THE UNIVERSITY OF HULL

PALAEOHYDROLOGY AND ARCHAEOLOGY IN RAISED MIRES: A CASE STUDY FROM KILNAGARNAGH

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by

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Summary of Thesis submitted for Doctor of Philosophy degree

By

Nóra Caitríona Bermingham

On

PALAEOHYDROLOGY AND ARCHAEOLOGY IN RAISED MIRES: A CASE STUDY FROM KILNAGARNAGH.

This thesis concerns the palaeohydrological reconstruction of a raised mire in Kilnagarnagh, Co. Offaly, Ireland in order to investigate environmental influences on human activity in mires as represented by archaeological deposits, and the mire's potential for broader palaeoenvironmental reconstruction. The results are compared against trends in other mires in Ireland, the UK and Northwest Europe. Analytical techniques used include gross peat stratigraphic and archaeological field survey, testate amoebae, plant macrofossil and colorimetric humification analyses and radiocarbon dating.

A Bronze Age wooden walkway in Kilnagarnagh Bog and a series of trackways from neighbouring bogs provide the archaeological focus of this study. It is shown that trackway construction, or the lack thereof, may be viewed in part as a response to changes in the environment. Very dry or very wet situations may not warrant trackway construction; however, simple models of behaviour occurring in either wet or dry situations may be misleading as local environmental conditions may be more complex.

Some models of peatland development typically suggest that external (allogenic) factors such as climate change control development. Others suggest that both external and internal (autogenic) processes combine to control development. In reconstructing environmental conditions it is important to separate these controls as this has implications for the use of peatland development as a proxy for climatic reconstruction. The timing of the most significant hydrological changes in Kilnagarnagh suggests autogenic factors rather than regional climate change controlled development, with one exception; from *c.*850BC to around the seventh century AD mire growth was greatly retarded due to a sudden and long-term drop in the water table which may ultimately have been driven by a regional change to wetter conditions.

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ABBREVIATIONS & ACRONYMS

AMS	Accelerator Mass Spectrometry
^{14}C	Carbon 14
DCA	Detrended Correspondence analysis
DEM	Digital Elevation Model
E	East
HHS	Highly humified *Sphagnum*
IAWU	Irish Archaeological Wetland Unit
IPCC	Irish Peatland Conservation Council
MHS	Moderately humified *Sphagnum*
NPWS	National Parks & Wildlife Service
N/NW/NE	North/Northwest/Northeast
OD	Ordnance Datum
OS	Ordnance Survey
PHS	Poorly humified *Sphagnum*
S/SW/SE	South/Southwest/Southeast
TA	Testate Amoebae
W	West
2D	2-Dimensional
4D	4-Dimensional

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CHAPTER 1

INTRODUCTION

1:1 Introduction

"...if we don't consider the role that wetlands had in [the] past, our knowledge of past human lifeways remains incomplete" (Nichols 2001, 262).

The above quote is from a paper on the archaeological importance of wetlands in which Nichols (2001) presents a strong case for the archaeological investigation of the wetlands as the background and setting of many under-explored and yet unknown aspects of past human behaviour. Nichols (*ibid.*) emphasises the importance of representativeness in the archaeological record, i.e., identifying the full range of variation that once existed regarding social, cultural, economic, and technological aspects of past human existence. An important aspect that can be added to this is the environment and the interplay between it and past populations. Archaeological investigations typically emphasise the cultural and material remains of past societies and give less attention to environmental reconstruction, though increasingly this situation is changing and this is reflected in the rising numbers of general publications concerned with environmental archaeology (e.g., Albarella 2000; Dincauze 2000; Wilkinson & Stevens 2003).

Palaeoecological research allows the reconstruction of past environments (e.g., Berglund 1986) but in some cases the results are not always integrated with the archaeological record. One such area is mires, particularly in Ireland where entire archaeological landscapes have been preserved but the relationship between the archaeology and the mire environment is frequently poorly understood. For example, there is an underlying assumption that gaps in the archaeological record from Irish raised bogs reflect periods of greater wetness when trackway construction was not possible (Raftery 1996; O Carroll 2001a; Casparie forthcoming). This assumption has yet to be adequately demonstrated.

Mires are complex dynamic ecosystems influenced to varying degrees by climate, hydrology, vegetation, topography and human activity (see Section 2:2). This complexity means it can be difficult to identify the controls on mire processes and can influence how palaeoenvironmental and hence archaeological records are interpreted. This thesis is designed to provide new information on the timing and nature of peat development within mires and their relationship with human activity. The research relates to mire development and land-use on a local and regional scale and develops our understanding of patterns of hydrological and climate change derived from mires. It therefore can be viewed as a contribution to the development of palaeoenvironmental and archaeological research in mires, specifically raised bogs.

1:2 THESIS STRUCTURE

This thesis is organised in the following manner:

In the remainder of Chapter 1 the main aims and objectives of this thesis are described. The reasons for carrying out this research are then outlined followed by a list of the conventions and definitions used. Chapters 2 and 3 provide background information for the study. Chapter 2 is a review of palaeoenvironmental research in mires in Ireland and the wider world. The archaeological significance of raised bogs is also described. Chapter 3 introduces the research site and places it within its local archaeological and palaeoecological framework. In Chapter 4 the research methodology adopted is explained and Chapter 5 details the specific palaeoenvironmental reconstruction techniques employed.

Chapters 6, 7, 8 and 9 contain the results of the research. Chapter 6 details the results of the archaeological and gross peat stratigraphic surveys. The results of the laboratory based core analysis are described in Chapter 7. Chapters 8 and 9 present interpretations of the various lines of evidence enabling the production of differently-scaled models of mire development.

Chapter 10 synthesises the results on mire development and archaeological land-use from Kilnagarnagh and the Lemanaghan complex. These are discussed in relation to environmental reconstruction from sites in Ireland, Britain and Northwest Europe as well as theories on the interplay between past populations and their environment. The overall thesis conclusions and future work recommendations are presented in Chapter 11.

1:3 RESEARCH AIM

The aim of this thesis is:

Palaeohydrological reconstruction of a small raised bog, in order to identify
(a) potential environmental controls on human interaction with the mire as expressed by archaeological structures preserved within the bog
and
(b) the mire's potential for wider palaeo-environmental reconstruction.

The emphasis is on palaeohydrological reconstruction as hydrology is arguably one of the main factors governing human activity in mires. The use of hydrological proxies permits reconstruction of past mire surface conditions (e.g., Caseldine *et al.* 1998, 2005; Charman *et al.* 1999; Mauquoy & Barber 1999a). By establishing how wet a bog was it may be possible to examine the influence this may have had on the behaviour of people living and operating in and around the bog. Conditions suitable for the formation of mires have been present in Ireland since the early Holocene and this is coincident with the arrival of the earliest human populations on the island of Ireland. Mires are therefore significant landforms, which the archaeological record indicates elicited specific human responses. However, there has been little research aimed at investigating the influence of environmental conditions on human activity in mires.

This study can be viewed as a case study aimed at informing the wider palaeoenvironmental and archaeological record. Raised bogs are rain dependent systems with the development of conditions on the bog largely determined by the level of rainfall and therefore changes in these conditions may be driven by climate. Hence, raised bogs may retain a "climate memory", which can be accessed by utilising wetness indices derived from the proxy data to identify wet-dry shifts (e.g., Aaby 1976; Chambers *et al.* 1997; Hendon *et al.* 2001). However, recent work in Ireland has found ascribing wet-dry shifts solely to climate problematic owing to the internal dynamics of the mire system (Caseldine *et al.* 1998; 2005). Distinguishing between autogenic (internal) and allogenic (external) controls on mire development and environmental change (Barber 1993 & 1994; Chiverrell 2001) is crucial to the interpretation of proxy based results. This thesis will assess the potential for palaeo-climate reconstruction from raised bogs.

1:4 RESEARCH OBJECTIVES

The specific objectives of this thesis are:

- to identify an appropriate study site.
- to conduct an archaeological field survey of the study site and of the wider bog complex.
- to establish the general gross peat stratigraphic sequence via multiple survey points.
- to collect cores for laboratory analysis from select sample locations (for selection criteria see Section 5:2:2).
- to identify key events and horizons within the mire by means of peat stratigraphic and archaeological survey, and establish higher resolution records of hydrological change across these.
- to establish an absolute chronology for the developmental history of the bog using radiocarbon dating (AMS).
- to combine the archaeological record, gross peat stratigraphy and palaeohydrological proxies to investigate issues of human interaction with mires and autogenic and allogenic controls on mire development.
- to create "timeslice" DEMs using GIS to illustrate this synthesis and the potential of mires as 4-D archives..

1:5 HYPOTHESES

Part of this thesis involves the examination of potential environmental controls on human activity with particular reference to trackway construction within raised bogs (See Section 2:5 for discussion of trackways). In general, there is a dearth of palaeoenvironmental research carried out in Irish raised bogs in association with archaeological structures (see Section 2:3). This has left many archaeological sites in an environmental 'vacuum' where 'natural' influences on human behaviour, if any, can be postulated but not demonstrated. At times environmental factors may have served as the dominant influence on trackway construction, overriding other concerns such as economics or religion.

Trackways constructed in mires provide an opportunity to examine the potential influence of the environment on human behaviour. To this end a number of hypotheses have been formulated:

Null hypothesis:
There is no link between trackway construction and hydrology.

Alternative hypothesis 1:
Trackway construction is primarily determined by cultural factors although these may coincide with hydrological change.

Alternative hypothesis 2:
Trackway construction is inextricably linked to hydrology, as this is the primary determinant in access to the mire. Construction is primarily determined by a hydrological shift which affects the accessibility of the mire and thus the connectivity between the mire and the surrounding dryland.

The direction of the hydrological shift referred to above can be towards increased wetness or greater dryness. Trackway construction can only take place when the mire is accessible, i.e., when it is sufficiently dry to permit construction. This includes periods of transition from one environmental situation to another, e.g., dry becoming wet or wet becoming dry. Very wet situations or very dry situations may not warrant the construction of trackways. Archaeologically speaking this can produce the same result, i.e., an absence of trackway construction.

1:6 RESEARCH JUSTIFICATION

There are three primary reasons for undertaking this research:

(a) Irish raised bogs are internationally significant archaeological repositories that are typically interpreted in a cultural context but not a cultural-environmental context.

Over the last 20 years archaeological survey has demonstrated Irish raised bogs are significant repositories of material of national and international archaeological importance (Coles 1984, 2001) (see Section 2:4). Identification of archaeological sites can be directly linked to the exploitation of these peatlands; the truncated bog surface and vertical exposures provided by drains allow for recognition of archaeological sites. New horizons are exposed annually with each harvest thereby increasing the chances of fresh exposures of archaeological material.

Some raised bogs within Ireland are now designated as Natural Heritage Areas (NHAs), Special Areas of Conservation (SACs) and/or Special Protection Areas (SPAs) e.g., Clara bog, Co. Offaly which is a SAC and a Nature Reserve with an active conservation programme (NPWS *cited* 2001). Protected or conserved peatlands however do not provide the same opportunities for archaeological study or for closely integrated archaeological and palaeoenvironmental research. It could be argued that as such peatlands are not currently under threat, resources should be aimed at bogs subject to extensive peat extraction, particularly those where a demonstrated archaeological presence exists.

The raised bogs of the Irish midlands were formed in shallow postglacial lake basins, eventually giving rise to a wet-dry patchwork terrain that does not survive elsewhere in Europe. This terrain may have demanded particular responses from those operating in and around it. Irish bogs represent one of the last available opportunities of studying past human interaction with and exploitation of such landscapes.

(b) There has been a limited amount of palaeoenvironmental work carried out on raised bogs particularly in direct association with archaeological sites.

Table 1:1 details the most recent archaeological projects and associated palaeoenvironmental aspects of each project. With the exception of work carried out at Derryville, Co. Tipperary (Caseldine *et al.* 2001, 2005) integrated projects are few and on a generally small scale, notably at Mountdillon, Co. Longford (Caseldine *et al.* 1996; Casparie & Moloney 1996; Moloney 1996; Reilly 1996) and Tumbeagh, Co. Offaly (Casparie forthcoming; Reilly forthcoming; Weir forthcoming). These are discussed further in Section 2:3 below.

In terms of IAWU survey and the limited investigations conducted by Bord na Móna archaeoenvironmental investigations, other than wood species identification, have concentrated on spot sampling of sites. Within the IAWU (unpublished data) these were generally intended to:

(a) demonstrate the potential for archaeoenvironmental approaches within raised bogs.

(b) aid the interpretation of a given site.

The investigations undertaken by Bord na Móna should have provided greater opportunities for integrated archaeoenvironmental investigations. Unfortunately, archaeoenvironmental approaches have been underemployed, specialists have yet to be involved in project design and on-site sampling is restricted to wood and the occasional peat deposit. A recent report entitled "Collation and Evaluation of Archaeological Data from Bord na Móna Bogs" (Whitaker 2002), compiled by Bord na Móna's archaeological consultants on behalf of the state heritage service, included *c.*200 words on the current state of palaeoenvironmental investigations in Bord na Móna bogs. Detailed recommendations on the future application/integration of palaeoenvironmental and archaeological records were conspicuous by their absence. The reports overall conclusions failed to mention any aspect of archaeoenvironmental research apart from a comment on the necessity of archiving unspecified environmental samples. An earlier report compiled for the same consultancy, provides a synthesis of coleopteran analysis from the Lemanaghan Complex aimed at informing future research strategies (Reilly 2002). Reilly concludes that the evidence gathered to date is patchy and discontinuous and though it can provide details of prevailing conditions at one point in time, generally in physical and temporal isolation, the Lemanaghan area "could benefit from further inter-disciplinary work of the kind seen at Tumbeagh" (2002, 18).

Project	Year	Peat Strata	Testate amoebae	Pollen	Coleoptera	Wood species
Mountdillon Excavations	1985-1991	Site specific (1 site, 3 locations)	n/a	Site specific (3 sites)	Site specific (2 sites, 10 samples)	4600 samples from 58 sites
IAWU Survey	1990-2002	Site specific (basic peat identification)	n/a	n/a	Occasional; Single samples from 7sites	Site specific; 3261samples from unknown no. of sites out of 3100
Derryville Excavations	1996-1997	Sites & mire wide	Sites & wider area	Sites & wider area	Sites & wider area	Archaeological & natural wood horizons; 8297 samples, from *c*.60 sites
Tumbeagh Bog Body	1998	Site & wider area	n/a	Single short core	One sampling column & site specific samples.	Small assemblage; fully sampled
Bord na Móna Investigations	1999-2002	n/a	n/a	n/a	Site specific; Single samples from 7sites	All sites sampled; 796 samples from unknown no. of sites

Table 1:1 Archaeological projects in raised bogs in Ireland and associated palaeoenvironmental work (see Section 2:3 for sources).

(c) Raised bogs are landscapes experiencing ongoing destruction and there is an urgent need to pursue research specific to these areas before they have been fully depleted.

The scale of peat extraction in Ireland means most of the country's raised bog can be viewed as a rapidly diminishing resource in terms of ecology, palaeoecology and archaeology. For example, Bord na Móna estimate reserves of peat will supply Ireland's peat-fuelled power stations for the next 30 years (Bord na Móna *cited* 2000). In other words within the next three decades most of Ireland's raised bogs will only survive as cutaway or re-developed cutaway (IPCC *cited* 2000).

Less than 5% of the raised bogs in the Republic are considered to have "nature reserve potential" (Cross 1987, 52) and there are "no totally undisturbed bogs" (Tubridy 1987, 57) surviving. There are programmes concerned with the conservation, restoration and management of a number of suitable raised bogs. However from a palaeoecological point of view there is an absence of legislative recognition of the importance of raised bogs as archives of the past (IPCC cited 2000).

1:7 CONVENTIONS & DEFINITIONS

1:7:1 Chronological framework

The timescale for this study spans the Holocene, approximately the last 11,500 years, up to the relatively recent past. All ages are expressed on a calendrical timescale. Dates derived from dendrochronological analyses are cited as AD or BC. Radiocarbon (^{14}C) and Accelerator Mass Spectrometry (AMS) determinations are cited as either calAD or calBC.

