Loch Dungeon (Birks 1972), Loch Dee (Edwards *et al* 1991), Burnswark Hill (Jobey 1978) and Machrie Moor, Arran (Robinson & Dickson 1988)). The frequency, extent and spatial impact of anthropogenic activities throughout this period, however, appear to have varied, with continuous occupation but small-scale clearance, followed by periods of woodland recovery (Tipping 1999). Radiocarbon dates and the palynological record indicate that there were no significant changes in the vegetation record at the start of the Bronze Age at Lagafater, with an apparent continuation of small-scale activities from the Neolithic period. A change in settlement patterns from the Neolithic, however, seems to have occurred, with the number, distribution and extent of hut-circles and associated field systems traditionally attributed to the Bronze Age increasing, particularly at lower altitudes (between c.100m OD to c.230m OD), but many of these sites are centred around earlier Neolithic monuments, perhaps highlighting the continuity of the 'importance of place' (Tipping 1994). Examples of apparently early rig-and-furrow field systems can be seen at Little Larg (NX 154 658) to the south of the coring sites, and at Barnvannoch (NX17SW 19), Stab Hill hut-circle (NX 146 719), Knockglass Rees hut-circle and field system (NX 148 716), and Glenwhilly hut-circle, clearance cairns and field system (NX 163 724). It is possible that further evidence for Neolithic settlement remains buried beneath the blanket peat but the local and regional field monument and palynological evidence implies an increase in the number of archaeological monuments in the early Bronze Age, conventionally seen to attest to an increase in population (e.g. Burgess 1980, 1984; McCullagh & Tipping 1998; Parker Pearson 1993), but this appears to have been centred at lower altitudes (below 300m OD). Evidence for agricultural activities during this period is limited for Lag 400m OD, suggesting that climatically and pedogenically this was an unsuitable area for arable agriculture.

A more intense phase of arable agriculture is recorded on the mid- and lower slopes at Lagafater 230m OD and Lag 300m OD from c.3500 cal. BP to c.2500 cal. BP, with a further reduction in trees, an increase in frequency of charcoal horizons and an expansion of *Calluna* heath. Increased levels of charcoal and the expansion of heath during this period have also been recorded at Loch Dee (Edwards *et al* 1991), Loch Dungeon (Birks 1972) and Burnswark Hill (Jobey 1978). Towards the end of this period, between c.2800 cal. BP and c.2500 cal. BP, a marked wet shift is recorded across all nine sites at Lagafater, correlating well with other sites in Scotland (e.g. Kentra Moss; Ellis & Tallis 2000), northern England (e.g. Bolton Fell Moss; Hughes *et al* 2000) and across Europe (e.g. the Netherlands; van Geel *et al* 1996).

A decrease or change in human activity is recorded at the close of the Bronze Age and early Iron Age, with fewer cereal type pollen grains and charcoal lenses being recorded. Reduced anthropogenic impacts have also been recorded from Machrie Moor, Arran (Robinson & Dickson 1988) and from Aros Moss (Nichols 1967), coinciding with the expansion of *Calluna* and other Ericaceae.

The pattern of woodland clearance during the late Iron Age and Romano-British period has been widely discussed, based on evidence from pollen diagrams from northern England and southern Scotland. These have suggested that the timing and removal of tree taxa and the intensity of agricultural activity varied widely (Turner 1979). Intensification of agriculture appears to have occurred in central and southern Scotland during the later Iron Age (Dumayne 1993; Mercer & Tipping 1994; Whittington *et al* 1991), with evidence for a massive woodland clearance episode extending into the south-west from Burnfoothill Moss (Tipping 1995), seen in a rise in pastoral herb indicators from Brighouse Bay (Wells & Mighall 1999). It is during this period that an increase in taxa indicative of pastoral activities is recorded at Lagafater, although the by now largely treeless landscape records no further reductions in arboreal pollen and few archaeological structures in the area can be related to this period. Other areas of southern Scotland and northern England appear to have been well wooded with only temporary small-scale clearances in the early-mid Iron Age (Barber 1981; Donaldson & Turner 1977; Dumayne & Barber 1994). A substantial loss of woodland, however, occurred across north-east England and southern Scotland during the Romano-British period (Rowell & Turner 1985; Dumayne & Barber 1994). Dumfries and Galloway, however, remained little affected by the presence of a Roman army and a largely cleared landscape existed prior to any short-term demands made by a Roman presence (Edwards & Ralston 2003).

Few pollen diagrams from the south-west of Scotland have considered the palynological evidence for the post-Roman and Mediaeval periods. The continued presence of agricultural indicators at Lagafater, however, and from Burnfoothill Moss (Tipping 1999b), at Rotten Bottom (Tipping 1999c) and from the Galloway Hills (Birks 1972), suggest a mixed farming economy of both pastoral and arable agriculture has existed from the Mediaeval period until the present day.

7.1.2 The Proxy Palaeoclimatic Record

During the last two decades, major advances in techniques to recover climate signals from the palaeoecological record have been made (see chapter 1 and chapter 2): in particular with the use of colorimetric humification analysis of blanket peat (Blackford 1990; Blackford & Chambers 1991). The results of the analyses made at the nine sites across Lagafater are presented in table 7.1, where a number of apparent dry/wet shifts have been identified. They are also summarised in chapter 6 alongside the pollen evidence. This section considers the results of humification and dry bulk density data in terms of local changes across the study area, and by comparison to more regional records. Where there is clear agreement across all nine sites of increased wetness, this is considered to have more regional significance. Table 7.1 shows darker shaded areas indicating a possible wet shift across Lagafater and lighter shaded areas indicate a dry phase across all nine sites. Symbols have also been used to indicate the presence of charcoal and cereals to try to relate these records to periods of human activity.

It is difficult to compare the data presented here with records published elsewhere as a result of differences in sampling resolution and regional differences in past rainfall regimes, as well as those interpretative problems outlined in section 2.1.4. A shortage of palaeoclimatic records from the south-west of Scotland also makes interpretation difficult. The compilation of data from across Scotland, however, is presented in Table 2.2. This may be used to make comparisons with other sites and identify particular periods when the climate may have been significantly different across Scotland.

All radiocarbon dates used in this thesis are calibrated at 2-sigma and presented as calendar years BP. For the purpose of this thesis, calibrated dates at Lagafater are regarded as synchronous when they overlap at 2-sigma (i.e. are statistically indistinguishable). For comparative reasons, dates from across other palaeoecological sites are considered similar when calibrated dates lie within c.100 years of each other.

230 BOS	230 MOS	230 TOS	300 BOS	300 MOS	300 TOS	400 BOS	400 MOS	400 TOS
		6375-6271 5947			**6135**-6008 6068			
					▲5954			
		▲5893			5846 (Dry)			
5185 ●5185		●Cereals						**5270**
5130 ▲5130	▲pre 4675					▲pre 4935		
5100 ●5090-5060	●pre 4675				5036			
▲4970 4950 (Dry)						▲4930-4862 **4935**		
4866 ●Cereals	▲pre 4675 **4675**		**4710** *4684 – 4652* ▲4671 ●4680			*4726*	**4620** ●4620	●4800 ▲4600
	4296						4262	
	●4400-3900						3998	3928
3744 (Dry)	3800 (Dry)	4125 (Dry)	3942 (Dry)		4150 (Dry)	3702 (Dry)		
				3600 ▲3600-3560 ●3520				
3378	▲3361	3290	3248	*3348, 3278* ▲3455 ●3455	*3350*		▲3382	3480
				3208 - 2736 (Dry)			3298 (Dry)	2970 (Dry)
2777	2476	2347	*3066*	*2500*	*2200-2800*	*2822*	2374	*2618*
2275 (Dry)	2100 (Dry)	2000 (Dry)	*2540* (Dry) 2200 (Dry)			*2142* (Dry)		2266 (Dry)
			1856		*1600*			
1092	1035	*1034*	*1044*	*1084*		*1190*	*1089*	*1122*
925			**788**	**630**				
494			**464**	**450**	**550**		**561**	**594**
				280		**374**		
							165	

Table 7.1; Wet phases inferred from humification data at Lagafater (dates in Cal. BP). Bold text indicates peat initiation dates and italicised text indicate significant change. Shaded areas indicate regional change. ▲charcoal horizons; ● cereals.