1:7:2 Nomenclature

Floral nomenclature follows Webb *et al.* (1996) and testate amoebae nomenclature is based on Charman *et al.* (2000). Place names follow Ordnance Survey of Ireland nomenclature.

1:7:3 Terminology

Common terms that appear frequently in this thesis are defined below. With the exception of the definition for archaeoenvironmental these are based on Gore (1983) and Moore (1986).

Archaeoenvironmental (*sensu* Gearey & Chapman 2004): integrated archaeological and environmental reconstruction approaches where palaeoenvironmental data is generally used to aid archaeological interpretation of past landscapes and environments.

Raised Bog: a mire that accumulates peat in a raised mass above the groundwater table with precipitation as the main water supply.

Fen: a mire primarily fed by groundwater which is typically rich in minerals and nutrients.

Mire: a peat producing ecosystem which can include marshes, swamps, fens and bogs. Mire types differ in relation to the position of their water tables relative to the peat surface as well as their source of water input.

Peatland: a generic term for any wetland that accumulates partially decayed remains of plants (i.e., peat).

CHAPTER 2

LITERATURE REVIEW

2:1 INTRODUCTION

2:1:1 Introduction

This research explores archaeological and palaeoenvironmental aspects of wetlands, specifically raised bogs, using an integrated approach. In this chapter, the contribution of raised bogs to our understanding of environmental change and past human behaviour is outlined. The methods, benefits and problems of the selected areas of palaeoenvironmental reconstruction are considered. The nature of the archaeological record from raised bogs is reviewed and the role this record can play in environmental reconstruction and interpretation of past human behaviour is outlined. The position of Irish raised mires within the wider research framework is described, as is the potential for further significant contributions from Irish sites. This demonstrates how the aims are developed from the literature review.

2:1:2 Defining wetlands & mires

The 1971 Ramsar Convention on Wetlands defines wetlands as "areas of marsh, fen, peatland or water, whether natural or artificial, permanent or temporary, with water that is static, flowing, fresh, brackish or salt, including areas of marine water, the depth of which at low tide does not exceed six meters" (Ramsar cited 2004). Others (e.g., Zoltai 1988), define a wetland as an area of land that has water at, near or above the land surface or which is saturated for a long enough period to promote aquatic processes. It can include land that is covered by water for part of each year or of each day, or land which has been flooded at any time over its lifetime (Coles 1984). Waterlogged organic soils are a characteristic feature of wetlands and are formed where the production of plant materials exceeds the rate of decomposition. The accumulated remains of dead plants form peat (Clymo 1983) which, given suitable climatic and morphological conditions can result in the formation of areas of peatland (Moore 1984a). A wide range of peat forming environments exist and of particular interest here are the wet, boggy peatlands that are found at mid-latitudes between 45°-75°N. Increasingly the term 'mire' is used to encompass the diversity of wet, peaty environments found throughout the world including fens, bogs, swamps and marshes (Gore 1983; Heathwaite *et al.* 1993). Within these mire types, wet anaerobic conditions are prevalent which can result in the preservation of a wide range of biological and inorganic matter. It is this potential for preservation that makes mires an important archaeological and paelaeoenvironmental resource.

2:1:3 The archaeological and palaeoenvironmental importance of wetlands

Wetlands offer opportunities for acquiring information that cannot be obtained from dryland sites. Within a wetland environment new archaeological site types and the landscapes in which these sites functioned can be preserved. Increasingly archaeological research is taking advantage of this (Bernick 1998; Coles *et al.* 1999; Purdy 2001; Raftery & Hickey 2001). Coles and Coles (1989) present one of the first in depth overviews of the development of what has come to be known as wetland archaeology. The authors provide a wide ranging synopsis of the most significant and inspiring discoveries made from mire, lake, river and coastal environments since the middle of the nineteenth century up to the late 1980s. In a sweep across Europe the lake dwellings of Estonia, Poland and Switzerland, the terps of the Netherlands and northern Germany, the crannógs of Scotland and the coastal settlements of eastern England and Denmark are described. Coastal settlements in the Florida Keys and British Columbian are also considered. The peatland trackways of Germany, the Netherlands, England and Ireland are placed within this wealth of well preserved, and overwhelmingly wooden, records. The same authors followed up this overview with a second in the mid-1990s which saw the inclusion of Japan, France, Chile and more recent projects in the USA, Ireland and mainland Europe (Coles & Coles 1995/6).

The preserving qualities of wetlands mean that many can be viewed as palaeoenvironmental archives that allow reconstruction of past environmental change on a local, regional, continental and global scale. Wetlands are rich in sub-fossil material derived from a wide range of natural and anthropogenic activities. Some of those sub-fossil groups with a long history of analysis include pollen grains (Berglund & Ralska-Jasiewiczowa 1986; Moore *et al.* 1991), the macrofossil components of plant remains such as wood, seeds, leaves and stems (Dickson 1986; Grosse-Brauckmann 1986; Wasylikowa 1986; Roberts 1989) and coleoptera (Coope 1977; Atkinson *et al.* 1986). Other groups preserved that are finding a wider application in the last two decades include testate amoebae (Tolonen 1986; Warner 1988) and fungi (van Geel

1978). These techniques are frequently employed in Quaternary and Holocene studies. The Holocene represents the most important time period for recent peatland growth and the proxies mentioned above have been used to produce centennial and decadal scale records of environmental change in mires from Europe, North America and the southern hemisphere (Charman 2002).

2:1:4 Ombrotrophic mires

This thesis is concerned with a particular type of mire known as ombrotrophic, i.e., mires that rely on atmospheric precipitation for their primary water and nutrient supply (Moore 1986, 1990). This means they have a low nutrient status, or trophic level, and hence are oligotrophic (Heathwaite *et al.* 1993). Ombrotrophic mires are distributed across northern Europe from Estonia, the Ukraine, and Russia to northern German, Denmark, Finland and Scandinavia as well as Ireland and Britain (Robertson 1968; Moore 1984a; Pfadenhauer *et al.* 1993). Extensive ombrotrophic peatlands exist in America and Canada (Osvald 1970; Hofstetter 1983; Zoltai 1988) and complexes occur in the southern hemisphere in Australasia, South America and New Zealand (Campbell 1983; Junk 1983; Charman 2002; Wilmshurst *et al.* 2003). Precipitation and temperature are the main controls governing ombrotrophic bog formation, with a correlation between the occurrence of certain types of ombrotrophic mires formation and climatic conditions (Moore & Bellamy 1973; Charman 2002). For example, the raised bogs of Ireland, the UK, the Netherlands and Northern Germany are subject to an Oceanic climate, while the cooler continental and boreal climates of northern Europe give rise to Aapa and Palsa mires (Moore & Bellamy 1973).

Ombrotrophic mires can be subdivided into three types: blanket mires or bogs, raised mires or bogs and transitional mires. Blanket bogs form on upland slopes where the rate of precipitation is high, in excess of 1250mm/yr. Lindsay *et al.* (1988) suggest a minimum annual rainfall of 1000mm and a minimum 160 wet days per year are necessary to allow the formation of blanket bog. They may form over impermeable soils and formation can be the result of climatic and perhaps anthropogenic changes (Caulfield 1983; Orme 1990; Feehan & O'Donovan 1996). Transitional mires are mires where a combination of ombrotrophic and minerotrophic (fen) conditions are present suggesting the mire system is moving from a fen to raised bog situation. They can have a similar distribution to raised mires (Heathwaite *et al.* 1993).

Raised bogs develop in situations where there is a current excess of rainfall over evapotranspiration in the order of 700mm-1250mm per year. They tend to develop in small basins, such as former lake sites, that serve to retard runoff from a site. This results in the retention of water, waterlogging of sediment and the eventual accumulation of peat. They may evolve either on a wet, impermeable soil or over fen peat (Fig. 2:1) (Streefkerk & Casparie 1989). Topographically, raised bogs are convex in cross-section, having an elevated or domed central massif elevated above the groundwater table and separated from the level to which the surrounding dryland drains (Ingram 1983). As a result they have a perched water table supplied solely by atmospheric input. Ingram (1982) suggests that raised bogs comprise a catotelm, a waterlogged and anaerobic peat core that impedes outflow, and a bounding acrotelm, a thinner layer of living vegetation in which water can move freely. Raised bogs typically recharge, i.e., receive water input, and discharge, i.e., expel water output, via the acrotelm. Hence the water table of a raised bog is largely controlled within the acrotelm. As this is where new organic material is formed, changes in the water table of the acrotelm or in mire surface wetness can be reflected in the character and composition of the accumulating peat deposit.

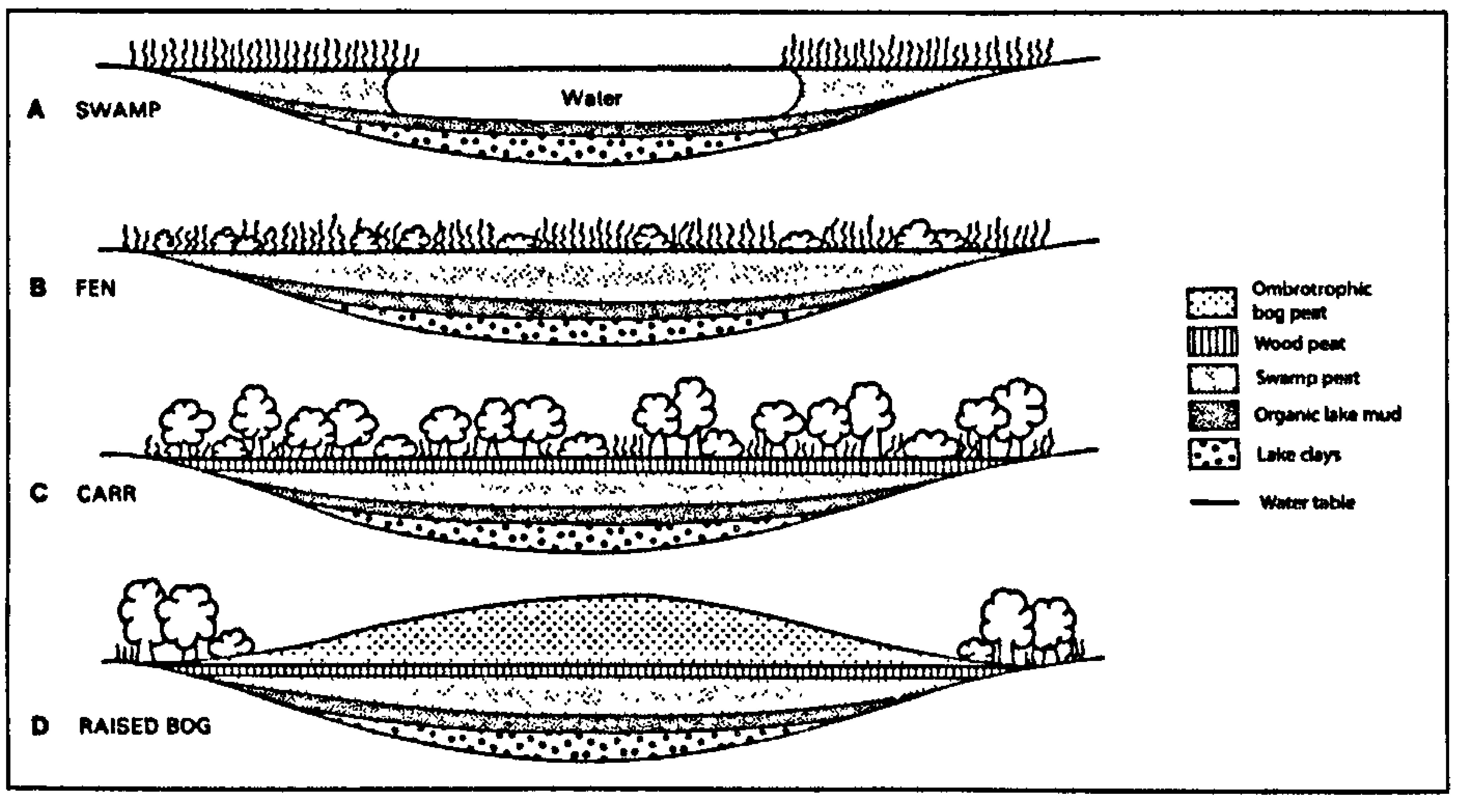


Fig. 2:1 Idealised cross-sections of raised mire development (after Moore 1990). Cross-sections A-D describe a hydroseral succession in which open water becomes invaded by swamp, fen and carr vegetation and finally the invasion of *Sphagnum*.

2:1:5 Extent & distribution of raised bogs in Ireland

The raised bogs of the Irish midlands represent the northwest extent of European raised bog formation. Of the island's *c.*8 million ha surface area, peatland occupies *c.*1.34 million ha or 16.2% of the total land cover (Fig. 2:2). This figure includes fen, raised bog and blanket bog, and within the Republic, raised bog accounts for 314,000ha

(Hammond 1981). The Republic is ranked tenth in the world order of total national peatland areas, coming third in proportional terms to Finland (33.5%) and Canada (18.2%) (Taylor 1983). Peatland is steadily declining however, because of peat extraction which occurs on an industrial and domestic scale with national supplies exhausted within the next 25-30 years (see Section 1:5).

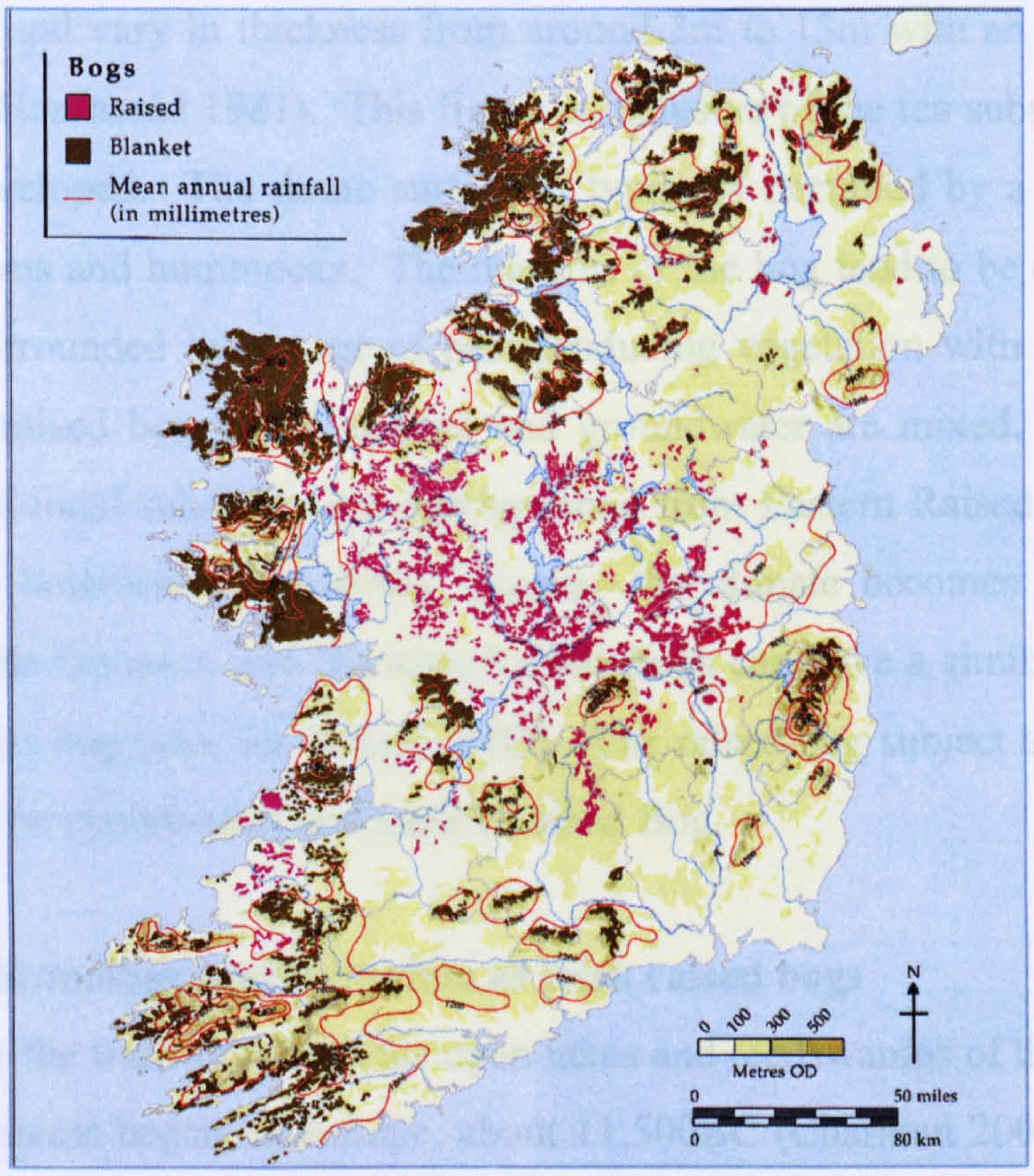


Fig. 2:2 Peatland cover Ireland. Taken from Aalen *et al.* (1997).

2:1:6 Classifying Irish Raised bogs

In Ireland raised bogs occupy much of the central lowlands where they developed over postglacial lake sites (Feehan & O'Donovan 1996). Over time the bogs expanded beyond their original boundaries eventually coalescing with other adjacent bogs and expanding over large areas. The result was a distinctive patchwork landscape of bog and dryland occupying much of the midlands of Ireland (Fig. 2:2). These bogs are sometimes referred to as 'Midland' type bogs, a classification based on botanical composition and rainfall levels (Hammond 1981, 1984). This classification was further divided into two sub-types based on their geographical position in relation to the 1000mm isohyet: True Midland sub-type and Transitional sub-type. The Midland sub-type lies to the east of this isohyet where annual rainfall is from 800mm-1000mm and represents somewhat drier bogs. Recently van der Schaaf (2002) has proposed renaming this category as Eastern Raised Bog thus distinguishing it from those raised bogs to the west of the 1000mm isohyet, i.e., the Transitional Sub-type, on which plant species typical of western blanket bogs can occur. Schouten (1984) re-classified the latter as Western Raised Bog.

Eastern raised bogs or True Midland sub-types generally have dome or plateau shaped cross-sections and vary in thickness from around 3m to 13m with an average depth of around 7.5m (Hammond 1981). This figure is inclusive of the fen substrate upon which raised bog developed. The dome surface is typically occupied by a system of pools, *Sphagnum* lawns and hummocks. The margins of the bog tend to be drier than the top and can be surrounded by a zone of peat-producing vegetation with characteristics of both fen and raised bog where rainfall and groundwater are mixed. Western Raised Bogs or Transitional sub-types are distinguished from Eastern Raised Bogs because of differences in botanical composition, because the climate becomes wetter and more oceanic towards the west, and Western Raised Bogs can have a similar morphology to lowland blanket bog (van der Schaaf 2002). The raised bog subject to investigation in this thesis can be classified as an Eastern Raised Bog.

2:1:7 The chronology and formation of Irish raised bogs

In broad terms the transition from the open lakes and reedswamps of the early Holocene to fen peat systems began, in Europe, about 11,500BC (Charman 2002). Around 2000 years later conditions became suitable for raised bog formation (Streefkerk & Casparie 1989; Feehan & O'Donovan 1996) though this does not mean that raised bog formation was a widely synchronous development. Both fen initiation and the switch to ombrotrophy can be viewed as time-transgressive developments (Figs 2:3, 2:4 & 2:5). Fig. 2:3 shows the range of dates available for the initiation of fen peat from a series of mires in the Ireland. The majority show fen initiation between 10,000BC and 8000BC though there are sites where this occurred considerably later. Fig. 2:4 indicates that the change to ombrotrophy occurred at various times between 7500BC and 2800BC, suggesting the importance of local conditions in the switch to ombrotrophy in these mires (see Section 2:2:3). The role played by local conditions and the time-transgressive pattern of peat growth is also apparent from sites where multiple centres of raised bog formation have been identified within the same mire complex.

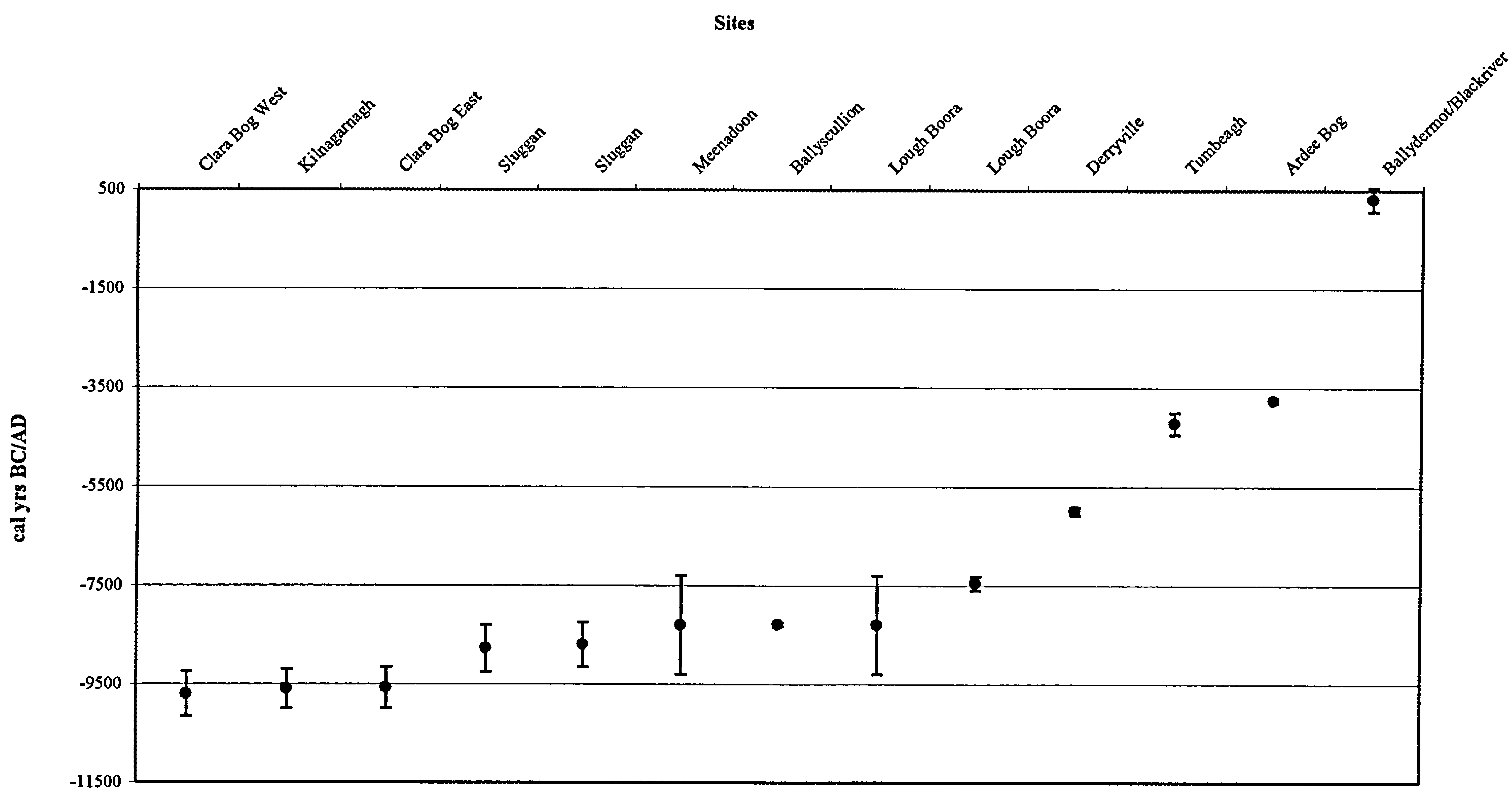


Fig. 2:3 Fen intiation dates from a selection of Irish raised bogs. The dates are calibrated years BC/AD. See Table 1:1, Appendix 1 for sources.

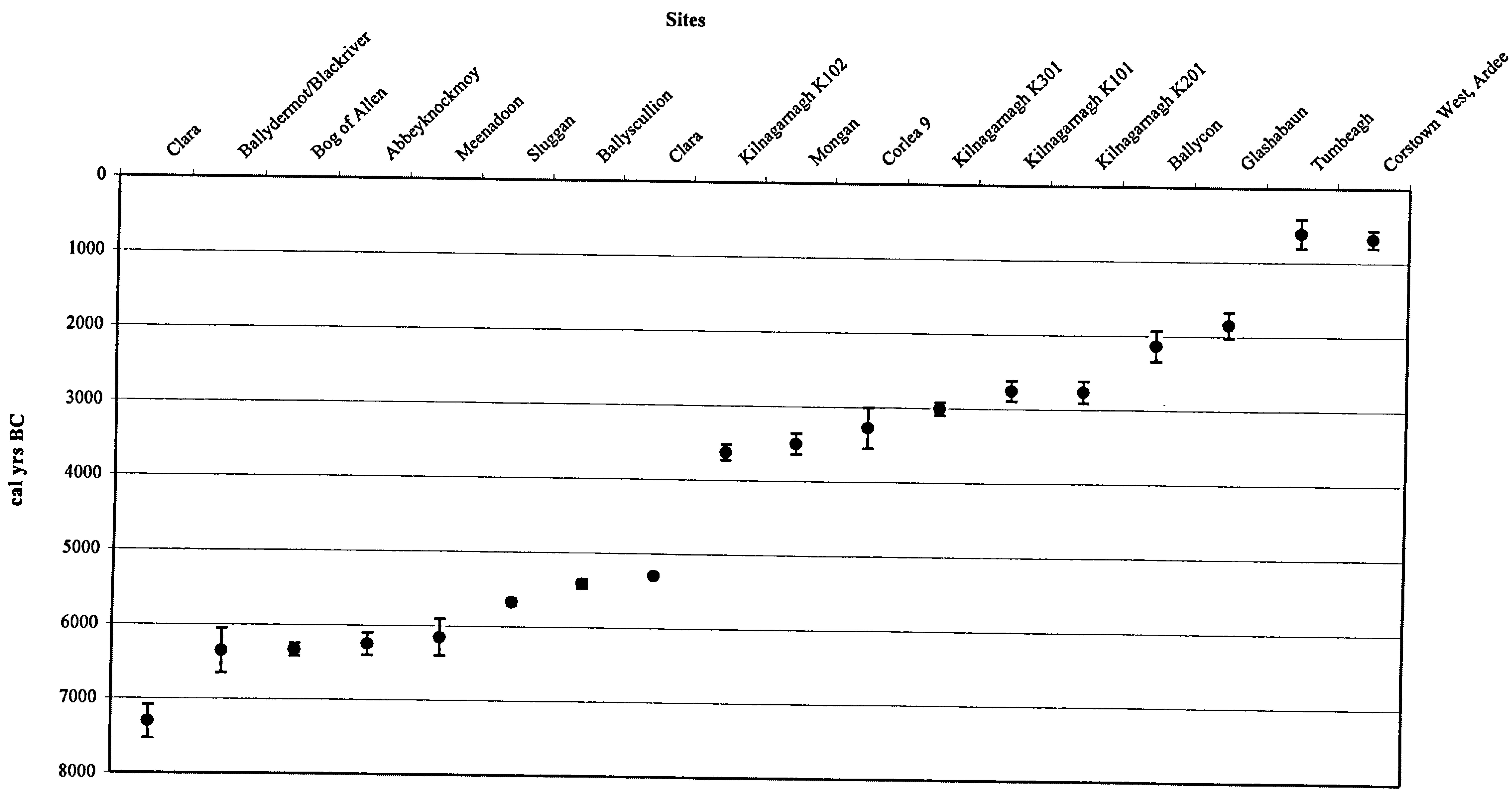


Fig. 2:4 Ombrotrophic initiation from a selection of Irish raised bogs. The dates are calibrated years BC. See Table 1:2, Appendix 1 for sources.

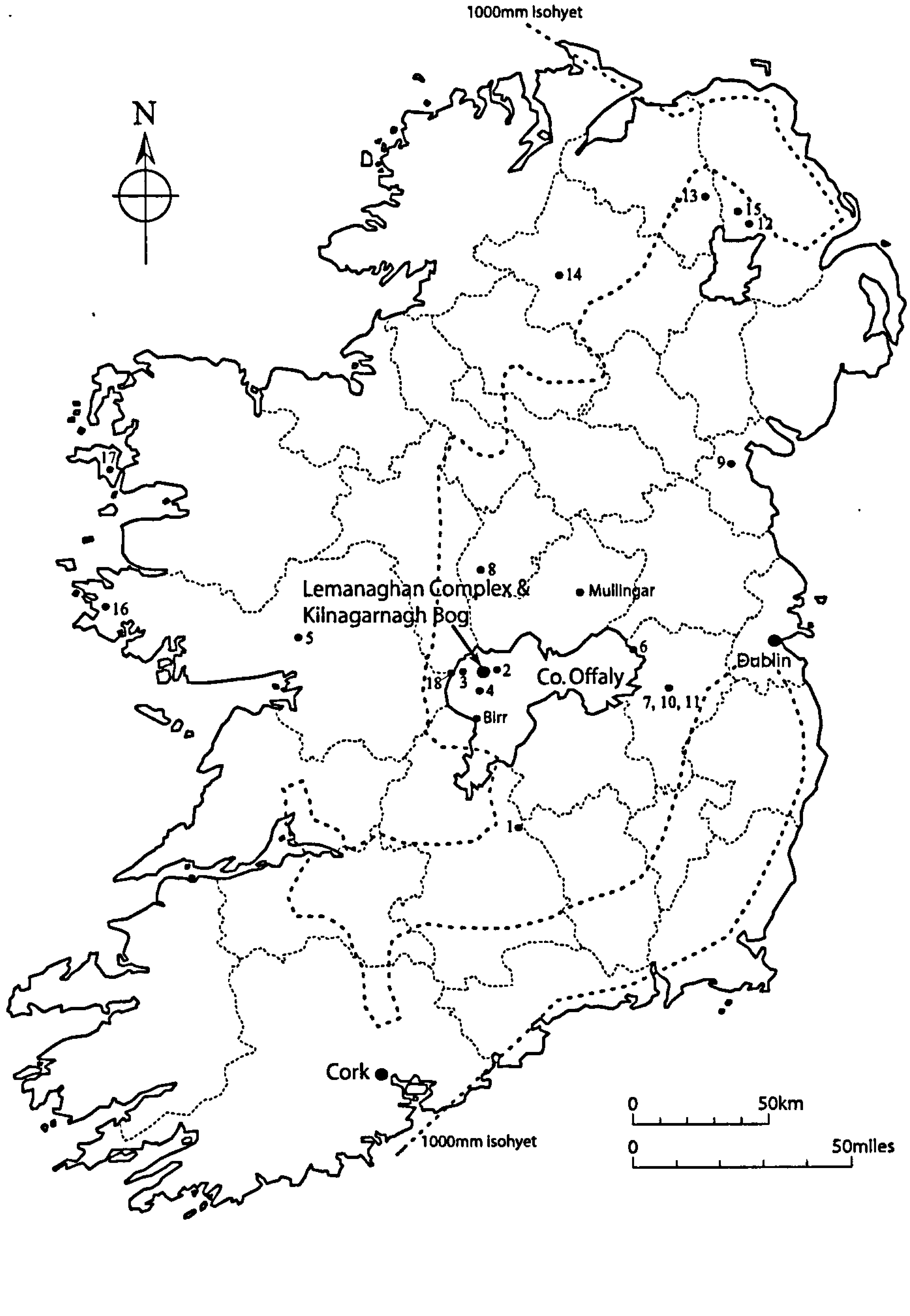


Fig. 2:5 Map of Ireland showing location of study site, meterological stations at Birr & Mullingar & 1000mm isohyet.