The palaeohydrological procedures adopted in this thesis have produced comparable records between sites and are accompanied by a shift to wet-loving species such as *Sphagnum* and Cyperaceae, outlined in table 7.1. Several horizons in which records agree can be found and are listed below, showing the approximate calibrated age and the sites from which the evidence was retrieved.

1. Lag 230 TOS, Lag 300 TOS and Lag 400 TOS show evidence for increased wetness from the period c.6375 to c.5500 cal. BP. Interpretation of these basal sequences is difficult as waterlogging is clearly a precursor to the development of blanket peat but is not necessarily initiated through climatic forcing alone. However, comparison with records from Burnfoothill Moss suggests that the climate became increasingly wet until c.4800 cal. BP.
2. All of the Lagafater sites, with the exception of Lag 300 MOS and Lag 400 MOS and TOS, record a dry period between c.4150 cal. BP and c.3700 cal. BP, correlating with the expansion of settlement in the area and the intensification of arable agriculture.
3. Multi-proxy data from Lag 230 BOS and TOS, Lag 300 BOS, MOS and TOS, and Lag 400 TOS identifies a wet shift dated to between c.3400 cal. BP and c.3100 cal. BP.
4. All sites record a shift to wetter conditions between c.2800 cal. BP and c.2500 cal. BP.
5. A dry shift is recorded from c.2200 to c.1850 cal. BP at all sites, with the exception of Lag 300 MOS and TOS, and Lag 400 MOS.
6. A further shift to wet bog surface conditions is recorded from all sites, except Lag 300 TOS, from c.1120 cal. BP to c.1034 cal. BP.
7. Multi-proxy data suggest a final wet phase at all sites, with the exception of Lag 230 MOS and TOS and Lag 400 BOS, between c.594 and c.464 cal. BP.

There is good correlation between sites at Lagafater for a palaeohydrological signal. With the exception of the wet phase at c.2800 cal. BP, however, none of the patterns are replicated at all sites. This is probably the result of differences across slope in hydrology as well as the sensitivity of the blanket bog in different locations to different climatic regimes. In particular, more intensive agricultural activity at Lag 230m OD may have made this site more sensitive to only minor changes in precipitation, with increased run-off resulting from areas cleared for arable activity. Similarly, as the blanket bog has grown both vertically and laterally, changing conditions on the surface may influence the hydrological activity and nature of plant decomposition.

The first significant wet phase at Lagafater occurred from c.3400 to c.3100 cal BP. Whilst this occurs during a period of increased evidence for human activity, Table 3.1 suggests that similar wet shifts were experienced across Scotland and the British Isles. Perhaps most significantly, a shift is recorded at Ellergower Moss at c.3390 cal. BP (Stoneman 1993) and at Talla Moss dated to c.3455 cal. BP (Chambers *et al* 1997) in south-west Scotland. Across Wester Ross and north-west Scotland (Anderson 1998; Anderson *et al* 1998; Bridge *et al* 1990) a similar shift at c.3300 cal. BP is recorded, and at Kentra Moss, Argyll, it is dated to c.3250 cal. BP (Ellis & Tallis 2000). Sites from the north of England (e.g. Bolton Fell Moss, Walton Moss and Coom Rigg Moss) also record a similar date for a wet shift and at Mongan Bog and Abberknockmoy bog in Ireland it is dated to c.3500-c.3200 cal. BP (Barber 1981, 1994; Barber *et al* 2003; Charman *et al* 1999). There is strong agreement in the published records from Scotland and elsewhere that the peaks in surface wetness at Lagafater may have a more regional significance.

A second and more prominent wet shift is recorded from c.2800 cal. BP to c.2500 cal. BP across the Lagafater region. This event is recorded from many sites across the United Kingdom and Ireland. In particular, it has been dated to c.2680 cal. BP at Carsegowan Moss (Stoneman 1993) in south-west Scotland. Dates for this event are presented in Table 3.1 and span the period c.2900 cal. BP to c.2400 cal. BP, covering the range of dates that were recorded at Lagafater. Archaeological and palaeoecological evidence for an abrupt climate change across Europe and the Netherlands has been reported at c.2650 cal. BP (van Geel *et al* 1996). Barber (1985) concluded that this was one of the largest climatic events of the late Holocene.

A 'Dark Age' climatic deterioration in the British Isles at c.1400 cal. BP is reported from several sites, including Migneint, north Wales, Latterfrack, west Ireland (Blackford & Chambers 1991), at Walton Moss (Hughes *et al* 2000) and at Kentra Moss, Scotland (Ellis & Tallis 2000). Unfortunately, a change to wetter conditions at Lagafater was not recorded from any of the sites during this period, but a later phase at c.1120-c.1035 cal. BP is clearly recorded. Table 3.1 also suggests that more sites recorded a shift at this time with dates varying from c.1000 cal. BP to c.1200 cal. BP. At Kirkpatrick Fleming, in south-west Scotland, a similar phase is recorded at c.1200 cal. BP (Tipping 1995).

The final shift to wetter conditions at Lagafater coincides with the recognised climatic deterioration during the 'Little Ice Age' at c.559 to c.464 cal. BP (Blackford & Chambers 1995; Chambers *et al* 1997; Mauquoy *et al* 2002). In the south-west of Scotland this is reported at Kirkpatrick Fleming at c.400 cal. BP (Tipping 1995) and at Carsegowan Moss at c.410 cal. BP, and occurs across Cumbria (Barber 1981; Barber *et al* 1994), southern Scotland (Charman *et al* 1997) and the north Pennines (Mauquoy & Barber 1999) (see Table 3.1). There is also historical data for such a shift to colder conditions (Lamb 1977) and it is recorded in glacier advance histories (Grove 1988).

Analysis of humification data from across the British Isles has demonstrated that mires show a periodic response to climatic forcing factors (Chamber & Blackford 2001), with possible solar, volcanic and sea temperature associations (see section 2.2). For example, periodicities of mire surface conditions of between c.200 and c.260 years have been identified from the Scottish Borders (Chambers *et al* 1997) and periodicities of c.600 and c.1100 years have been shown from Walton Moss in northern England (Hughes *et al* 2000). However, it is not possible at Lagafater to demonstrate any clear periodicity between the nine sites, perhaps as a result of local conditions at the coring site, lags in the response of vegetation to climate and hydrological change (up and down slope), the autogenic nature of many of the wet shifts identified, and the different intensity of anthropogenic activity across the landscape. It is possible that higher resolution humification analysis of the peat cores at Lagafater (here only sampled at 4cm and 1cm through the transition zone) may, for example, have identified further shifts to wet conditions and further, more comparable, correlations with the dry bulk density data. A decrease in sea surface salinity as a result of increased sea surface temperatures has, however, been dated to c.3500 and c.3000 cal. BP and may have had an affect on wet shifts in the north of Scotland (Anderson 1998). Variations in solar activity have also been suggested for climatic changes in the 'Little ice Age'. (Mauquoy *et a*l 2002). These theories, however, remain speculative and cannot be demonstrated to have had an effect here.

7.2 Blanket Bog initiation at Lagafater and across the British Isles

A unique analysis of the factors responsible for blanket peat initiation has been undertaken at Lagafater. A survey of the underlying topography on slopes at three different altitudes produced a transect showing the variation in peat depth across a relatively short distance, highlighting the importance of sub-peat topographic surveys in order to identify key coring locations. The radiocarbon dates for the initiation of blanket peat at the nine sites indicate that peat first began to accumulate at the top of the slope at Lag 230m OD, with an initiation date of c.6375 cal. BP, and was last to form on the middle of slope at Lag 300 MOS at c.3600 cal. BP. It therefore appears to have taken a period of c.2775 years for blanket peat to have effectively covered the Lagafater area. The pattern of peat accumulation and spread appears to correlate well across all three sites with early initial foci being centred in hollows at the tops of slopes, subsequent development at the bottom of slopes, and lastly, peat encroaching onto the middle of slopes. It is likely that additional dating and examination of other points along these transects would record other initiation dates but which would follow a similar pattern of spread.