The map also shows other mire sites mentioned in the text:
1. Derryville, 2. Clara, 3. Mongan, 4. Lough Boora, 5.Abbeyknockmoy, 6. Ballydermot/Blackriver, 7. Bog of Allen, 8. Corlea, 9. Ardee, 10. Glashabaun, 11. Ballycon, 12. Sluggan, 13. Fallahogy, 14. Meenadoon, 15. Ballyscullion, 16. Letterfrack, 17. Achill Island, 18. Blackwater.

At Derryville, Co. Tipperary raised bog formation has been dated from *c.*1800BC and *c.*1400BC with the zones of development separated by a distance of 400m (Casparie 1998, 2005).

2:1:8 Raised bogs and their exploitation in Ireland

The vast majority of raised bog in Ireland, historically and currently, is subject to a range of destructive processes including industrial-scale milling, moss peat production, domestic peat extraction, drainage and reclamation for agricultural purposes. Bord na Móna are the biggest peat-product producers in Ireland and also the largest owner of peatland in the Republic. Within the Irish midlands and the west of the country, 85,000ha of peatland is given over to peat extraction by Bord na Móna. They supply to peat-burning electricity generating stations and peat products to the domestic and international market. Established in 1946 in order to develop Ireland's peat resources following the Second World War, Bord na Móna became a public company in 1999 composed of four subsidiaries. One subsidiary, Peat Energy Ltd, is mainly responsible for peat extraction via milling.

Bord na Móna's primary product is milled peat, that is air dried peat in powder or crumb form produced by cutting the horizontal surface of a drained bog into thin layers which are then allowed to air dry. The cut layers are about 15mm deep and over the course of a year, depending on the weather, up to 12 crops or layers can be harvested. Bogs under production can therefore be reduced at a rate of *c.*15cm per year. Annually Bord na Móna harvest 4 million tonnes of milled peat, 80% of which goes to supplying thermal power plants. The other 20% is used to produce domestic fuel and horticultural products (Bord na Móna cited 2000).

All bogs subject to this form of extraction are first drained to reduce the water content of the surface and increase carrying capacity to facilitate machine access. Drainage takes place via a network of parallel open drains 15m apart. The strip of bog between two drains is called a field. Initially shallow drains are opened or ditched. As the surface of the bog gets firmer, the drains are gradually deepened until they are *c.*1.4m deep. The drains therefore provide accessible longitudinal or transverse cross-sections through a bog that can be up to a kilometre or more in length.

Drainage results in the 'death' of the growing bog. The bog becomes progressively drier as water input is drawn away from the mire surface and body via the drainage network. The peat shrinks with the greatest compaction in the upper parts of the deposit in which the drains are cut (see Section 5:4:4). Within a few years, ericaceous plants, tree saplings and lichens replace *Sphagnum* and there is a clear shift towards vegetation favouring dry conditions, as a result peat accumulation is greatly reduced. The vegetation cover on a drained bog is known as "the skin" (Tom O'Donnell pers. comm.). The skin is removed once the bog is ready for milling, turning the bog into an expansive brown mass generally devoid of vegetation.

2:2 OMBROTROPHIC MIRES AND 'CLIMATE MEMORY': THE ATTRACTION FOR PALAEOECOLOGISTS

2:2:1 Introduction

The relationship between climate and raised bogs makes these peatlands of special interest to palaeoecologists (Frenzel 1983). As rain-fed systems, raised bogs may be sensitive to changes in precipitation and temperature. This sensitivity is expressed in changes in the type of flora and fauna that inhabit a bog and in the degree of decomposition or humification of the peat formed by the incomplete decay of plant remains. Increased decomposition suggests greater surface dryness implying oxidation, increased microbial activity and greater decay of plant remains. Conversely, less humified deposits suggest an environment that is more waterlogged resulting in reduced microbial activity and a slow-down in decay processes. In broad terms, decay can therefore be viewed as a function of hydrology which also determines the type and distribution of plants that grow on any given mire. Different species of plants have different ecological and hydroecological preferences. Thus the species present mirrors the hydrological conditions on the mire which in turn may be a product of climate. In palaeoenvironmental studies the principal of Uniformitarianism, developed from geological and evolutionary studies (Darwin 1996; Lyell 1997), is typically applied. Uniformitarianism assumes that the same determinants that link biological processes, such as plant growth, to environmental conditions, such as moisture, today also did so in the past. Thus taxa which favour wet situations today probably had the same requirements in the past. The same holds true for those species characteristic of drier environments. A sequence of change in mire hydrology and, by implication, climate, through time can be inferred by tracing changes in species representation and preservation. This approach to the reconstruction of palaeoclimate records has been practiced for more than a century. The early development of mire-based palaeoclimate studies has been detailed by several authors including Barber (1981), Frenzel (1983), Feehan & O'Donovan (1996) and more recently by Charman (2002). Here, some of the more significant and well-known developments are briefly touched upon.

2:2:2 Developing models of mire evolution

Over a century ago, a model of European post-glacial climate change was developed utilising changes observed in gross peat stratigraphy from Scandinavian bogs (Sernander 1908). The Blytt-Sernander scheme divided the post-glacial into six climatic periods: the Pre-Boreal, the Boreal, the Atlantic, the Sub-Boreal and the Sub-Atlantic. Each period varied in individual duration and was characterised by a particular peat type from which the nature of the climate was inferred. For example, *Pinus* sp. stumps in well humified peat suggested warm and dry conditions present in the Boreal. In contrast, poorly humified *Sphagnum* peats were suggestive of the warm, wet stage referred to as the Atlantic (Roberts 1989).

Contemporary work in German raised bogs further utilised changes in stratigraphy to suggest evidence of widespread climate change (Weber 1900; Frenzel 1983). The *Grenzhorizont*, the name given to the boundary between well-humified *Sphagnum-Calluna-Eriophorum* peat and the overlying fresh to poorly humified *Sphagnum* peat, was identified by Weber (1900) in mires in northern Germany. To Weber, it represented a hiatus in the growth of the mire in the later sub-Boreal, a dry, warm phase. The sub-Atlantic saw a return to cooler, wetter summers and renewed accumulation of poorly humified *Sphagnum* peat deposits. This boundary was identified in mires elsewhere in Europe and the *Grenzhorizont*, which was dated in one place on archaeological grounds to between 1000BC and 750BC (Frenzel 1983), was subsequently applied as a significant stratigraphic and chronological marker to mires in other parts of Europe. For example, Walker & Walker (1961) deliberately sought out "post-'Grenz'" peats in their examination of peat stratigraphy of Irish raised bogs.

In the 1930s another term used to distinguish significant stratigraphic boundaries in raised bog peats entered the literature. Granlund's (1932) work in Swedish bogs identified multiple boundaries of a similar nature to the *Grenzhorizont* which Granlund referred to as Recurrence Surfaces, i.e., levels at which a recurrence or surge in the rate of peat accumulation occurred. Granlund (1932) described five recurrence surfaces, RYI-RYV, (RY is derived from the Swedish *Rekurrensytor*), dating to AD1200, AD400, 600BC, 1200BC and 2300BC. Nilsson (1935) added another four following surveys of twelve Swedish mires, with the earliest dating to *c.*3500BC-3000BC. These have traditionally been interpreted as corroborating evidence of climatic deterioration (Barber 1981). The Swedish records suggested the presence of the *Grenzhorizont* as well as eight other significant boundaries dating from *c.*3600BC-AD1200. The identification of multiple recurrence surfaces of varying age demonstrated that the relationship between Holocene climate and bog growth was potentially more complex than first anticipated.

Radiocarbon dating of peat sequences since the 1960s enabled independent correlation of biostratigraphic sequences between mires (Godwin 1960; Lundqvist 1962; Casparie 1972; Aaby 1976). Better dating showed that there was a greater variation in the timing of stratigraphic changes, such as the *Grenzhorizont* and recurrence surfaces and this had implications for identifying and understanding the controls on mire development.

Fundamental to the identification of climate-driven responses in mires is timing. Where changes between mires are synchronous, climate is generally regarded as the primary agent of change. In the later Holocene documentary records may also provide corroborative evidence for climatically-induced changes (e.g., Lamb 1995). Asynchronous events suggest that mires responded to factors other than climate. One of the difficulties in identifying synchroneity is the "suck-in and smear" effect (Baillie 1991a). There is a danger that dates may be moved towards a given event without due consideration of the differences in range between dates. This issue of timing of changes is returned to in Section 2:2:3 as interpretation of radiocarbon-derived age estimates can be problematic and may result in the mis-identification of climate forcing within mires. One of the first studies to incorporate comprehensive dating of the microstratigraphy of a raised bog was that of Aaby (1976). The combination of 70 radiocarbon dates, peat stratigraphic, plant macrofossil, pollen and humification analyses suggested the possibility of cyclic climate variation. Where Blytt-Sernander suggested six climate periods over the last 10,000 years, Aaby (1976) inferred 32 climatic shifts over the last 5500 years. This had significant implications for the interpretation of palaeoclimate records at a time when theories on the mechanisms behind bog growth were being re-evaluated.

It has been shown that for more than a century, raised bogs have been regarded as archives of changing climate conditions. However, not all scientists believed that climate was the single most important factor - others viewed raised bogs as self-perpetuating, peat-producing systems driven by internal or autogenic mechanisms. For example, Osvald's (1923 cited in Barber 1981) regeneration complex theory of bog growth suggested that the mosaic of hummocks, hollows and pools should be regarded as a miniature hydroseral succession where degenerating hummocks became loci for new pools and pools were eventually replaced by hummocks (Moore & Bellamy 1973). The replacement of a hummock by a pool and vice versa was responsible for progressively increasing the altitude of the bog surface and for drawing the bog water table upwards. Detailed scrutiny of this model of bog growth began in the 1960s. Researchers found that few bog pools conformed to the model of shallow, recently flooded sites developing over collapsed, degenerating hummocks (Walker & Walker 1961). In addition it was shown that hummocks could persist for millennia (Casparie 1972; Aaby 1976) and rather than encourage the formation of pools hummocks may have limited pool formation. These challenges to the regeneration complex theory provoked further testing of the model by Barber (1981).

Barber's multi-proxy approach to investigating the mechanisms of bog growth corroborated some of the findings of earlier researchers. Hummocks could persist for up to a thousand years and displayed no evidence of cyclicity in relation to pool formation. Barber (1981) also showed that the entire mire surface reacted in the same direction to a change in conditions, an observation previously made by Walker & Walker (1961). Barber (1981) proposed that changes in peat stratigraphy, such as contemporary and extensive hummock or hollow expansion or contraction, reflected dry and wet phases in the evolution of a bog. He argued that not only does climate influence the formation and distribution of raised bogs but climate change is the primary modifying influence on the peatland environment through time and that wet-dry shifts at micro-, meso- and macro-scales can be explained in terms of climate change.

Despite falsification of the Regeneration Complex Theory and the ascendancy of Barber's Phasic Theory (1981), the primacy of climate in bog growth remains open to question. Anderson *et al.* (2003) suggest that autogenic processes and local topography exert greater control on mire development than regional climate change. As techniques of environmental reconstruction are broadened and refined there is an increasing emphasis on the separation of climate signals from internal ecosystem controls (Hendon *et al.* 2001). The basis for distinguishing between signals is discussed further in Section 2:2:3 below.

2:2:3 Autogenic and allogenic controls on mire development

Controls on mire development fall into two categories: autogenic processes, which refer to the internal dynamics of the system, and allogenic controls that are external influences on mire evolution. Autogenic processes may be a consequence of: topography, both basin morphology and mire surface topography; vegetation, the types of plants and plant communities present; and hydrology, specifically the movement and storage of water within the mire system. An example of autogenic change is hydroseral succession, i.e., a plant succession commencing in waterlogged sites which eventually results in the displacement of water by peat (Tansley 1939). Here the direction of change is typically towards drier conditions.

Climate and human activity are examples of allogenic change with the potential to modify mire development in the long and short term. Each has the potential to shift the hydrological balance of a mire towards wetter or drier conditions. In general allogenic processes can be viewed as the background conditions against which mire development and hence autogenic change takes place (Charman 2002). This means hydrological shifts arising from allogenic factors may be superimposed on autogenic trends (Bunting & Warner 1999). This may accelerate an existing trend or cause a reversal in conditions (*ibid.*). Thus, the actual catalyst for change may be obscured by the over-riding external trend in the shift towards drier or wetter conditions.

Distinguishing between the effects of autogenic and allogenic processes can be difficult (Charman *et al.* 1999). As stated above (page 23), allogenic change, such as climate, is generally inferred on the basis of timing. Synchroneity of events across different sites or regions implies changes brought about by a shift in climatic conditions towards a wetter or a drier regime. Where changes are found to be asynchronous, i.e., independent of a wider pattern, then internal, natural factors are the most likely modifiers. However, defining the cause of asynchronous change may be complicated by the potential influence of past human activity such as drainage and agriculture-related activities (Lomas-Clarke & Barber 2004). In addition, research over the last twenty years in particular has shown that while climate change can 'push' a system along a new developmental pathway not every system will necessarily be influenced to the same extent or respond in any way to changes in climate (see below).

Factors influencing the likely climate sensitivity of mires may include the geographical location of the mire; in the case of North West Europe, this means mire location in relation to the north Atlantic and the modifying effects of the Gulf Stream on climate (Langdon & Barber 2004). Mire size, basin geometry and topography, drainage and internal hydrological systems can also influence mire responsiveness to climate change (Charman 2002). Some systems appear to be 'insulated' from changes in either temperature or moisture. In the case of raised mires in Bergslagen, Sweden (Foster & Wright 1990; Almquist-Jacobson & Foster 1995) and Derryville Bog, Ireland (Casparie 1998, 2005) neither temperature nor moisture were limiting factors on the growth of these raised bogs. Significant hydrological changes at Hammarmossen, Sweden (Foster & Wright 1990) such as changes in water table and the thickness of the acrotelm may have been caused by changing bog shape rather than wet-dry climate shifts. On the basis of their work in Sweden, Foster and Wright (1990, 460) suggest "allogenic processes should ... be interpreted as an overlay on [an] internal signal and can only be understood after the internal signal has been accounted for". At Derryville, major hydrological shifts inferred in testate and humification data were best explained by a series of bog bursts; topography and human agency worked at different times to impede drainage causing the system to discharge and interrupting bog growth on more than one occasion (Casparie 1998, 2005). Caseldine *et al.* (1998, 30) stated that "Derryville bog is clearly not a 'sensitive' enough mire-system for palaeoclimate reconstruction in terms of Barber (1994)".

Barber (1985, 1994) suggests that mires lying in areas marginal for mire development, i.e., at the edges of the limits for mire growth, are more likely to register a climate signal than mires where changes in effective precipitation are irrelevant to mire growth. Hence the Swedish and Irish mires are less likely to be climatically sensitive than mires in northern England for example, as moisture and temperature were never limiting factors. This might suggest that some bogs are not worth investigating in terms of climate record or that more work is needed in such bogs to distinguish between internal ecosystem and external environmental signals. Clearly allogenic controls such as climate can be subordinate to autogenic processes. Climate however, remains an important feature of mire development, even if in some cases it is operating in the background.

Evaluating climate sensitivity includes adopting high resolution, multi-proxy analytical approaches with tight chronological control. Plant macrofossils, testate amoebae and the degree of peat humification among others have proven to be useful palaeohydrological indicators. While each has limitations (see Chapter 4) these approaches produce data which can be interpreted as changes in mire surface wetness. Ascribing these changes to climate or internal forces however requires additional information. Greater understanding of the mechanisms behind bog growth is clearly one area which will enable better distinctions to be drawn. On a site by site level however individual mires may exhibit idiosyncratic features which may obscure a potential climate signal. Stratigraphic survey can identify topographic, vegetative and hydrological phenomena which may otherwise complicate interpretation of a purely core-based record, for example, gross features such as ridges, gullies, wood horizons, or individual microforms such as pools or hummocks. It has been shown that hummocks are best avoided as lawn-hollow-pool microforms are more responsive to hydrological change than hummocks (Aaby 1976; Barber *et al.* 1998). In addition to choosing core sample location carefully, taking cores from multiple locations increases the potential for identifying related mire-wide changes (Hendon *et al.* 2001). This issue of the need for replication is itself contentious as some studies suggest that the variation between profiles from the same site is slight with broadly simultaneous changes occurring across profiles (Barber *et al.* 1998).

Another obstacle to the identification of climate signals from mires is the type of peat-forming vegetation. For example, Barber *et al.* (2003) have suggested that bogs dominated by a single *Sphagnum* species capable of tolerating a wide range of water tables may be less sensitive to climate forcing than sites in which a variety of *Sphagna* occur. Changes in surface moisture conditions may be obscured because the dominant *Sphagnum* was not affected. Stoneman *et al.* (1993) suggest that *Sphagnum imbricatum* once occupied a wide water table niche and was capable of withstanding greater fluctuations in moisture than its modern equivalent/counterpart. Sequences dominated by *S. imbricatum* may therefore fail to return a climate signal, as changes in effective precipitation are not registered in the macrofossil record. As species composition tends only to be revealed once laboratory analysis is underway it cannot be easily allowed for when sampling in the field. To some degree, especially where the stratigraphy of a site may be little known, selecting for species diversity may not be possible.

As stated above, timing is the key element in identifying climate change in mires. Where changes can be found to be synchronous between sites, on a local, regional or broader scale, then external climatic forcing may be responsible for a shift in conditions. The timing of changes in environmental conditions from peatlands is largely derived from radiocarbon determinations. However, using radiocarbon dates to compare environmental sequences can be problematic and leaves results open to misinterpretation. AMS dating, rather then conventional radiocarbon dating is generally applied to studies where higher temporal definition of environmental change is required because AMS dates offer narrower probability ranges. Calibration is used to transform results into calendar ages thus facilitating inter- and intra- site comparisons of changes in palaeoenvironmental sequences (Bowman 1990). Nonetheless, calibration can produce dates with multiple maxima and minima (Telford *et al.* 2004). Efforts to increase dating accuracy and narrow the probability range have concentrated on 'wiggle-matching' (Kilian *et al.* 1995). More recent research, focused on reducing potential sample errors, has recommended selecting, where possible, for botanically pure species, modelling rates of peat accumulation and accounting for changes in stratigraphy (Kilian *et al.* 2000). Speranza *et al.* (2000) combined wiggle-match dating and changes in the rate of peat accumulation, inferred from arboreal pollen concentrations, in an attempt to improve on accuracy. One problem with this approach however is the assumption that arboreal pollen influx or pollen accumulation rates (Bennett 1994; Hicks 2001) are constant. Long-term monitoring of pollen dispersal has shown that AP influx can vary annually and between species (Hicks *et al.* 2001) thus leaving its use in estimating rates of peat accumulation open to question.

For more than a decade tephra isochrons have been utilised as a means of chronological control (Pilcher & Hall 1992; Pilcher *et al.* 1995) and to correlate more closely proxy-based records from peat sequences (see Section 2:3:8). Recently Langdon and Barber (2004) examined peat sequences from seven mires in northern Scotland for tephra, testate amoebae, plant macrofossils and humification. Utilising tephra from the Hekla-4 and Glen Garry eruption events as time markers they produced palaeoecological reconstructions suggestive of decadal to centennial shifts in climate. In central and southern Scotland before, at and after the Glen Garry isochron the proxy data implies the climate was relatively dry. In contrast around the same time in northern Scotland a wetter situation is suggested. The difference in climate between northern and southern/central Scotland is also in evidence around the deposition of the Hekla-4 tephra. Langdon and Barber (2004) suggest that applying tephra-based chronologies to proxy data can allow for better definition of patterns of regional climate change where tephra layers are usefully placed within a given sequence. Of course, tephra will not necessarily be available at every site and radiocarbon determinations remain the most convenient way to date palaeo-records.

2:2:4 Conclusion

The above discussion has shown that accurate dating of changes in mire hydrology is pivotal to identifying the frequency, duration and magnitude of past climate change. While there are two schools of thought as to which group of factors, i.e., autogenic or allogenic, is the more important in mire development and hydrological change, it is clear that both can influence mire growth and may have worked either in tandem or separately at any given time. Over the last decade, more work has been carried out aimed at improving the nature of the palaeoclimate record from mires. The development of quantitative hydrological reconstructions using testate amoebae in combination with more widely used proxies such as plant macrofossils and humification has enabled production of reliable, high resolution records of hydrological change (e.g., Chiverrell *et al.* 2001; Hendon *et al.* 2001; Mauquoy & Barber 2002).

2:3 PALAEOENVIRONMENTAL STUDIES IN IRISH RAISED BOGS

2:3:1 Introduction

A number of authors have recently presented a comprehensive list of techniques aimed at extracting records of system development and climate change from mires (Charman 2002; Chambers & Charman 2004). Many have been applied in an Irish context and, in keeping with the wider trends in the development and application of proxy palaeoecological approaches, some techniques have a longer history of use in an Irish context then others. In this section an overview of the application of familiar and relatively standard approaches, as well as less frequently employed or newly developed methods, is presented. The emphasis is on those techniques most appropriate for use in mires. The methodologies utilised in this thesis may then be considered against this background of wider palaeoenvironmental research in Ireland.

2:3:2 Peat stratigraphy & plant macrofossils

Stratigraphic surveys may be spilt into two types:

(a) surveys completed using coring transects in which 'key-hole' views of the stratigraphic composition and changes are acquired.

(b) surveys of peat sections such as peat cuttings or drain faces in which detailed stratigraphic relationships and the extent and type of mire microtopes/microforms may be recognised.

In this discussion surveys of type (a) are referred to as stratigraphic surveys while those of type (b) are called gross stratigraphic surveys. Most stratigraphic surveys conducted in Ireland fall into the first category of survey though some have combined both approaches especially where records of deeper peat may only be obtained through coring. In the last fifteen years type (b) surveys have emerged as an important tool in the reconstruction of mire landscapes.

In Ireland gross peat stratigraphic studies were first employed in the 1930s "... to advance the studies of late glacial and post-glacial development of flora and climate..." (Jessen 1934, 130). To progress the classification and evolutionary mapping of Irish bogs von Post (1937) described advances made in Sweden using gross peat stratigraphic, ecological and geological survey techniques and their potential applicability in an Irish context. With the foundation of the Irish Turf Board in 1922 and its subsequent transformation into Bord na Móna in 1946 (Feehan & O'Donovan 1996) surveys of Irish peat bogs were geared towards identifying those most suitable for exploitation rather than study. In-house surveys, such as Dubsky's work in Lemanaghan, Co. Offaly (Dubsky 1945), saw a proliferation of peat surveys that included raised and blanket mires. The industrial exploitation of ombrogenous mires and hence their progressive destruction spurred on researchers interested in understanding mire evolution and how mires might inform our view of the past. Broad descriptive terms, often derived from industrial surveys, were employed to help elucidate mire origin and distribution (Barry 1954; 1969). In Ireland, terms such as 'Younger *Sphagnum*' and 'Older *Sphagnum*' were later replaced by more ecological/plant specific descriptions. For example, in the 1960s Walker (1961) and Walker and Walker (1961) focused on eight bogs across the

Irish midlands and northeast Ulster to explore peat regeneration and its implications for climate reconstruction. Field identification of peat types was generally confined to five main types: *Calluna-Sphagnum* peat, *Sphagnum-Calluna* peat, Fresh *Sphagnum* peat, *Sphagnum cuspidatum* peat and *S. cuspidatum* mud. The mechanisms of peat growth were explored further by Hammond (1968) who provided a comprehensive description of the stratigraphy and development of the lower peats in a major raised bog complex located in the east central Ireland, the Ballydermot and Blackriver Bogs (Fig. 2:5). The study incorporated the use of pollen, plant macrofossils and radiocarbon dating. Interestingly this study identified wood-fen peat levels, at the interface between the fen and the raised bog, the formation of which Hammond related to local edaphic factors. As well as the investigation of individual mire sites, gross peat stratigraphic survey was employed to map the distribution, and define the range, extent and number, of mires existing in Ireland (Hammond 1981).

Following the completion of the all-Ireland peatland survey (Hammond 1981) gross stratigraphic surveys of Irish mires appear to have declined. Instead survey resolution was decreased with surveys tied to other investigations such as pollen analyses (see Section 2:3:6) with records of stratigraphic sequences generally limited to core-based records (type (a) surveys). Difficulties in interpreting pollen records and assessing the degree to which they reflect climatic behaviour have prompted Weir (1995, 115) to call for "more detailed study of stratigraphic change in raised bogs ... [it needs] to be more fully developed to provide independent evidence of climate change". Recently, stratigraphic surveys aimed at identifying sampling locations within mires likely to be responsive to climate change (Blundell 2002) or at providing cross-sections through bogs to investigate the transition from fen to raised bog (Hughes & Barber 2004) have been completed for raised bogs in central Ireland. In addition, Clara Bog, and nearby Raheenmore Bog, have long histories of study as they have been the focus of conservation and restoration efforts since the mid 1980s (Connolly 1999; Schouten *et al.* 2002). Here, a series of baseline studies, incorporating stratigraphic, ecological, and hydrological and palaeoecological studies were conducted. The primary aim of these studies was to inform future management and restoration strategies. The stratigraphic surveys were targeted on specific areas such the soak system at Lough Roe (Connolly *et al.* 2002) and were based on coring (type (a) surveys) rather than peat face (type (b) surveys) records.

The increased awareness of the archaeological importance of Irish raised bogs in the 1980s (Raftery 1990) saw gross peat survey re-emerge as an important means of reconstructing peatland landscapes and, of addressing wider issues of palaeoenvironmental reconstruction (see Section 2:2:3). Integration of archaeological and palaeoenvironmental issues, via the peat stratigraphic record, was developed in the Netherlands by Casparie (1972, 1982, 1984 & 1987) at Bourtanger Moor. Here gross peat stratigraphy was used to address questions of site location, construction and function. This approach was extended to Irish trackways in the early 1990s (Casparie & Moloney 1994, 1996) and formed a fundamental part of the excavation project at Derryville, Co. Tipperary from 1996-1998 (Casparie 1998, 2005). In a similar vein, extensive stratigraphic survey was conducted at Tumbeagh Bog, Co. Offaly at the site of a medieval bog body (Casparie forthcoming).

Peat stratigraphic studies rely on field identification of peat types and laboratory analysis and identification of the individual plant components comprising the peat, i.e., plant macrofossil analysis. Plant macrofossils represent the semi-decomposed remains of plants that can be recognised by the naked eye or with the aid of a low power microscope. Analysis demonstrates the local presence of a taxon enabling location-specific vegetation reconstruction (see Section 4:5). Plant macrofossil investigations generally go hand in hand with peat stratigraphic projects and as such these approaches have a shared history of use in an Irish context. Macrofossil analysis was an essential component of many of the projects already mentioned. It was fully integrated into the palaeoecological work undertaken at Derryville, one of the most significant multi-proxy projects in Ireland to date (Caseldine *et al.* 1998, 2005). Plant macrofossil use in an Irish context has been further extended by two recent projects which combined these techniques focused on (a) utilising macrofossils as palaeohydrological proxies for climate change (Barber *et al.* 2003) and (b) elucidating the nature of the fen-bog transition in raised bogs in the Irish midlands (Hughes & Barber 2004). Macrofossils represent a valuable means of reconstructing hydrological and vegetation change in mires and are essential to understanding mire developmental pathways. In Ireland, as elsewhere, plant macrofossil studies can be viewed as a standard component of mire-based palaeoecological research.

2:3:3 Testate Amoebae

A review of testate amoebae work undertaken in an Irish context has found an almost complete absence of modern ecological research, a limited number of fossil studies and a paucity of pre-existing appropriate hydrological data upon which development of a modern data set could be based.

There are no completed testate amoebae modern studies from the Republic that would allow the development of a transfer function applicable to fossil assemblages though there are two projects at varying stages of development. The ACCROTELM initiative is a Europe-wide project (ACCROTELM cited 2004) concerned with study of raised bog systems stretching from Iceland to Russia. It includes one site in Ireland, Ballyduff Bog, Co. Offaly, from which modern testate assemblages will be studied (Dan Charman pers comm.). A separate project is underway in Northern Ireland. Dr. Wendy Woodland, University of West England, Bristol, has gathered three years' water table monitoring data, and 30 samples from Fairywater raised bog, Co. Tyrone, aimed at establishing a modern data set which may have applications for the island as a whole. The work is not yet at a stage where the data are available (Dan Charman pers. comm.).

At present palaeoecological studies that utilise testate amoebae in Ireland are limited and at different stages of completion. In only one instance has a fossil study been completed as a study in its own right as well as having formed part of a broader integrated palaeoenvironmental programme of research. Fossil testate analysis was undertaken on sequences from a raised bog archaeological complex at Derryville, Co. Tipperary (Caseldine *et al.* 1998, 2005). The palaeoenvironmental programme involved a comprehensive peat stratigraphic survey, pollen, coleopteran, and wood species analyses as well as plant macrofossil and humification studies (Caseldine *et al.* 2001; Caseldine *et al.* 2005; Casparie 1998, 2005; Reilly 1998, 2005; Stuijts 1998, 2005). The multi-proxy approach to environmental reconstruction found good correspondence between testate amoebae and the other proxies (Caseldine *et al.* 1998; 2005). A second fossil study formed part of a palynological and tephra based study of blanket bog in Croghaun East, Co. Mayo (Dwyer & Mitchell 1997) although the testate results remain unpublished. Analysis of peat profiles from Achill Island, Co. Mayo (Caseldine *et al.* 2005) included testate amoebae but poor preservation hindered the use of testates. Recently completed PhD research by Blundell (2002) concerns climate reconstruction over the last 2000 years and utilised testate amoebae, macrofossil and humification analyses. Fossil material from two sites in Ireland, Cloonoolish, Co. Galway and Ardkill, Co. Kildare is examined and compared with sites in the UK. The studies mentioned above have pioneered the study of fossil testate stratigraphies in an Irish context and their results are discussed in Section 10:3.

It is therefore clear that the use of testate amoebae in Irish contexts has been limited and there is a need for further work on modern and fossil testate assemblages from mire sites in Ireland.

2:3:4 Humification analysis

Irish mire sites have been used in the development of colorimetric humification analysis as an environmental proxy and exploring the suitability of blanket mires for palaeoenvironmental reconstruction. One of the first projects undertaken in blanket bog was in Letterfrack, Co. Galway (Blackford & Chambers 1991). On comparison with data from English and Welsh mires, the Letterfrack data suggested mid-first millennium AD climatic deterioration, a result of short-term climate cooling or prolonged climatic wetness. Later investigations focused on the last five hundred years with changes in humification curves from two cores linked to the Medieval Optimum and the Little Ice Age (Blackford & Chambers 1995). More recent work has used humification trends between *c.*4000BC and *c.*2600BC to help explain how and why a silt layer was deposited across blanket peat on Achill Island, situated on Ireland's west coast (Caseldine *et al.* 2005). The silt, deposited *c.*3200BC, is viewed as representative of a series of severe storms that took place towards the end of a warm and dry climate phase. By *c.*2600BC humification curves imply increased mire surface wetness which Caseldine *et al.* (2005) suggest can be linked to a period of wider North European climatic deterioration that began around 2000BC.

Humification studies have also been conducted on a small number of raised bog sites from Ireland. Two are linked to archaeological investigation of wooden structures lying within bogs in counties Longford (Caseldine *et al.* 1998) and Co. Tipperary (Caseldine & Gearey 2005; Caseldine *et al.* 2000). The Longford study looked at the impact of any volcanic activity, in this case Hekla 4 *c.*2310BC, on climate (see Section 2:3:8). Humification suggested a trend towards greater surface wetness which pre-dates eruption. The authors suggest "that the effects of Hekla-4 were superimposed on a climatic shift to wetter or cooler conditions" (Caseldine *et al.* 1998, 110). In Tipperary, at Derryville bog, humification analysis has served two main purposes. Firstly, it formed one of several palaeohydrological techniques applied to peat sequences from the bog to reconstruct mire development and the controls on mire evolution (Caseldine & Gearey 2005). Secondly, humification results from colorimetric analysis have been compared with estimates obtained by means of luminescence spectroscopy (Caseldine *et al.* 2000). This study and its implications are discussed in Section 4:6.