Detecting the transition to true blanket peat was possible in the sequences that appeared to contain a soil profile beneath the peat or contained a well humified peat with some sand/silt component. All of the profiles sampled were targeted in deeper locations and all, with the exception of Lag 400 MOS, appeared to sit on a thin soil horizon, varying in depth between 5cm and 28cm. The earlier, top of slope sites, contained a thin soil lying directly on bedrock. The palynological record indicates the already acidophilous nature of the plant taxa and it is perhaps the topography and altitude in small hollows that were the predominant factors in influencing the earliest peat initiation. The deeper sediment depth at the BOS sites, in particular Lag 230 BOS, shows a greater transition from minerogenic soil to well humified peat. As already discussed, increased surface and through-flow from the slopes above would have led to greater moisture levels and water collecting at these predominantly lower, water receiving sites. It is therefore possible that waterlogging of the soils occurred periodically, creating ground water gleys (as recorded at Lag 230 BOS) which were a factor of topography rather than the impermeable nature of the underlying soil (as demonstrated through particle size analysis). The importance of topography is similarly highlighted with the middle of slope sites. At Lag 400 MOS, blanket peat appears to have formed directly over bedrock, suggesting that it had encroached laterally to this point from elsewhere, but at Lag 230 MOS and Lag 300 MOS, particularly the former, a thin soil horizon was evident prior to peat initiation. The humification and dry bulk density data clearly show comparable records of surface wetness, indicating the balanced nature of water receiving and shedding on these sloping sites. Particle size analysis indicated that there were no pedogenic reasons for blanket peat initiation. An allogenic force was therefore required to change the hydrological balance at these MOS sites, and at Lagafater human activity is implicated.

The soil profile beneath the blanket peat, often showing a gley profile or sitting directly on bedrock, was sampled for pollen to elucidate the pre-peat vegetation history across Lagafater. The interpretation of pollen counts through mineral soils has many difficulties (as outlined in section 4.6): e.g. overall pollen preservation, mixing of pollen from elsewhere, disturbance of the pollen stratification by downwash. The present study, however, analysed pollen through the basal layers on an empirical basis, and standard pollen counts (i.e. 500 grains) were often achieved through these layers. Inter-site comparison of the pollen was achieved and detailed palynological descriptions can be found in sections 5.4 to 5.7. Overall, *Corylus*, Poaceae and *Alnus* typified the tops of slopes with various tree taxa and *Calluna* also recorded. At the MOS and BOS slopes, similar sequences were noted but with an absence of *Calluna*, suggesting heath development was initially confined to the more exposed tops of slopes. The presence of wet-loving taxa such as *Sphagnum*, *Pteridium* and Cyperaceae through the soil layers indicate that initial waterlogging and gleying of the mineral soil started prior to peat accumulation. The early pollen sequences from Lagafater correlate well with pollen profiles from pre-peat vegetation recorded across the Southern Pennines (Tallis 1964).

The factors responsible for blanket peat formation have been the subject of much discussion and are outlined in chapter 2. Whether climate, pedology, topography or anthropogenic activity acted individually or collectively is difficult to discern. At Lagafater, the close sampling interval of peat profiles from a number of sites in a relatively small locality has allowed factors to be separated. Pedology, for example, was not a factor in the initiation of blanket peat. An initial shift towards wetter climatic conditions, however, does appear to be a prerequisite for the very beginning of peat initiation, as demonstrated by the closely-dated early samples at Lagafater from the tops of the slopes. Topography is also important, with the top, moisture receiving slopes acting as initial foci for waterlogging and thereafter influencing the downslope movement of water. Blanket peat spread across the landscape then becomes a battle between climate and anthropogenic affects, with these two factors affecting the spread and speed at which the landscape is effectively covered.

Across Lagafater there is demonstrable evidence for human activity having accelerated and caused peat formation at certain localities. Activities such as burning, catchment deforestation, mire drainage and the grazing of livestock have caused a variety of changes in wetland systems (e.g. Frenzel 1983; Pearsall 1956, Pennington 1972) and have been responsible for peat initiation at other localities (e.g. Moore 1975). Tipping (1995) proposed that anthropogenic activity, in particular prehistoric woodland clearance and an increase in the frequency of charcoal records, was responsible for the transition to raised bog at Burnfoothill Moss, south-west Scotland. At Lagafater, only small-scale woodland disturbances have been recorded, which are difficult to see as causal in hydrological change. These may, however, have accelerated paludification at Lag 400 BOS, where a noticeable reduction in tree taxa occurs with a corresponding increase in pastoral herbs at the point of peat initiation at c.4935 cal. BP.

Extensive deforestation is often associated with increased levels of run-off, leaching of soils, and increased peaks in mineral matter as a result of erosion. Some episodes of increased erosion have been recorded between c.4675 cal. BP and c.3648 cal. BP at Lag 230 MOS and Lag 400 BOS but these have not been recorded across all nine sites, suggesting activity was relatively small-scale and localised. Human-induced fires, however, may have played a more significant role in blanket peat initiation. Charcoal was seen to be present in increasing concentrations during and after peat initiation at Lag 230 BOS, Lag 230 MOS, Lag 300 BOS, Lag 300 MOS and Lag 400 MOS (see Table 7.1). Tolonen *et al* (1985) suggested that fires raise the water table of a peatland due to the blockage of the peat matrix by fine charcoal particles. If this process occurs, as it appears to have done at Lagafater, over an area above the line of the seasonally fluctuating water table, then an impermeable layer may form, suitable for the retention of rainwater on the surface leading to progressively more ombrotrophic conditions. The development of peat at these sites also appears to correlate with relatively dry conditions, heightening the vulnerability of the soil surface to fire. Separating the precise cause and effect of fire and peat initiation is difficult. However, at Lag 230 MOS (c.4675 cal. BP), at Lag 300 BOS (c.4671 cal. BP), Lag 300 MOS (c.3600 cal. BP) and at Lag 400 MOS (c.c.4620 cal. BP), charcoal horizons associated with increased anthropogenic activity are directly associated with the timing of peat initiation (or a little before). It is, therefore, apparent that in a changing, predominantly ombrotrophic environment with raised water tables, these areas were already susceptible to blanket peat development, but direct human activity accelerated this and was ultimately responsible for the beginning of its initiation. The factors responsible for peat initiation are summarised in table 7.2.

Site	**Peat initiation factors**
230 TOS	Climate & Topography
230MOS	Human activity
230 BOS	Topography & human activity
300 TOS	Climate & Topography
300 MOS	Human activity
300 BOS	Human activity
400 TOS	Climate & Topography
400 MOS	Human activity
400 BOS	Topography & human activity

Table 7.2: Factors responsible for peat initiation at Lagafater, south-west Scotland

At this stage it is not possible to understand the timing of blanket peat initiation across the south-west of Scotland as few other comparable data sets exist for the area (Birks 1973; Boatman 1983), and only isolated dates for the transition of raised mires from fen communities to bog communities have been recorded (e.g. at Burnfoothill Moss (Tipping 1995) and at Carsegowan Moss (Stoneman 1993)). Table 2.2 outlines the radiocarbon dates for blanket peat initiation across the United Kingdom and Ireland. A survey of the dates for blanket peat initiation across Ireland (Edwards 1985) shows that most derive in the Bronze Age but span c.4500-1000 cal. BP. Similarly, a comparison of initiation dates has been made for sites across Finland (Korhola 1994) where two phases of peat initiation have been recognised (c.8000-7300 cal. BP and c.4300-300 cal. BP), for Norway (Kaland 1986) and for sites across Canada (Halsey *et al* 1998). Previously, no comparison of blanket peat initiation dates has been made for Scotland and dates that do exist embrace different altitudes, different initiation horizons and span many different periods. A collation of basal dates from across Scotland (based on those displayed in Table 2.2) is presented in Figure 7.1 along with the dates for peat initiation from Lagafater. This shows the spread of initiation dates from c.10380 cal. BP to c.1700 cal. BP, disproving the theory of sudden climatic deterioration instigating initiation across Scotland. The average of these dates places peat initiation at c.5058 cal. BP, during the Neolithic, suggesting blanket peat formation at Lagafater was an early phenomenon compared to elsewhere in Scotland, perhaps as a result of intensive agricultural activity and its oceanic situation. A clustering of peat initiation dates can also be seen between c.5270 cal. BP and c.4620 cal. BP (Neolithic) indicating a period of widespread peat initiation across Scotland, and a second phase between c. 4010 cal. BP and c.3355 cal. BP (Bronze Age). The majority of the Lagafater dates fall within these phases, particularly the earlier Neolithic phase. Lag 230 TOS and Lag 300 TOS, however, are earlier still and fewer dates from across Scotland for blanket peat initiation appear to fall before c.6300 cal. BP.