Two other projects which have included Irish raised bogs in their remit are the TIGGER IIa Project (Barber *et al.* 1999) and recent PhD research by Blundell (2002). Results of the latter are unpublished, though two raised bogs from counties Kildare and Galway were included in a comparative UK and Ireland study. Fallahogy bog, Co. Tyrone, served as the raised bog type-site for the TIGGER IIa project and detailed results await publication. Preliminary humification results suggest decreasing mire wetness early in the first millennium AD, after AD600 and in the last part of the Little Ice Age (Barber *et al.* 1999).

2:3:5 Dendrochronology & sub-fossil pine studies

Dendrochronology uses tree rings to provide a means of dating past environmental and cultural phenomena. Trees grow by forming clear annual growth rings around their circumference. Counting backwards from the outermost ring or cambium gives the age of a given ring and measuring the width of each ring provides an indication of the environmental conditions in which the ring was laid down. Overlapping records of tree-ring counts and widths are used to develop master curves or chronologies (Baillie 1982). Irish dendrochronological studies have utilised oak-tree ring records to produce a long master chronology dating back to 5474BC (Brown 2005). This is largely based on oak trees from bogs including archaeologically-derived timbers. The precision provided by dendro-dates makes them highly attractive for use in environmental reconstruction as accurate timing is fundamental to the identification of changes which may be climate driven. Typically, however, most palaeoecological studies are not directly tied to dendrochronological dates. This is mainly because bog oaks suitable for dating may not be present, or identified, at sites selected for investigation. Core-based records also require large numbers of dates at intervals best suited to radiocarbon dating. Palaeoenvironmental investigations associated with archaeological sites, such as trackways, have benefited most from the chronological constraints provide by dendrochronological dating of trackway timbers (Caseldine *et al.* 1996, 1998, 2005; Casparie 1998, 2005).

Dendroclimatology is the study of the relationships between climate and tree-growth parameters and their use in the reconstruction of past climates (Briffa 2000). Changes in climate towards a warmer or a cooler regime may affect tree growth resulting in changes in tree ring width. Dendroclimate inferences have been used to trace the development of environmental and cultural processes in Ireland and to provide evidence for abrupt changes in climate related to volcanic activity (Hughes *et al.* 1978; Baillie 1991, 2001; Baillie & Brown 1996). For example, links have been postulated between the introduction of metal working to Ireland, the beginning of the pine decline and potential catastrophic consequences of the eruption Hekla 4 on the basis of changes in tree-rings (Baillie 1995). In the case of earlier prehistoric depletions gaps in the dendrochronological record, inferred from depletions in bog-oak populations, may relate to an increasingly wet climate (Baillie & Brown 1996). In later prehistory anthropogenic factors may confuse any potential climate signal in the dendrochronological record (*ibid.*).

Sub-fossil pine studies in an Irish context have been aimed at three inter-related areas of research. The first research area relates to dendrochronological studies and the construction of pine-based chronologies. Two such chronologies, derived from bog pines from raised bogs in Northern Ireland, have been constructed for the third and sixth millennia BC (Pilcher *et al.* 1995). The later of the two correlates well with the Irish oak chronology for the period 3451BC-2569BC (*ibid.*). Having two chronologies, derived from different species, increases the possibility of dating palaeoenvironmental change as well as archaeological landscapes or sites in which *Pinus* sp. (pine) was present.

The second area to benefit from the pine-based chronologies is the timing of the Irish and British pine declines identified from pollen records and dating to approximately 2000BC. Recent work in southwestern Ireland (Mighall *et al.* 2004) has shown that there is broad agreement between the presence or absence of pine trees and changes in the percentages of pine pollen indicative of a pine decline although radiocarbon rather than dendrochronological dates were needed to confirm the relationship between the pollen and pine macrofossil stratigraphies.

The third area that sub-fossil pine studies have been pursued is in relation to mire development. Tree growth on bogs can be linked directly to mire hydrology. Drained or dry mire situations provide for optimum tree growth (Mighall *et al.* 2004). Ancient pine woodlands in raised bogs in counties Offaly and Kildare provide evidence of woodland cover on Glashabaun Bog (Fig. 2:5) for up to 500 years with individual trees living on average 132 years (McNally & Doyle 1984a). Here peat stratigraphic, pollen and macrofossil evidence are used to suggest that seral succession, driven by the separation of the mire surface from the water table due to the accrual of highly humified *Eriophorum* peat, enabled the pine woodland to establish and regenerate over a period of 500 years (McNally & Doyle 1984b). Climate change is thought to have sealed the woodland's fate due to a shift towards wetter conditions around 2000BC (*c.*4000BP).

2:3:6 Pollen

Pollen analysis has a long and widespread history of use within palaeoenvironmental studies globally (Lowe & Walker 1997). In common with many other parts of the world pollen analysis has been frequently employed in an Irish context in order to examine vegetation change, enable environmental reconstruction, and establish the chronology and nature of human impact on the environment. Investigations have included a range of mire types as well as lakes (e.g., Molloy & O'Connell 1991; Selby *et al.* 2005) though the latter are not discussed further here. Mitchell's work (1956, 1965) represents some of the earliest applications of pollen analysis to raised bogs in Ireland. These studies provided long sequences of Holocene environmental change and demonstrated the potential for studying the development of agriculture and its impact on the landscape. These are themes followed up by several researchers particularly in and around raised bogs where archaeological sites are present (Weir 1987, 1993, 1995; Caseldine *et al.* 1996; Lomas-Clarke & Barber 2004) as well as archaeological landscapes in blanket mires (Pilcher & Smith 1979). Lengthy pollen-based sequences of Holocene environmental change are available from raised bogs several counties. For example, Meenadoan Bog in County Tyrone (Pilcher & Larmour 1982), Sluggan Bog, Co. Antrim (Smith & Goddard 1991) and Clara Bog, Co. Offaly (Connolly 1999) all provide records spanning the last 12,500 years. Shorter palynological records were obtained from Woodfield Bog, Co. Offaly (van der Molen 1988) and Carbury Bog, Co. Kildare (van Geel & Middledorp 1988) which yielded records covering the last 850-250 years. Research focused on identifying well established climate changes, such as the Medieval Warm Period, the Little Ice Age and more recent twentieth century warming, in the pollen record has involved examination of sequences from three mire types including the raised bog at All Saints, Co. Offaly (Cole & Mitchell 2003). The suitability of pollen for reconstructing past vegetational and climate change is thus well established. Despite, however, von Post's assertion that "[p]ollen sequences carefully worked out always are the *conditio sine qua non* of investigating bog evolution reliably" (von Post 1937) pollen performs less well at mapping mire evolution than other fossil groups with stronger links to the mire being investigated in terms of origin and site hydrology. As a means of reconstructing mire palaeohydrology other fossil groups such as plant macrofossils and testate amoebae are more appropriate.

2:3:7 Coleoptera

A history of entomological study in Ireland by O'Connor (1997) details the beginnings of this discipline from its genesis in the 1700s, through to the development of a national collection of insects. O'Connor (1997) also highlights human-insect interactions via insect extinctions and introductions as revealed in the fossil study of insect remains typically from archaeological contexts. Studies of this nature were relatively infrequent until the mid 1990s when coleopteran analysis of peat samples, taken in conjunction with the excavation of prehistoric wooden trackways in Corlea, Co. Longford, was carried out (Reilly 1996). While analysis enabled reconstruction of the mire surface on which two Neolithic trackways had been constructed, this study also showed the contribution beetles could make to the investigation of the changes in temperature which are difficult to recognise in bogs. Where certain thermophilous taxa are represented, as at Corlea (Reilly 1996), beetles can serve as a useful proxy for change. The importance of the excavations and palaeoecological analysis carried out at Corlea (Raftery 1996) cannot be underestimated. Although limited in extent the palaeoecological work at Corlea served as an important benchmark for the approach adopted at Derryville, Co. Tipperary (Reilly 2005). Here, coleopteran analysis was one of several lines of evidence pursued, resulting in an integrated and comprehensive view of the bog and the wider hinterland over several thousands of years (Caseldine *et al.* 2001). At Derryville, the insects successfully highlighted contrasts in water quality, vegetation and land-use between different areas of the mire, augmenting and amplifying the results of the peat stratigraphic and palaeohydrological proxies. A similar degree of correspondence between proxies is present in records from Tumbeagh Bog, Co. Offaly (Reilly forthcoming). The coleopteran studies mentioned above have been driven by archaeological research. Within an Irish context comprehensive coleopteran analyses of peat sequences aimed specifically at mire or wider environmental reconstruction are still under-developed.

2:3:8 Tephra

Tephrochronology and tephra-linked palaeoecological studies have been ongoing in Ireland since the early 1990s (Pilcher & Hall 1992). Tephra layers, ash deposits derived from volcanic eruptions, can provide precise-time parallel markers between sediment sequences. These facilitate the correlation of bio-stratigraphic records from within and between sites. Tephra research generally falls into two distinct but related categories of research: (a) investigations aimed at identifying the presence of tephra horizons used to provide absolute dating and (b) tephra-linked palaeoecological analyses. The second of the two generally follows from the first. In general, tephra horizons have been identified in mires, both raised and blanket bogs (*ibid.*; Pilcher *et al.* 1995, 1996) and recent work in western Ireland has also identified lacustrine sediments as a reliable source (Chambers *et al.* 2004). Initial investigations in Ireland were concentrated in the north-east but more recent investigations have extended the distribution into the west (*ibid*; Plunkett *et al.* 2004), northwest and the midlands (Hall & Pilcher 2002) including Mongan and Clara bogs which lie near to this thesis research site (Fig. 2:5). At least twelve ash deposits dating from AD1947 to *c.*4902BC have now been identified (*ibid.*) with evidence of yet unidentified eruptions also known (Chambers *et al.* 2004).

Tephra-linked palaeoecological studies are typically pollen based and address a range of themes including:

- the timing of the pine decline (Hall *et al.* 1994).
- landscape change associated with medieval agricultural activity (Hall *et al.* 1993; Hall 1998).
- the impact, if any, that the deposition of volcanic ash may have had on vegetation (Dwyer & Mitchell 1997; Hall 2003).

Recently tephra has been linked with diatoms to constrain the timing of lake-level change and how it may relate to wider environmental change (Plunkett *et al.* 2004).

The research carried out in Ireland, particularly in the northeast, has shown the enormous benefit of carrying out tephra-dated palaeoecological studies.

2:3:9 Additional & developing approaches

The individual approaches described above are more commonly used in combination with other techniques. Table 2:1 lists mire sites that have incorporated unusual approaches generally aimed at elucidating past environmental change. Ancillary techniques include sub-fossil, chemical, isotopic and spherical carbonaceous particle (SCP) analyses. Some techniques may not be used again at other sites particularly where they have been shown not to serve as a proxy for climate change. For example, changes in the ratio of stable isotopes from Carbury Bog (van Geel & Middeldorp 1988) were shown to reflect local hydrological and trophic conditions rather than the effects of climate change. Other analyses have been successful in identifying the intensity of human impact on the environment. For example, the silicon and titanium composition of peat from Abbeyknockmoy showed a strong correlation between these minerals and pollen indicators for increased human disturbance (Lomas-Clarke & Barber 2004).

Site	Techniques	Reference
Carbury Bog, Co. Kildare	Stable isotopes ^{2}H & ^{1}H, fungal spores, pollen, testate amoebae & ^{14}C	van Geel & Middeldorp (1988)
Letterfrack, Co. Galway	Sunspot records, humification & ^{14}C	Blackford & Chambers (1995)
Ardkill, Co. Kildare & Cloonoolish, Co. Galway	Spherical carbonaceous particle (SCP), plant macrofossils, testate amoebae, humification, peat stratigraphy & AMS	Blundell (2002)
Cadogan's Bog, Co. Cork	Peat chemistry (element analysis), plant macrofossils, pollen, peat stratigraphy, dendrochronology & ^{14}C	Mighall *et al.* (2004)
Abbeyknockmoy, Co. Galway	Geochemical (silicon & titanium) analysis, pollen, tephra & AMS	Lomas-Clarke & Barber (2004)

Table 2:1 List of mire sites at which less conventional analytical approaches have been applied.

2:3:10 Conclusion

The above review has shown that there is a growing body of palaeoenvironmental work from Ireland. Some techniques have a longer history and higher frequency of use than others, e.g., pollen, plant macrofossils, tephra. In the last five to ten years newly developed methods have been employed successfully at a small number of sites, e.g., testate amoebae and coleoptera. At the same time older approaches, such as gross peat stratigraphic survey, have re-emerged as an essential component of integrated archaeological and palaeoecological studies in Irish bogs. The combination of techniques employed in any research project is typically determined by the aims of that project. In general, within mire-based environmental change research over the last decade, there has been an increased emphasis on reconstructing mire evolution utilising hydrological proxies (Chambers & Charman 2004), in particular testate amoebae, plant macrofossil and humification analyses. Key themes being explored are the climatic sensitivity of mires and the identification of controls on mire development both are relatively under-explored in an Irish context. Recognition of regional differences in mire response to climate change (Mauquoy & Barber 2002) has highlighted the need for more work across the distribution of raised bogs in the northern Europe. There are few dedicated Irish studies, notable exceptions being Walker & Walker (1961) and more recent work from Derryville Bog (Caseldine *et al.* 1998) and Tumbeagh Co. Offaly (Casparie forthcoming), which address these themes and fewer still which combine the range of approaches mentioned above.

Palaeohydrological studies from mires have multiple applications, in particular their utility within archaeological contexts. Projects such those from Corlea Bog (Raftery 1996) and Derryville (Caseldine *et al.* 1998) have succeeded in integrating research questions of the palaeoenvironmental and archaeological communities. They have shown regardless of the precise issues of climate change, the benefit of reconstructing the mire in environment in archaeological terms can be considerable. Elucidating patterns of human behaviour is fundamental to all archaeological exploration and environmental reconstruction of mires allows greater understanding of past landscapes and their possible influence on human activities. Consequently more integrated archaeological and palaeoenvironmental studies are required.

2:4 THE ARCHAEOLOGY OF IRISH RAISED BOGS & ITS EUROPEAN CONTEXT

2:4:1 Introduction

The diverse nature of the wetland archaeological record from Ireland has been briefly touched upon above. In this section, the record from raised bogs is discussed with trackways emphasised as the relevant site type from the study area. The term trackway is used here to describe a structure laid down within a bog in order to enable the bog to be crossed, accessed or bridged in part. Within Ireland the term 'togher' is frequently used to describe trackways and here the terms can be considered interchangeable. In general trackways are longer than they are broad and can extend for a few metres or up to several kilometres in length. Wood is the most common construction material utilised with stone, gravel and turf elements also known. Wooden structures vary in composition with brushwood, roundwood and plank sites all known.

2:4:2 The Irish Record

Up to the mid 1980s the best known archaeological findings from the mosaic of raised bogs that characterise the Irish midlands were generally artefacts including domestic, agricultural and ritual objects of wood, leather, stone and precious metals (Wilde 1861; Eogan 1983; Halpin 1984). The earliest signs of human habitation in Ireland were revealed through peat cutting at Lough Boora, Co. Offaly (Fig. 2:5). A Mesolithic settlement dating from the seventh millennium BC (Ryan 1984), it helped move the focus of early prehistoric studies from the northeast of the island (Woodman 1978) to the midlands and has continued to inform the search for vestiges of the Mesolithic in other parts of the country (Zvelebil 1992; Stanley 2000). In common with the bogs of northwest Europe, the Irish peatlands have also yielded bog bodies (Ó Floinn 1988; 1995). Some appear to fall within the group of Iron Age ritualistic bog burials identified across the bogs of Europe (van der Sanden 1996). Neolithic, Bronze Age, and historic instances are also known with the majority of Irish bodies dating to the medieval period (Bermingham forthcoming b).

Trackways have been a feature of the archaeological record in Ireland since at least the middle of the twentieth century (Tohall & van Zeist 1955; Rynne 1965), with accounts of sites and superficial examination of a small number of sites dating from the nineteenth century (Lucas 1985; Raftery 1999). As new discoveries were made limited investigations were conducted by personnel from the National Museum over the course of the 1950s and 1960s (Rynne 1961-3, 1964-5). By the late 1980s the potential of Irish raised bogs as rich archaeological repositories was recognised because of the survey and excavation of 58 trackways in Corlea Bog, Co. Longford (Raftery 1990). This, the first systematic archaeological survey of a bog in Ireland, propelled the midland peat complexes into a new national and international archaeological arena. The findings prompted Coles & Coles (1989, 159) to suggest that "...there is some argument for saying that the Irish bogs still hold more information about the past than any other wetland in Europe...".

2:4:3 European parallels

By the time Raftery (1990, 1996) began his work in Ireland five decades of investigation and analysis of peatland sites had taken place in Germany. Hayen (1987) had explored the roadways of the raised bog complexes of Lower Saxony and developed a typology for sites based on the nature of construction rather than chronology. In the late 1960s in the Netherlands, Casparie's (1972) peat stratigraphic surveys of bog systems in northern Holland included consideration of the remains of trackways lying within the greatly diminished bogs. Subsequent excavations revealed a network of Neolithic, Bronze Age and Iron Age trackways (Casparie 1982, 1984, 1987). In the 1970s the bogs of Somerset revealed many hidden routeways now known by names such as the Abbot's Way, the Eclipse Hurdle, Honeygore, Skinner's Wood, Tollgate, Westhay and of course the Sweet Track (Coles & Coles 1986). Trackways of a similar nature, but lacking the detailed analyses of the structures from those areas from Somerset, are known from raised bogs in Denmark and in southern Germany (Jørgensen 1993). Prehistoric and medieval trackways, built to cross areas of bog, have also been identified and excavated in Norway over the course of the last fifteen years (Smedstad 2001). Prior to this trackways had not been reported from the Norwegian archaeological record.

Hayen's constructional typological approach has been adopted as a useful means of grouping and describing trackways from raised bogs (Raftery 1996; Cross *et al.* 2001). Where more detailed analyses are required Hayen's typology has limitations, as individual site types are rarely period specific, often reoccurring intermittently over millennia. Raftery (1996) identified six categories of trackway over the course of his excavations in Co. Longford, 1985-1991: brushwood paths, roundwood paths, hurdle tracks, plank paths, corduroy roads and Iron Age roads. The structures date from the Neolithic to the first half of the first millennium AD and each site type has parallels in Europe. Raftery's roundwood paths equate to Hayen's *Pfahlsteg*, plank paths to *Bohlensteg* and corduroy roads to *Bohlenwege*, literally roadway (Hayen 1957 & 1989 cited in Raftery 1996). Raftery (1996, 411) views the occurrence of analogous site types in other European raised bogs as a reflection of "commonly executed, but independently conceived, methods of traversing wet bogs".

2:4:4 Higher numbers

The Irish situation differs from the rest of Europe in terms of the number and range of sites known from raised bogs. Before Raftery began his work in Longford around 70 trackways were known from Irish bogs (Raftery 1999). As of 2002, 3100 sites have been identified (Whitaker 2002). A further 228 new sites were identified in 2002 (Murray *et al.* 2002) with other surveys conducted in 2003 and 2004 also producing additional sites. These results are not yet available for analysis though preliminary figures push the number of sites in excess of 3500 (Cathy Moore pers. comm.). Trackways make up almost 40% of the sites known from Irish raised bogs - 1228 of the 3100 sites identified have been classified as toghers or trackways (this figure includes gravel roads and paved ways) (Whitaker 2002). The majority of sites, at 53%, are broadly classified as deposits of worked wood; the remaining 7% consist of post rows, settlement sites, artefacts and miscellaneous features.

In the late 1980s Coles & Coles (1989) suggested that there were around 1000 trackways known from Ireland, Britain, the Netherlands, Denmark and Germany. Surveys in Lower Saxony between from the 1950s to *c.*1990 had produced somewhere between two and three hundred sites which date from the middle Neolithic to the Middle Ages (*ibid.*; Casparie 1987). In the Netherlands only 40 wooden structures, dating from 2100BC to AD1665, were known before 1987 (Casparie 1987). As recently as 2001, only 26 sites were recorded in Norway (Smedstad 2001). There are now more trackways, let alone other site types, known from Ireland than there are in the rest of northwest Europe.

There are a number of reasons that the Irish bogs have higher site numbers and densities than their European counterparts:

(a) Raised bog occupies so much space in the central lowlands that they were difficult to avoid. Past populations had little option but to operate within and around them. As with any wetland they may also have wished to exploit the resources these wetlands had to offer (Dinnin & van de Noort 1999).

(b) The bogs were not always so extensive as to be impenetrable. For the most part midland raised bogs represent a series of smaller bogs that have over time coalesced and in doing so have engulfed pre-bog settlement, sites built in marginal areas, as well as those lying within a bog. Many of their European counterparts covered larger areas (Casparie 1972) and this is reflected in the length of trackways in Irish versus continental bogs (see Section 2:5:3).

(c) The persistence of the bogs themselves. Unlike their Dutch and English counterparts Irish bogs were not subject to intensive drainage and exploitation until the second half of the twentieth century.

2:4:5 New types of sites

Increasingly in Ireland more and more new site types and combinations of sites are being recognised, with bogs in different parts of the midlands having individual 'personalities'. Some bogs are characterised by the presence of trackways, e.g., Corlea Bog, Co. Longford (Raftery 1996), Annaghcorrib and Kilmacshane Bogs, Co. Galway (Moloney *et al.* 1995). Others are distinguished almost by the absence of trackways and the occurrence of other types of site suggesting other approaches or attitudes to the use of these landscapes. In contrast to several bogs in the Lemanaghan Group, Curraghalassa Bog offers an archaeological record dominated by small-scale structures, which may be platforms, many of which form successive horizons of archaeological stratigraphy (IAWU 1997a; McDermott 2001). Linear plank or brushwood trackways typical of other bogs in the complex are not known. Current dating evidence indicates repeated activity from the late Iron Age into the medieval period. Elsewhere in Co. Offaly a survey of Ballybeg Bog produced almost 100 sites which included a lengthy brushwood and roundwood trackway; a number of wooden platforms; several stone surfaces, one of which has been interpreted as a barrow; a possible log boat; and an extensive complex of wood deposits which remain unclassified. Finds from the bog included a bow stave and a yoke (McDermott *et al.* 2002). Dates so far returned from Ballybeg indicate that much of the activity now revealed through peat cutting has origins in the Early Bronze Age (O Carroll pers comm.). During a visit to the bog in 2003 it was observed that many of the sites were situated in what was once the bog-dryland margin while others appeared to be sited next to a former lake site (Bermingham unpublished data). It is possible that an entire Bronze Age wetland landscape survives at Ballybeg and that, unlike other bogs, it lacks the multiplicity of sites belonging to different chronological periods, although the degree to which peat has been removed will have influenced site representation.

Some of the most exciting work undertaken in a European raised bog in recent years was the excavations conducted at Derryville Co. Tipperary from 1996-1997 (Casparie & Gowen 1998; Cross *et al.* 1999; Cross *et al.* 2001; Cross May *et al.* 2005). This project followed on from two surveys undertaken by the IAWU (1995) in 1994 and 1995 in which 178 sites were identified. In contrast to bogs previously surveyed, the Derryville record included dense complexes and arrangements of site types hitherto unrepresented; e.g., platforms were identified for the first time in the raised bog archaeological record. One complex, known as the Cooleeny Complex, comprised a minimum of 48 wooden structures, a mix of well-defined toghers or trackways and platforms lying within an area 100m x100m. Archaeological strata lay up to 2m deep in places. The sites lay on the lower reaches of the bog-enveloped gently sloping upland (*ibid.*). While this complex was not the subject of further investigation (Casparie & Gowen 1998) other parts of the bog revealed complexes of platforms, burnt mounds with wood-lined troughs, and stone, plank and hurdle trackways (Cross *et al.* 2001). House sites and a cremation cemetery were revealed on the lower slopes of the surrounding dryland, providing the strongest evidence to date of a direct link between dryland occupation and human activity in the margin of a peatland in prehistory (*ibid.*).

2:4:6 Conclusion

The above discussion has shown that, in common with many other wetlands, Irish raised bogs can be regarded as important archaeological repositories. The archaeological character of these bogs can vary from one bog to another. Given that hundreds of new sites are discovered annually, it is likely that more new site types and arrangements of sites remain to be identified. While analogous sites occur elsewhere in Europe, Irish bogs are distinguished by the number and range of site types known. The raised bog archaeological record can provide evidence for human occupation in areas where well-dated dryland archaeological records are often sparse or non-existent (see Section 3:5:2). The volume and variety of sites in Ireland raises many questions, particularly in terms of the accessibility of these mires. For instance, why did past populations wish to operate in and around bogs? How easy was it to gain access to the bog? Were practical measures, such as site construction, required for every journey on to the bog? How frequent were such journeys? This thesis explores the question of access [to the Lemanaghan complex] in more detail.

2:5 HOW AND WHY PAST POPULATIONS ACCESSED RAISED BOGS

2:5:1 Introduction

There are two primary explanations as to why trackways were constructed: (a) to cross a bog or (b) to access a particular part of a bog. Structures built to cross a bog include long sites designed to span the width of the bog and shorter examples laid down to bridge difficult parts of the bog which would otherwise render the bog impassable. The latter may not be easily distinguished from structures of similar magnitude which enabled access to specific places within the bog for reasons other than crossing the bog. Nonetheless, some sites can be clearly identified as a means to access certain points within the bog. Such sites may run from the bog margins towards the bog centre or they may lie entirely within the bog interior; Raftery (1996, 198) refers to sites of this nature as "intra-bog toghers". The desire to either cross or enter a bog may be driven by a variety of reasons including economic, social, religious, military and cultural motives (Table 2:2). The underlying reasons behind the construction of individual sites have in some cases been identified though interpretations are open to re-consideration.

Controls on access to raised bogs	Controls on location
Communication & travel Economic - local & regional Ritual & religion - Sacred space Cultural exchange Territorial control/expansion including war	Distance, e.g., shortest route Resources – labour/raw materials/knowledge - availability & access Ownership/territorial control Population density Environment, ease of access

Table 2:2 List of possible reasons why people wished to access bogs and factors which may have influenced the location of access routes/points.

2:5:2 Trackways which span a bog

Several authors have used the presence of trackways and other sites to suggest how bogs were viewed in the past. Trackways which span a bog reflect that the view of the bog as obstacle, i.e., as a barrier to communication that could be negated with the construction of a trackway (Hayen 1987; Cross *et al.* 2001). Such sites can be regarded as attempts at linking the flanking dryland. Raftery (1996) suggests that Irish toghers reflect the local communication networks of settled agricultural communities which inhabited the upland surrounding a bog. Toghers were laid down to facilitate local journeys for economic, and other forms of social, religious and cultural exchange. In some cases it is possible to demonstrate the specific purpose behind the construction of a trackway which extended across a bog. For example, in Norway Smedstad (2001) observes that all the trackways currently known are positioned in relation to natural lines of communication and hubs of communication within the landscape. As with the Derrynagun site referred to above, the Norwegian sites often lie close to modern roads reflecting continuity in the choice of route through the landscape. Smedstad (2001) views the trackways as former footpaths or bridle paths intended for use in the summer. The sites, most of which date between the ninth and fifteenth century AD, are thought to represent an initiative by a governing authority aimed at developing local infrastructure.

The notion of building routeways through bogs as part of a wider, perhaps regional, communications system has been put forward by Hayen (1987) in relation to Neolithic, Bronze Age and medieval tracks situated in the moors of Lower Saxony and also those of Drenthe in the Netherlands. Bronze Age *Bohlenwege* and *Pfahlwege* extended for up to 10km. These roadways were intended for use by wheeled vehicles rather than serve as simple footpaths across the bog. As a result Raftery (1996) suggests that they formed part of a communications network relevant to the needs of the wider society.

Hayen (1987) refers to the structures from Lower Saxony as rough wooden streets that usually appear in the area around settlements. This link with habitation is further emphasised in relation to medieval trackways which Hayen (1987, 136) suggests were laid down to "strengthen settlement thoroughfares, secure fords or muddy loose foundations". Finding direct links between habitation or other dryland sites and trackways in bogs however is not particularly common, though it does occur. Plank walkways dating from the late sixth and mid-seventh century AD situated in Lemanaghan, Castletown and Derrynagun bogs (see Section 3:3) cut through the bog towards a monastery established in the first half of the seventh century (Gwynn & Hadcock 1970). The Derrynagun walkway evolved into a four metre wide plank and later flagstone roadway which served the monastery until at least the fifteenth century (O Carroll 2001a).

2:5:3 Trackways into the bog

Throughout the north European distribution of trackways are sites that were clearly never intended to cross a mire. Rather these sites extended from the mire edges inwards suggesting they were constructed to access on-site assets. The resource value of bogs to past populations lay in hunting, fowling, fishing and in providing rough grazing, wood, turf, herbs and berries (Kelly 1998). It is likely that structures were established to assist in these ventures. Other trackways may signal commercial motives and ritual or votive influences. These explanations owe much to historical documents, folklore, pictographic sources, and ethnographic parallels as well as adopting a common-sense approach to the use of the bog landscape. There are cases, however, where it is possible to suggest a specific purpose for which a trackway was laid down. The examples presented owe much to an understanding of the wider bog environment and consideration of other archaeological discoveries from the relevant bog and period.

Recent work in Ballybeg Bog, Co. Offaly identified a Bronze Age trackway that ran from the fen margins to a platform situated near the shore of a former bog lake (O Carroll pers comm.). It remains to be seen if the archaeological structures and the lake are indeed contemporary although the bottom of the lake and the platform structure appeared to share a common stratigraphic position, i.e. close to the top of fen peat (Bermingham personal observation). It appears likely the sites were constructed to aid access to the water and the resources it offered.

In considering the distribution and character of Early Bronze Age structures, revealed through excavation in Derryville Bog, Co. Tipperary, Cross *et al.* (2001) identified the exploitation of marginal resources such as woodland and pools as the driving force behind the construction of several narrow trackways and associated platforms. These sites were laid down in the fen margins and later sites, which had a common spatial distribution, allowed exploitation of marginal woodland and oak-covered ridges that lay further into the mire (Cross May *et al.* 2005).

Two of the Netherlands' better known trackways are the late Neolithic site of Nieuw-Dordrecht and the Iron Age Valtherbrug (Casparie 1982, 1987). The Nieuw-Dordrecht track is composed of transverse whole and split oak timbers lying on a substructure of longitudinal birch trunks. Traced for *c.*1km, the site may have originally been up to 2.5km in length, considerably shorter than the width of the bog in which it lay (*c.*12km). Casparie proposes this trackway was laid down to allow exploitation of siderite (bog iron ore) deposits that lay in the vicinity. Alternatively, the site may not have been completed, and can be viewed as failed attempt at crossing the bog (Casparie *et al.* 2004). The later Valtherbrug site is represented by two lengths of trackway which enter Bourtanger Moor from opposing edges and run towards the centre of the bog (Casparie

1987, 1993). It is not known whether the two ends met in the centre. Casparie believes they did not, suggesting instead the Valtherbrug represents more than one trackway each designed to provide access to the centre of the raised bog. Earlier interpretations proposed the site was continous, possibly up to 12km in length (van Zeist 1958) and viewed the site as a routeway across the mire. More recently van der Sanden (2001) has proposed an alternative explanation for the construction of both the Nieuw-Dordrecht and Valtherbrug trackways. Based on the array of artefacts found beside or beneath the Neolithic trackway, van der Sanden (2001) suggests the trackway had a ritual function. Similarly, finds made in proximity to the Valtherbrug (bog bodies, wagons, parts of wagons and rotary querns) and new dating evidence from the site, which places it in the first century AD, convinces van der Sanden (2001) that this roadway was used for ritual processions.