Greater numbers of radiocarbon dates and a more thorough regime of sampling for blanket peat initiation across smaller landscape areas (recording variables such as topographic location, slope angle, depth of peat, underlying terrain) are needed to assess the factors behind peat initiation across areas of Scotland and to further clarify more regional phases of peat development. Numerous descriptions and terminology used in blanket mire investigations appear to have clouded the issue and it would seem a more quantified approach to blanket mire terminology is required if inter-site comparability is to prove meaningful.

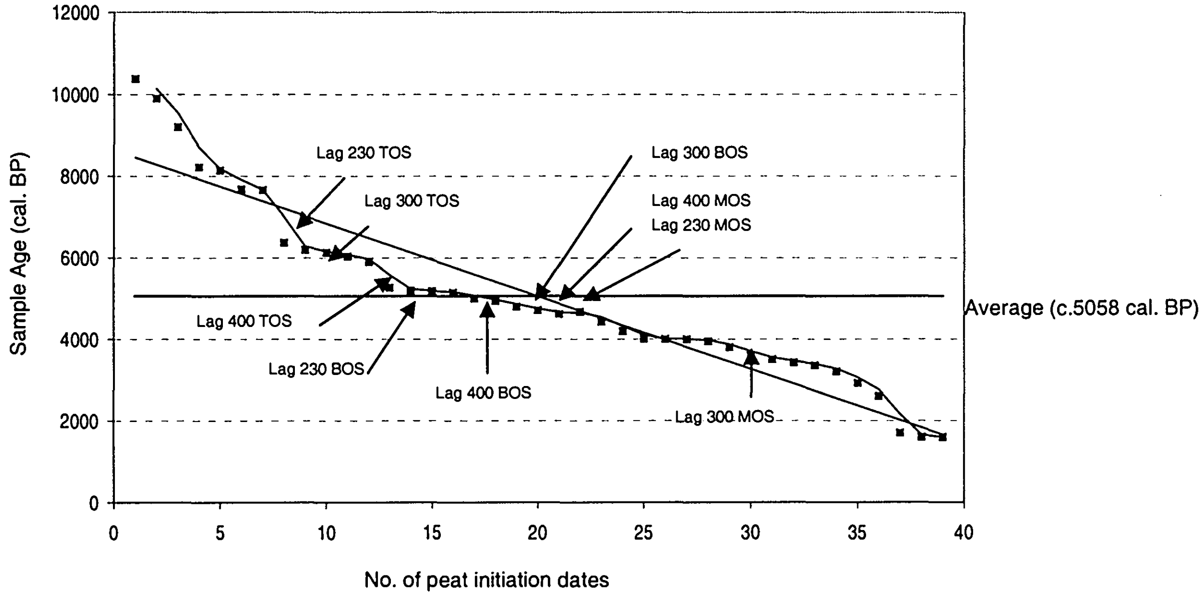


Figure 7.1: Scatter plot of 39 radiocarbon dates (cal. BP) for blanket peat initiation across Scotland and Lagafater showing a linear trend line and moving average (see also table 2.2)

7.3 *Models of blanket peat initiation*

As outlined in chapter 1, there are four principal hypotheses for blanket peat initiation across any given landscape. These are outlined below, summarising suggestions as to the processes required.

1. The first is the autogenic hypothesis, where peat accumulation is driven solely by internal hydrological factors such as natural pedogenesis. Peat will begin to accumulate in a relatively stable climatic situation where little or no human activity affects the local hydrology. Carr species such as *Alnus* and *Betula* may be widespread and produce large volumes of litter. The upper layers of the peat may also become seasonally aerated allowing for the constant deposition of organic material and the release of humic acids. The development of ombrotrophic conditions would then ensue, with the development of mire communities, such as *Sphagnum* and *Calluna*, resulting in further acidification. A series of similarly dated profiles for peat initiation may be expected across a small area.

At Lagafater, the basal sediments were subject to a number of soil tests including particle size analysis which showed little vertical distribution of structural and textural pedogenic processes typical of podzolic profiles (e.g. Scheffer & Schachtschabel 1989) and little evidence for the development of podzolised horizons and iron-pan. Soil micromorpholgy would have shown in greater detail the minerals and features within the soil prior to blanket peat initiation including any weathering, soil / plant interactions, sedimentology and ground water flow but was not undertaken as part of this study. Pollen analysis however, did show the relatively high percentage of arboreal taxa at Lagafater before peat initiation, and in some cases, the delayed transition from a partially wooded landscape to a *Calluna* and *Sphagnum* dominated heath (Lag 230m BOS and Lag 230m MOS). This evidence, and the spread of radiocarbon dates across the site, suggests that pedogenic change was not responsible for blanket peat initiation at Lagafater.

2. The second hypothesis suggests that climate change may have been responsible for peat initiation. A regional shift to wetter conditions occurs with a subsequent rise in the water table and widespread paludification as drainage is impeded. Such an effect will

result in the development of blanket peat over a similar time-scale across a wide area. The climatic factor is also reliant on drainage being impeded, a factor of topography, soil type and underlying substrate, as well as the extent of the hydrological network covering the area (i.e. the ability of streams and channels to remove excess water).

At Lagafater, the spread of radiocarbon dates across all nine sites indicates that regional climate change was not responsible for blanket peat initiation as this was time-transgressive. The predominance of wet loving, acidophilous flora in the basal sediments and the earlier dates for peat initiation at the TOS sites however, indicate that climate may have been responsible for peat initiation at these water receiving sites. Synchronous changes in the humification records across all nine sites were also identified in the blanket peat record post its inception, at c.3400 cal. BP and c.2800 cal. BP (see section 7.1.2). Internal hydrological variations were separated from the climatic signal by comparison of the humification and dry bulk density data (Figure 6.1 – 6.3). The BOS sites for example, showed a greater number of wet phases as a result of greater throughflow and disturbance to the hydrological network upslope.

3. The third hypothesis is that human activity alone was responsible for blanket peat initiation. This would rely on changes to the hydrology of the area created by deforestation, burning and grazing. Such activities would lead to increased surface soil erosion, possibly down to more impermeable bedrock, leaching of nutrients causing increased acidification, and changes to the overall surface hydrology. Timing of peat initiation would be sporadic and site-specific, dependent on the intensity of activity. It is often difficult to separate human activity as a factor from climate change but if little evidence exists for local climate change then human activity may be implicated as the instigator of change.

At Lagafater, the pollen record showed a number of Cerealia grains and weed species (e.g. *Plantago lanceolata*) indicative of disturbance to the soil prior to, and at the same time as, peat initiation. Similarly, a number of charcoal horizons were identified at the crucial peat initiation interface (e.g. Lag 300 MOS) and the spread of radiocarbon dates indicate a prolonged period of peat initiation (see Table 5.1). Together, this evidence indicates that human activity did influence the initiation and spread of blanket peat at key locations.

4. The fourth hypothesis states that blanket peat initiation is time-transgressive with peat beginning in small isolated areas and progressively covering the landscape.

At Lagafater, detailed examination of blanket peat samples from the top, middle and bottom of three separate slopes allowed for the separation of the key factors involved in peat initiation and outlined in the previous hypotheses. Blanket peat initiation at any one of the nine sites if sampled in isolation, could give a misleading representation of how peat formed in this area. For example, peat began to form initially in isolated locations at the tops of slopes where climate was the causal factor (e.g. Lag 230 TOS). The sampling of nine sites at different topographical locations however, showed that peat initiation was time-transgressive at Lagafater with different dates from all nine sites (Table 5.1). A number of phases of peat initiation were centred between c.5270 cal. BP and c.4620 cal. BP and between c.4010 cal. BP and c.3355 cal.BP (see section 7.2) and no one individual factor was responsible for blanket peat initiation across the whole area.

Separating the three suggested pathways to peat initiation is often difficult and any number may occur simultaneously. However, these hypotheses should be the starting point for any blanket peat initiation study. The need for multiple sampling across a small area is clear. If, for example, radiocarbon dates are very similar across a wide area then Hypothesis 3 may be dismissed. At Lagafater, the first hypothesis does not seem to apply to the area but a combination of the second and third were responsible for peat initiation. The importance of topography, soil and underlying geology is also key to understanding the timing of, and reasons why, thresholds were crossed and peat began to develop.

The final hypothesis relates to peat accumulation and spread once one of the above factors has been instigated. It has been shown from this study that peat accumulation did begin in small isolated areas at the tops of slope where the nature of the sub-peat topography played an important role. Peat accumulation was then time-transgressive, as suitable locations across the landscape became ideal for waterlogging and peat initiation. This process was accelerated by topographical location, increased surface wetness as a result of climate change and, more importantly at Lagafater, as a result of localised human activity in the form of woodland and scrub clearance by fire for small-scale agricultural activity.

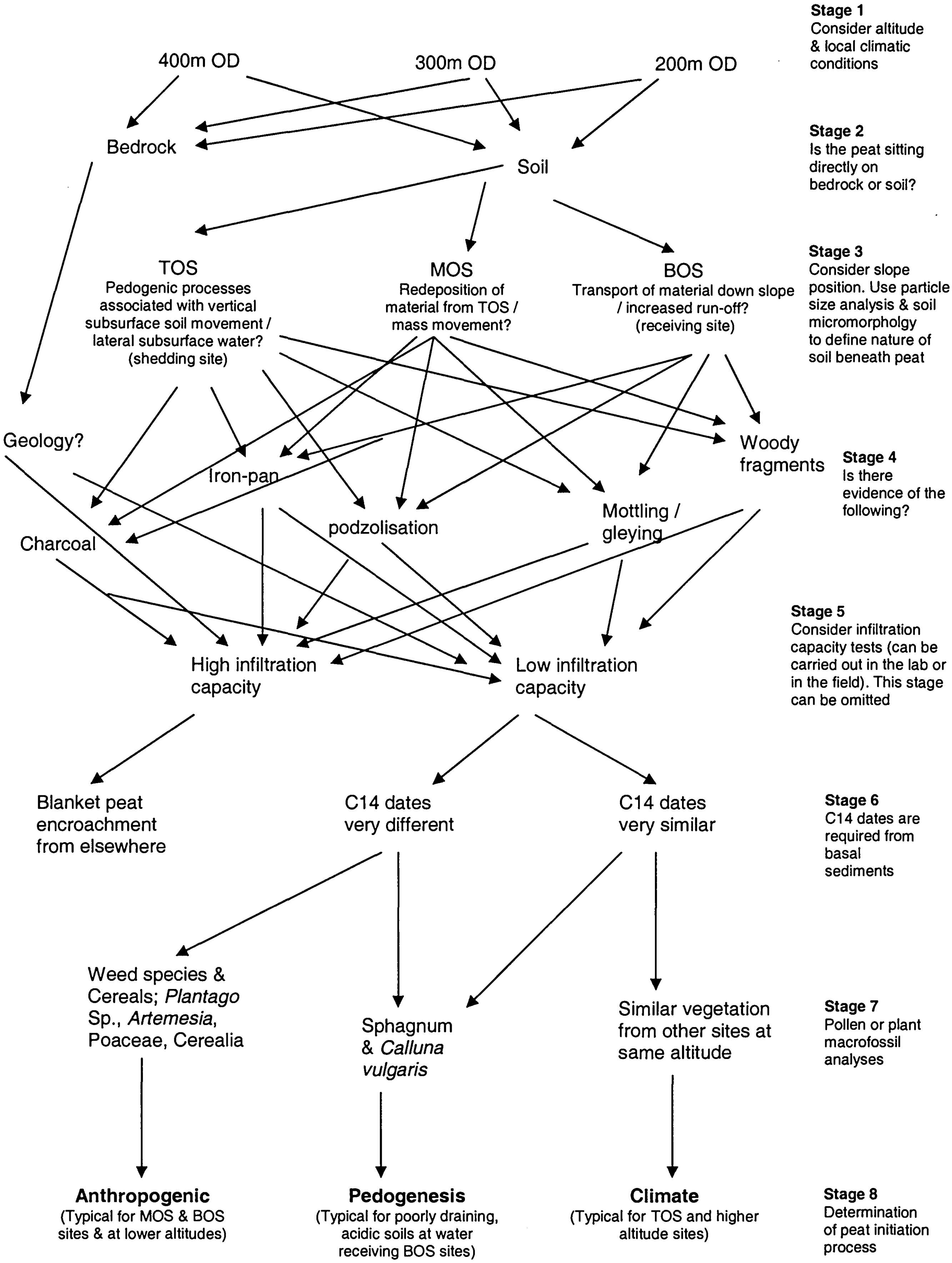


Figure 7.2: The interaction between potential factors involved in blanket peat initiation.

Figure 7.2 presents a schematic diagram of the potential factors responsible for blanket peat initiation against which a series of questions based on observations can be derived (stages 1 to 8 to the left of the diagram). This should be used as the basis for future blanket peat initiation studies.. If anthropogenic factors are cited as the causal effect of peat initiation then Moore's (1993) diagram should also be referred to (Figure 7.3). At Lagafater, the processes involved in the development of blanket peat have been circled (Figure 7.3.).

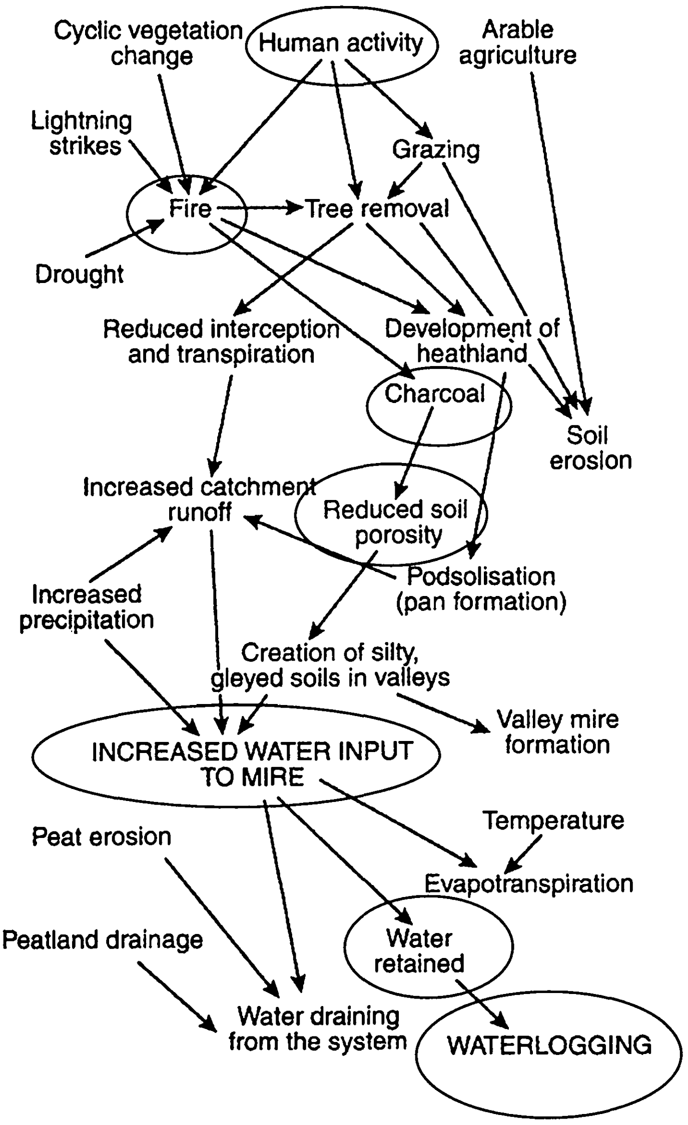


Figure 7.3: Factors responsible for waterlogging in mires, with particular reference to anthropogenic activity. Redrawn from Moore (1993). The processes involved at Lagafater have been circled.

The results of this PhD have conclusively shown that climate change and human impact were responsible for the initiation of blanket peat across Lagafater in the south-west of Scotland. Initially, at the top of slopes, climate alone was responsible for increased waterlogging of the soils and the development of blanket peat (e.g. Lag 230 TOS). Lagafater would inevitable have become peat covered over the last c.6000 years given the further periods of increased wetness identified in the peat record but the extent and depth of deposits may have been different from today's picture if it hadn't been for the influence of local human activity.

Blanket peat began to grow at c.6375 cal. BP at Lagafater through to c.3600 cal. BP (Lag 300 MOS), at which point the area was effectively covered. The samples from the TOS sites (the earliest dates to have been recorded) show a spread of dates covering c.1105 years; similarly, at the MOS sites, dates span 1075 years, and across the BOS sites dates span 475 years, indicating the time-transgressive nature of peat development across different altitudes and up and down slope.

The importance of local topographical and geomorphological factors have been highlighted with small changes identified in the humification and dry bulk density data sets, indicative of autogenic influences (section 6.1.4). The pollen record also shows a dominance of acidophilous flora and early heath development at the tops of slopes prior to encroachment elsewhere, and human activity appears to have been concentrated at the lower altitude sites of Lag 230m and Lag 300m with greater numbers of Cerealia and agricultural weed species. Particle size analysis also highlights some surface water gleying across the BOS sites and some sorting by flowing water at the MOS sites (e.g. Lag 230 MOS). Slope angle is therefore considered to be an important factor in the development of blanket peat, encouraging the spread of peat from the tops of slopes primarily, to the bottom of slopes secondarily and then encroaching into the middle of the slopes finally.

The nature of human activity preserved within the blanket peat consists primarily of changes to the pollen record with fluctuating levels of tree and shrub species and the inclusion of greater numbers of Poaceae, Cerealia, associated weed species and charcoal. The types of activity envisaged at Lagafater include small-scale coppicing and burning of woodland and heather, to create open areas for the cultivation of some cereals and the creation of open areas for arable activity, perhaps used as part of a rotating system of farming.

The results have therefore provided evidence and answers to the initial thesis questions shown in section 1.7 and the key factors responsible for blanket peat initiation have been separated and identified through strategic sampling locations across the area and up and down slope. The results generated have allowed for the creation of a simple model (Figure7.2) to aid in understanding the nature and timing of peat initiation which may be applied to any region.

Chapter 8 Conclusion

8.1 *Conclusion*

The use of nine closely spaced pollen diagrams at Lagafater in the Glenn App valley, south west Scotland has allowed the reconstruction of the local vegetation history in three dimensions. Within this area, blanket peat ranges from over 500m OD to under 150m OD, also providing the opportunity to study blanket peat development and initiation factors as well as human interaction over a range of altitudes.

The palynological evidence allows us to picture firstly a relatively open landscape dominated by *Corylus, Alnus* and *Betula* stands with some open grassland and patches of *Calluna* at higher altitudes. An increase in precipitation and a slight climatic deterioration at c.6200 cal. BP, allowed for the development of the first blanket peat across the tops of the slopes. The marginal areas of woodland were eventually replaced by heath, first dominating the higher altitude site at Lag 400m and the more exposed tops of slopes. Early Neolithic agriculture, in particular pastoral based activities at higher altitudes and cereal cultivation on lower ground, also instigated several phases of woodland loss, coupled with small scale burning, encouraging the development of blanket peat at Lag 230m and Lag 300m. This intensive phase of agricultural activity also continued into the Bronze Age and the area was effectively covered in blanket peat by c.3600 cal. BP. Open, peat forming communities dominated by grasses, herbs and *Calluna* gradually developed across the whole landscape. There is clear evidence from the peat records of plant communities responding to human pressure over the last c.1000 years, mire loving taxa have dominated the plant record with changing quantities of herb taxa attesting to a continued human presence. The data from Lagafater emphasize the importance of selecting several pollen sites from across a relatively small landscape setting and applying high resolution pollen analyses through key sedimentary horizons in order to fully understand the vegetation and land use history of an area.

Four periods of increased surface wetness have also been recorded from Lagafater all of which support inferred climatic shifts from other sites across the British Isles and Ireland. In particular, a prominent wet shift is recorded at c.2800 cal. BP to c.2500 cal. BP and is supported by evidence from across Europe and the Netherlands, suggesting this was a significant Holocene climatic event. Similarly a wet shift at c.559 to c.464 cal. BP coincides with the well published climatic deterioration during the 'Little Ice Age' also identified across the British Isles and South West Scotland.

Blanket peat initiation at Lagafater began in the Mesolithic period and appears to have followed two models of formation; one where climate is responsible for increased wetness and the initial waterlogging of primary sites and the second, where human activity can be seen to have been responsible for peat initiation. The latter had a particular impact at lower topographical situations and at lower altitudes where more intense agricultural activity had occurred. Removal of woodland is evident in the palynological record and several charcoal horizons are associated with the initiation of blanket peat across Lagafater. The tops of slope were the first to act as *foci* for peat initiation and following increased levels of soil moisture coupled with human activity, the bottom of slopes then began to accumulate peat. The middle of slopes were the last to be covered in blanket peat and human activity is likely to have accelerated this process.

Peatland development is often multi-directional and has been attributed to both autogenic and allogenic processes that operate and interact over the history of the landscape (Hu & Davis 1995; Halsey *et al* 1998). At Lagafater, the evidence supports the views presented by Moore & Bellamy (1973), Tallis (1991), Charman (1994) and Foster & Fritz (1987), whose ideas of peat development in primary, secondary and tertiary states and the variability the landscape has made in the timing and spread of blanket peat initiation, highlights the need for an understanding of the topographical location from which samples are taken. Similarly, Korhola (1995) and Almquist-Jacobsen & Foster (1995) found a correlation between blanket peat initiation and wetter periods which has been identified at the tops of slopes across Lagafater. Evidence from pollen and charcoal sequences has also led many authors to suggest that early prehistoric human activity was responsible for blanket peat initiation throughout Scotland (e.g.; Bohncke 1988, Edwards 1996; Hirons and Edwards 1990, Newell 1988) and throughout the British Isles (e.g.; Moore 1975, Case *et al* 1969, Tallis 1991; Taylor & Smith 1980), where differences in topography and altitude alone could not explain the range and dates of peat initiation. Human activity at Lagafater was crucial in accelerating peatland development across much of the area.

Blanket peat contains a wealth of information including macro-and microfossil evidence, charcoal analysis, age / depth sequences and isotopic signatures. Knowledge derived from all of these sources could feed into the validation and creation of blanket peat initiation models (e.g. Figure 7.2), a process that would require close co-operation between the palaeoecological and modelling community. For example, by recording physiographic parameters of substrate texture, topography, peat depth, soil type and aspect at each site, a more detailed understanding of blanket peat development could be had. Numerous radiocarbon dates from across peatland landscapes, having defined an agreed 'peat initiation horizon' (here taken to be over 80% organic material), multiple and meaningful basal dates could be available. These could then be gridded and contoured and physiographic parameters (e.g. angle of slope) transferred into numeric values (as adopted by Halsey *et al* 1998). Predictions may then be made of blanket peat basal dates and a greater temporal database would allow greater understanding of the factors responsible for initiation.

The ability to refine the AMS radiocarbon chronology also relies on the identification of tephra isochrons through the blanket peat. Lagafater and its oceanic position as well as the depth of peat deposits presented an ideal opportunity to search for tephra horizons. Unfortunately, none were found at Lagafater, although given the time restraints of this study, it may prove that further, more detailed research could detect these important isochrones.

Overall, this thesis has presented a detailed case study in order to understand the processes of blanket peat initiation across a wider landscape, at the 'meso-scale'. The key questions outlined in Chapter 1 regarding the nature of human activity, the periodicity of climate change and how these have affected blanket peat initiation have all been answered. Similarly, the date, pattern of spread and factors responsible for blanket peat initiation at Lagafater have also been uncovered. I hope that the results of this study will add to our understanding of how to tackle the complicated and persistent problem of understanding blanket peat initiation and will add to the important and little studied palaeoenvironmental picture of the south west of Scotland.

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APPENDIX 1

Standard Soil Tests

Moisture Content

1. Place small amount of sub-sample (i.e.; 10-20g) onto a petri dish and weigh
2. Take sediment and dry at 35°C for 24hrs
3. Remove from oven and reweigh
4. Using the following equation work out moisture content

100-[{ (w after drying – w of petri dish) / (w before drying – w of petri dish) } * 100]

Organic Matter Content

1. Weigh a clean, dry, porcelain crucible (to 0.01g)
2. Take sediment sub-sample and oven dry at 35°C for 24 hrs. Crush soil to powder form (or sieve through a 2mm fraction and retain below 2mm fraction)
3. Add circa 5g of oven dry, crushed sediment to crucible. Reweigh and record weight.
4. Heat for 5mins at 110*c to drive water off
5. Place samples in muffle furnace at 550°C for 4 to 4 ½ hrs
6. Allow oven to cool and then remove samples from muffle furnace
7. Heat for 5 mins at 110°C again. Remove and weigh immediately
8. Using the following equation work out organic percentage

100-[{ ('w after LOI' – 'w of crucible') / ('w before LOI' – 'w of crucible') } * 100]

APPENDIX 2

Dry Bulk Density (after Berglund, BE 1986).

1. Heat a porcelain crucible (about 30ml) for 1 hour at 550 °C in a muffle furnace, cool it to room temperature in a desiccator and determine the weight of crucible (*A*) to an accuracy of ± 0.1mg
2. Transfer a fixed volume of the fresh sample (5-10ml) to the crucible and immediately determine the *weight of sample and crucible* (*B*)
3. Place the crucible in an air-circulation oven at 60 °C and dry to constant weight (overnight for about 12 hours).
4. Let the crucible and sample cool to room temperature in a desiccator and determine the *weight of the dry sample and crucible* (*C*). Alternatively place crucibles in an oven at 110 C for 5 mins to drive off water and weigh immediately. This will give you DRY BULK DENSITY
5. Place the crucible with the dry sample in a muffle furnace for 2 hours at 550 °C. If the sample has a high organic content put a porcelain lid on the crucible and start at a lower temperature. By this procedure, ash losses by violent burning of the sample can be prevented.
6. Let the crucible with the ignited sample cool to room temperature in a desiccator and determine the *weight of ash and crucible* (*D*). This will give you LOI / ASH CONTENT
7. Place the crucible with the ignited sample in a muffle furnace for 4 hours at 925 °C.
8. Let the crucible with the ignited sample cool to room temperature in a desiccator and determine the *weight of ash and crucible* (*E*). This will give you CARBONATE CONTENT.

APPENDIX 3

Particle Size Analysis Preparation

1. Dry soil at 35-40°C for 24 hrs and pass through a 2.00mm sieve
2. Place 5-10g of each sediment sample into a 250ml wide necked pyrex conical flask, labelled with the same sample number or other identifying symbol (if the sample is sandy, add more weight, if they are clay rich, add less)
3. Put the flasks onto a hot plate inside a fume cupboard. Ensure that the fume cupboard extractor fan is on.
4. Working within the fume cupboard, add between 50 to 100ml of H2O2 30% (Hydrogen Peroxide) to each sample. This will remove the organic content from the sample. **CAUTION** samples will react violently and overflow from the flasks. When this occurs, remove the flask (s) from the hotplate and let them calm down. Once any effervescence has stopped, return to the hotplate.
5. When the samples have boiled down slightly and only a small amount of liquid is left at the bottom of the flask, add a little more H2O2 until the reaction stops completely and the pH is neutral (don't let samples boil dry). If a sample is blocky, stir gently using a glass-stirring rod.
6. Once the reaction has stopped, the sample must be decanted into a 50ml centrifuge tube (labelled) using distilled water, making sure all the contents of the flask are transferred into the centrifuge tubes.
7. The centrifuge tubes are spun at 3000 rpm for 10 minutes. ALWAYS ensure the centrifuge tubes have the same amount of fluid in each to be balanced.
8. Decant the clear liquid from the centrifuge tube leaving the sample pellet at the bottom of the tube and refill with distilled water. Shake the tube so that the sediment mixes with the clean water and centrifuge at 3000 rpm for 10 minutes again. Repeat this washing process 2-3 times. After the final wash, ensure that only a small amount of water (1ml) is left covering the pellet to ensure that it does not dry out.

COULTER LS 230 Sedigraph

The samples should be mixed using a spatula and have a 'toothpaste' like consistency. This must be stirred evenly and not shaken up and down.If a small amount of water remains in the tube prior to mixing, place tube in a watch glass or on top of the machine (which gets warm) to evaporate off any excess water.If the sample aggregates, add 1-2 drops of 5% calgon before mixing.

APPENDIX 4

Acid Digestion Technique for the Extraction and Concentration of Volcanic Tephra from Peat (developed by Anthony Newton and Andrew Dugmore, Department of Geography, University of Edinburgh, Drummond Street, Edinburgh. EH8 9XP Scotland)

Tephra

The currently accepted method for extracting microscopic tephra shards from peat is by dissolving the peat in acid. This technique is based on Persson (1971) and does not affect the geochemistry of the glass shards (Dugmore et al., 1992). Below there is a method for this technique. We would recommend that this technique and not an ashing technique is used for extracting glass shards, especially if they are to be microprobed, as alteration of the alkali content of the glass can occur (Dugmore et al., 1995; Dugmore and Larsen in prep).

Note

This method is suitable for peat samples a few cm3 in volume.
All of the below must be carried out in a fume cupboard.
Always add acid and water very slowly.
Do not leave unattended.

Method

1. Place the peat sample in a conical flask (eg 150 ml) and break into smaller pieces.
2. Add 50 ml of concentrated (98%) sulphuric acid.
3. Shake the flask.
4. Add a few ml of concentrated nitric acid by pipette.
5. Shake the flask. Some samples will react vigorously to this treatment. Keep some Octan-2-ol nearby and if the foaming is going to overflow the flask, add a few drops. This should cause the foam to disperse. This may have to be repeated.
6. Once the foaming looks controllable add several more ml of nitric acid to the flask and shake. Brown fumes should be given off and the foaming should be under control.
7. Add some more nitric acid as in 4.
8. Once the foam disappears quickly after the flask is shaken place the flask on a hot plate.
9. Let the flask boil until the contents turn clear or yellow. Add some more nitric acid slowly by pipette if the fumes turn white before the liquid clears. The liquid will turn red first.

10. Once the liquid is clear (yellow) take off the hot plate and allow to cool.
11. Once cool add some distilled water slowly and leave for an hour to allow any sediment to settle.
12. Very carefully decant the liquid from the flask leaving enough in the bottom to keep the sediment.
13. Pour the contents into a centrifuge tube and add distilled water to the mark. Spin down for 5 minutes at 3000 rpm.
14. Pour out supernatant and repeat until the pH of the solution is near neutral.
15. Store sediment in a small sample bottle.

References

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APPENDIX 5

Humification

1. Dry peat at 40* and crush
2. Weigh **0.2**g of peat
3. Make up 5% NaOH (50g of pellets to 1 litre of distilled water).
4. Place **0.2**g of peat into a 150ml conical flask
5. Add **100**ml of 5% NaOH
6. Place on a hotplate for 1hr (move sample around if some are boiling faster than others). 1hr form the moment samples go on hotplate to the moment they come off
7. Leave to cool for 5-10mins
8. Transfer into a 250ml measuring cylinder and top up to the **200**ml mark with distilled water (boiling process reduces sample to 70-80mls)
9. Pour this mixture through filter paper and large conical flask. Make sure valve is switched on to allow air to pass through and switch the pump on until the mixture has all passed through (should take 30 secs. approx.)
10. Pour **50**mls of this filtered solution into a 250ml measuring cylinder and add **150**mls of distilled water (making it up to 200mls in total and producing a 1:3 solution).
11. The rest of the filtered liquid (i.e.; non diluted mixture) should be retained in a small conical flask
12. Pass **100**mls approx. of the diluted mixture through the machine which should give a stable reading
13. Pour the rest of this solution into another small conical flask
14. Using the original solution that has been passed through the filter and retained in a small flask, pour **50**mls of this into a 100ml measuring cylinder and add **50**mls of distilled water making a 1:1 solution. Pour this mixture into a small beaker to allow mixing
15. Pour this solution through the machine to give a reading. Should have 2 readings from the 1:3 solution and the 1:1 solution
16. Between each sample the machine should be washed through with distilled water so that it stabilises at 100.00.

To Set up the Machine

Switch on at the beginning of the experiment as it takes approx. 1hr to stabilise. Press Shift4 to set to % transmission (wavelength of 540nm)

The first sample should be of distilled water to set the machine to 100.00.

APPENDIX 6

Pollen Preparation Procedure

The samples were prepared for pollen analysis using the methodology of Anderson 1960, Erdtman 1960, Benninghoff 1962, Bonny 1972, Faegri & Iversen 1975, Berglund & Ralska-Jasiewiczowa 1986, and Moore *et al* 1991:

1. A standard volume of sediment (1ml) was subsampled. The volume was calculated by measuring the displacement of 5ml of 10% HCl in a graduated centrifuge tube.
2. A standard volume (40µl) of exotic pollen (*Lycopodium clavatum)* suspension was added to each sample. Each sample was then mixed thoroughly and allowed to stand until any effervescence had stopped. The samples were then centrifuged at 3000rpm for 5 minutes and the supernatant decanted. 6ml of distilled water was added to each sample, followed by mixing, centrifuging and decanting of the supernatant. (This step resulted in the removal of any calcium carbonate from the sediments.)
3. 6ml of 10% NaOH was added to each sample. The samples were mixed and placed in a boiling water bath for 15 minutes and cooled with distilled water. The samples were then centrifuged at 3000rpm for 5 minutes and the supernatant decanted. 6ml of distilled water was added to each sample followed by mixing, centrifuging and decanting of the supernatant. (This step resulted in the removal of humic acids from the sediments.)
4. Very coarse and very fine particles were then removed from the sediments by sieving. Sampled were sieved (using distilled water) through a 150µm sieve with a 5µm sieve placed below. Residues retained in the 5µm sieve were returned to the centrifuge tubes. (Some of the samples, notably those from the 'palaeosol,' visibly contained a high minerogenic content. This was removed by using the 'swirling' technique of Traverse (19XX, XXX). Following this, the samples were returned to the 5µm sieve using distilled water, then the residues retained were transferred to the centrifuge tubes.) The samples were then centrifuged at 3000rpm for 5 minutes and the supernatant decanted.
5. 6ml of concentrated glacial acetic acid were added to each sample. The samples were mixed, centrifuged at 3000rpm for 5 minutes and the supernatant decanted. 6ml of acetolysis

mixture[1] was added to the samples which were then miced and placed in a boiling water bath for 2 minutes. The samples were then centrifuged and the supernatant decanted. The samples were resuspended in 6ml of glacial acetic acid, mixed, centrifuged and the supernatant decanted. Finally, the samples were resuspended in 6ml of distilled water, mixed, centrifuged and the supernatant decanted.

6. 6ml of 2-methylopropan-2-ol (TBA) and two drops of stain (0.2% safranin) were added to each sample. The samples were mixed, allowed to stand for one minute, centrifuged at 3000rpm for 5 minutes and the supernatant decanted. 6ml of 2-methylopropan-2-ol was added to each sample. The samples were mixed, centrifuged and the supernatant decanted. The samples were then transferred to small storage tubes using 2-methylopropan-2-ol, centrifuged at 2000rpm for 10 minutes and the supernatant decanted.
7. A small amount of silicone oil (12500 centistokes) was added to the samples. The samples were centrifuged at 2000rpm for 10 minutes. Cotton wool plugs were placed in each tube to prevent any atmospheric contamination. The samples were then placed in a previously warmed drying cabinet overnight allowing any excess alcohol to evaporate. The sample tubes were then sealed to prevent drying.
8. During slide preparation, silicone oil (12500 centistokes) was used as the mounting medium and slides were sealed using clear nail varnish.

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[1] Acetolysis mixture: 5ml sulphuric acid added to 9ml acetic anhydride was prepared for each batch of eight samples.

APPENDIX 7

Charcoal

1. Count 8 complete transects, each of which encompass 56 fields of view, each of 10 points. In total this is 5660 points counted. So **N** = **5660** (fixed).

2. Every time charcoal touches one of the points, add it to your count, **C**.

3. Every time a *Lycopodium* spore touches one of the points, add it to the 'marker' count, $\mathbf{C_m}$.

4. Now estimate

   P: probability of random point falling on charcoal

   $\mathbf{P = C / N}$

   $\mathbf{P_m}$: probability of random point falling on marker

   $\mathbf{P_m = C_m / N_A}$

5. Estimate area of charcoal on slide*, **A**. Area of sample on slide, $\mathbf{A_p}$ = **4.84cm^2** (fixed)

   $\mathbf{A = P} \times \mathbf{A_p}$

   *Units of A are cm^2

6. Calculate standard deviation of **A:** s_A:

   $s_A = \mathbf{A_p} \sqrt{[\mathbf{P\,(1\text{-}P) / N}]}$

7. Relative error:

   $s_A / \mathbf{A}$

   95% confidence limits

   $\mathbf{A \pm 2}\, s_A$

8. Estimate total area of markers on slide*, $\mathbf{A_m}$.

   $\mathbf{A_m = P_m . A_p}$

*Units of Am are cm^2

9. Estimate **M_p**, number of markers on slide. Mean area of individual marker, **M_a** = **113µm^2 = 0.00000113cm^2** (fixed)
   M_p= A_m / 0.00000113

10. Estimate **A_c**. Area of charcoal in unit volume of sediment*. Volume of original sediment sample, **V=1cm2** (fixed). Number of marker spores added to original sediment sample, M=2 tablets = **21358** spores ** (fixed)
    A_c = A.M / M_p.V
    * Units of Ac are cm2 / cm3.
    * Batch 938934 Lycopodium spores from Quaternary Geology department, Lund University, Sweden.

Symbols used are:
A = estimated area of charcoal on slide
A_c = estimated area of charcoal in unit volume of sediment
A_p = area of sample on slide.
C = number of points falling on charcoal
M = number of marker grains or spheres added to original sediment sample
M_p = number of marker grains or spheres on slide.
N = total number of points applied.
P = estimated probability of a random point falling on charcoal
s_A = standard deviation of A
V = volume of original sediment sample.