2:5:4 "Intra-bog toghers"

In an Irish context the presence of short (*c*.2m-40m), often narrow, structures lying within a bog away from the bog margins is relatively commonplace. Early IAWU surveys referred to the shorter examples as puddle toghers, defined as " a short stretch of trackway laid down to cross a small area of localised wetness in a bog" (Moloney *et al.* 1995, 204). Based on the morphology of these sites, it was assumed they were intended to either by-pass or cross particularly wet parts of the bog. Because of limited peat stratigraphic recording only in a minority of cases has a togher and a wet zone in the peat been directly linked. For example, a short togher in Curraghmore, Blackwater Bog, Co. Offaly crossed a palaeochannel filled with poorly humified peat (Moloney *et al.* 1995). A light brushwood structure from Curraghalassa Bog, Co. Offaly lay at the base of a peat-filled pool close to the surface of the bog (Bermingham 2001). In Castletown Bog, within the Lemanaghan Group, Co. Offaly, a series of narrow brushwood linear structures lay within a zone of hummock and hollows (IAWU 1998). The sites, which date from the fourteenth century AD (O Carroll 2000), lie more than 60m to the east of a highpoint known as Broder's Island (see Section 3:3). It appears that these tracks were used to negotiate this wet zone. It is unclear however if they were designed to aid passage across the area or secure access to it.

Recent excavations in Co. Offaly included the limited investigation of a number of short brushwood structures (≤3m in length/width). In some cases the sites were poorly defined constructions having the appearance of loosely-laid deposits of wood; in others efforts had been made to establish a stable surface on the former bog surface (O Carroll 2002). The excavator has defined these structures as small platforms, and several appear to have been located in and around former wet zones. The sites are thought to have served as hunting platforms, presumably because of the presence of water in the area which may have attracted animals and birds. Artefactual or palaeoenvironmental evidence which might support this interpretation has yet to be identified.

2:5:5 Conclusions

Trackways in raised bogs reflect two aspects of past attitudes to the bog landscape: (a) the bog as a barrier and (b) the bog as a resource. In order to overcome the obstacle, trackways ranging from simple footpaths to wider roadways capable of bearing vehicles were laid down at various times in the past. These sites linked areas of dryland either by spanning the bog or in some cases by connecting high points within a bog with the surrounding upland. Some continental examples are thought to reflect the desire for a regional communications network, with bog crossings aimed at cutting journey times. In an Irish context, of the trackways studied to date, only a small number seem to have functioned on the broader level. For example, the scale of construction of the second century BC corduroy road at Corlea, Co. Longford leads Raftery (1996) to suggest that its assembly was instigated by the special needs of wider society rather than the local community alone. Similarly, paved ways in Derrynagun, Co. Offaly (O Carroll 2001a) and Bloomhill, Co. Offaly, the former built to service the church at Lemanaghan and the latter possibly contributing to the pilgrim's journey to Clonmacnoise (Breen 1988), may reflect wider influences on site construction. The majority of trackways however, including sites that span a bog and those that enter it, are plausibly explained as local responses to local requirements and conditions (Raftery 1996).

2:6 ARCHAEOENVIRONMENTAL RECORDS FROM IRISH RAISED BOGS & HUMAN-ENVIRONMENT INTERACTIONS

2:6:1 Introduction

Palaeoecological studies carried out in association with archaeological sites from raised bogs in Ireland have so far been limited to four projects (Moloney 1995; Raftery 1996; Caseldine *et al.* 2001, 2005; Bermingham & Delaney forthcoming). Collectively, themes central to these investigations have included:

- environmental reconstruction via pollen records - local and extra-local.
- palaeohydrological reconstruction of mire surface conditions.
- identifying human-environment interactions, e.g., environmental influences on human behaviour and/or anthropogenic influences on the environment.

The projects differ in the level of investigation carried out and in the range of reconstructive techniques utilised. The small number of projects is in stark contrast with the large numbers of archaeological sites now known from Irish raised bogs. Project results have also demonstrated the potential of such studies for addressing issues relevant to archaeologists and palaeoenvironmentalists, and provide a sound foundation for new studies.

2:6:2 Fifteen years of research

The earliest work, started in the early 1990s, took place in Corlea Bog, Co. Longford (Raftery 1996). Consultations with individual specialists, generally on an individual basis, resulted in trackway specific sampling programmes with either immediate-to-site or wider landscape objectives. Peat stratigraphic study focused on reconstructing the bog surface on which a mid-second century BC roadway, Corlea 1, was assembled (Casparie & Moloney 1996). Detailed investigation of ten centimetres of peat immediately below the roadway's timbers addressed the carrying-capacity of the bog surface and the implications for site construction and use. Plant macrofossil and pollen analysis of peat samples from three prehistoric trackways concentrated on ascertaining the pattern and nature of anthropogenic activity on the surrounding dryland (Caseldine *et al.* 1996). Results suggested the possibility of a relationship between the elm decline, woodland clearance and trackway construction in the middle Neolithic (mid-fourth millennium BC). The late Neolithic and Early Bronze Age was a period of low human impact with greater variability suggested in the Late Bronze Age and Iron Age (*ibid.*). The coleopteran analysis from Corlea represents the first study of its kind undertaken in an Irish context (Reilly 1996). Samples taken in direct association with two Neolithic brushwood tracks provided 'snapshot' images of the contemporary bog surface and tantalising evidence for dryland human activity. Wider landscape reconstruction was inhibited as few "Old Forest" fauna were represented (*ibid.*). The programme of wood species analysis from Corlea represents a second 'first', having no earlier parallel within Ireland (Moloney 1996). It developed from occasional limited sampling to 100% sampling of 58 excavated sites for identification purposes and addressed issues of species selection, woodland management and landscape reconstruction. The final element of the palaeoecological research from Corlea was dendrochronology. Many of the trackways had oak timbers suitable for dating but also valuable for refining the Irish oak chronology (Baillie & Brown 1996). The oak ring sequences from Corlea were also used to suggest mire surface conditions in which trackway construction could have taken place. This is discussed in Section 2:6:3. The palaeoecological approaches employed at Corlea were followed by low-level integration of palaeoenvironmental approaches into the field surveys of the Irish Archaeological Wetland Unit (Moloney 1995; Bermingham 2001; O Carroll 2001b). The utility of this record is curtailed by limited dating and excavation (see Section 3:7:3).

In 1995 identification of more than 150 new archaeological sites in Derryville Bog, Co. Tipperary (IAWU 1995), fast-tracked the application of palaeoenvironmental approaches within raised bogs both within Ireland and beyond. The significance of this development for national and international archaeoenvironmental research cannot be underestimated, particularly when anecdotal evidence suggests it is viewed as a special, once-off occurrence rather than serving as a benchmark for further work. The proposed construction of a lead-zinc mine necessitated 100% excavation of any archaeological site lying within the footprint of the mine's tailings pond; Derryville Bog was selected as the site for the latter (IAWU 1995; Casparie & Gowen 1998). The project included an integrated archaeological and palaeoecological programme with sampling and surveys conducted by on-site specialists who then completed the individual analyses. The completion of specialist and archaeological results were conducted in tandem resulting in a comprehensive and integrated record. Site specific and mire-wide peat stratigraphic surveys showed that human activity, expressed as trackways, influenced mire development, apparently triggering in one case a catastrophic bog burst. Mire conditions within the fen, the raised bog and the bog margins clearly influenced site placement and construction (Casparie 2001, 2005). The dual emphasis on individual sites and the wider landscape was a feature of all biostratigraphic analyses carried out with testate amoebae, coleoptera, plant macrofossils and colorimetric humification determinations, being utilised for the first time in an Irish context (Caseldine *et al.* 1998, 2001, 2005). Given the role of pollen analysis in reconstructing local and extra-local landscapes (see Section 2:3:6), it provided new evidence for peaks and lulls in human activity around Derryville (Caseldine *et al.* 1998, 2005). Extensive wood species analyses of both archaeological and natural wood deposits have revealed the bog margins as the primary source of wood used in site construction regardless of period (Stuijts 1998a, 1998b).

The research arising from the excavations at Derryville has clearly provided a body of data that will take many years to be absorbed by the archaeological and palaeoenvironmental research communities. The publication of the full project results (Gowen *et al.* 2005) and publication of individual papers (Casparie & Stevens 2001; Caseldine *et al.* 2001, 2005; Caseldine & Gearey 2005) has begun this process. Perhaps most importantly, the work undertaken at Derryville has shown the difficulties of completing mire-based archaeological excavations without utilising high resolution palaeoenvironmental techniques.

The fourth and most recent archaeological project to include multi-proxy environmental analyses is the Tumbeagh Bog Body Project (Bermingham & Delaney forthcoming). The methods and results from Tumbeagh, which lies within the study area of this thesis, are discussed in Section 3:7 in relation to the archaeoenvironmental record from Lemanaghan. In the last five years Bord na Móna excavation programmes have been ongoing but a comprehensive palaeoenvironmental strategy has yet to be incorporated (see Section 3:7:1).

2:6:3 Environmental models of human behaviour and trackway building

The existence of archaeological sites in raised bogs implies that the bog surface was sufficiently accessible in order to allow a site or a deposit to be made. Different types of deposit require different levels of access, though a minimum level is requisite before deposits of any kind could be made. Some researchers have used the presence of trackways in bogs as a means to infer past climate conditions (see below). Trackway construction is contingent on being able to access the bog and on the capacity of the bog surface to bear the presence of the trackway (Casparie & Moloney 1994; Casparie & Stevens 2001). In wet or very wet conditions both of these requirements may be compromised and result in a lack of trackway construction.

Raftery (1996) and Baillie and Brown (1996) have suggested that trackway construction in Ireland forms part of a wider European pattern of trackway building in drier periods, with trackway construction not linked to periods of increased wetness. Raftery (1996) supposes that the form of any given trackway is a reflection of the needs of the trackway builders, i.e., the purpose for which the site was intended, rather than purely a response to mire conditions. Hence wide plank trackways were laid down where wheeled vehicles and/or draught animals were to be used and narrow plank walkways were established where pedestrian access alone was required. Individual site construction might take into account variability in the load bearing potential of the bog surface but local environmental factors held a secondary role in the reasons behind site construction.

In building an Irish bog-oak chronology Baillie and Brown (1996) assumed that gaps in the dating sequence were a reflection of a decline in the growth of oak trees because bogs had become increasingly wet thus inhibiting tree growth. They identified seven bog-oak dating clusters representing periods when oak was used in the construction of sites in bogs which correspond well with reductions in the wider representation of oak. Hence, Baillie and Brown (1996) suggest the construction of archaeological sites may have resulted in depleted bog-oak woodland. They suggest that the presence of settlement sites and trackways in bogs reflects the prevalence of drier conditions as in wetter periods bogs were inaccessible and site construction would have been impossible. That the sites were subsequently preserved reflects a later shift to wetter conditions. Hence trackway construction in Ireland can be viewed as having occurred in drier periods. This theory assumes the dominance of broader, allogenic controls in determining the nature of the environment in which a site was constructed. It does not account for internal factors, which in some cases may have had a greater influence on the environment.

In contrast, in their examination of radiocarbon and dendrochronological determinations from Irish trackways Brindley and Lanting (1998) conclude that Irish trackways were constructed in both wetter and drier periods. Construction cannot be ascribed to particular climatic regimes and the authors emphasise that each site, in terms of its morphology and composition, should be seen as an individual response to the demands of local environmental conditions.

While some researchers (see above) explain episodes of trackway construction in terms of wetter and drier climate periods, others emphasise internal hydrological dynamics, viewing site construction as a reflection of wetter and drier phases in mire evolution not necessarily related to climate (Casparie forthcoming). Two clusters of trackway dates from Lemanaghan, Co. Offaly, the earlier from *c.*960BC-900BC, the later from *c*.AD550-AD700, appear to bracket the formation and discharge of a bog lake in Tumbeagh Bog (Fig. 3:2) (see Section 3:6:3). For the entire period of the lake's existence and demise, Casparie suggests the surrounding peatland was extremely wet. He attributes the earlier episode of trackway building as an attempt to counter the increasing wetness of the bog surface in the northern parts of the Lemanaghan complex (*ibid.*). These efforts were ultimately unsuccessful as worsening conditions made the bog impassable until the middle of the sixth century AD when the next episode of trackway construction began.

In Derryville Bog site construction and use appears to have been directly influenced by the hydrological conditions on the mire, both in the earlier fen peat levels and the later ombrotrophic phases of growth (Cross *et al.* 2001; Cross May *et al.* 2005). Few sites were constructed across the fen, as it was too wet. Instead, building activities were largely confined to the edges of the fen system. Trackways that spanned the wetland appear once the raised bog was established. Their presence suggests an accessible bog surface but Casparie (2001, 2005) suggests that the hydrological balance on the mire was easily tipped towards disaster because of human error. The construction of the corduroy trackway in Cooleeny townland around 600BC posed a serious obstacle to the bog's drainage. It blocked the system from draining naturally southwards. This caused the bog to burst, an event inferred in the palaeohydrological proxies from Derryville (Caseldine & Gearey 2005).

The above discussion shows that models of human behaviour vary in emphasising the roles of the climate, local environmental conditions and the needs and experience of past populations. The models proposed by Raftery and others (see above) typically rely on interpretation of dated archaeological sequences. They are perhaps overly simplistic, however, as they do not take into account local mire conditions which have been found to influence human behaviour on mires regardless of prevailing climate conditions. The number of sites where local mire conditions have been reconstructed is few and more studies are required to develop and test the types of models of human behaviour suggested above.

2:7 AIM STATEMENT

The aim of this thesis, as described in Section 1:3, is palaeohydrological reconstruction of a small raised bog, and identify potential environmental controls on human interaction with the mire as expressed by archaeological structures preserved within the bog and, the mire's potential for wider palaeoenvironmental reconstruction. This chapter has demonstrated the need for greater understanding of the controls on mire growth. This is essential where palaeo-sequences are used to suggest patterns of environmental change commonly linked to the influence of climate. The need to establish the environment in which archaeological sites, specifically trackways, were constructed is fundamental to investigating the controls governing mire access and how these controls may have influenced the decision to lay a trackway. Examining mire access at a single site and how access was influenced by changing environmental conditions, be they internally or externally driven, is a key aim of this thesis.

CHAPTER 3

RESEARCH SITE

3:1 INTRODUCTION

3:1:1 Introduction

The raised bog subject to investigation is known as Kilnagarnagh Bog and is situated in northwest Co. Offaly (OS 7; 215245 230650) in the Irish midlands (Fig. 2:5). Kilnagarnagh is one of eight bogs that comprise a larger raised bog complex known as Lemanaghan (OS 7 & 15; 216000 228515). In this chapter a description of the area in which Kilnagarnagh Bog lies and the reasons why the area was selected for further study are detailed. The archaeological character of the wider raised bog complex and its hinterland is discussed, and all archaeoenvironmental work carried out in the area to date is reviewed. The archaeological significance of the study site, Kilnagarnagh, is discussed in Section 6:2.

3:1:2 Geology of the region

The Lemanaghan Complex lies within the Central Lowlands of Ireland (Fig. 3:1). The central lowlands extend from east Galway to Dublin, reaching Roscommon in the north and as far south as South Tipperary and Limerick. They lie between 30m-120m OD and are predominantly composed of Carboniferous limestone (Whittow 1974) covered by irregular Quaternary deposits of peat, sand, gravel and till (Hammond *et al.* 1987). The limestone is divided into lower (Dinantian or Reef main limestones), middle (the Calp limestone), and upper (a deposit of pure coarse limestone) units. The first, Dinantian limestone, forms the underlying bedrock in the Kilnagarnagh area (Hammond *et al.* 1987; Delaney 1997).

3:1:3 Geomorphology

The central lowlands can be subdivided into three parts on the basis of their post-glacial morphology (Aalen 1997): the drumlin belt in the north, the central bogland and moraine zone, and the southern hill and vale area (Fig 3:1). County Offaly lies within the central bogland segment, which as its name suggests is characterised by raised bogs and glaciofluvial landforms produced by the final deglaciation of the area (Hammond *et al.* 1987). Conditions suitable for the formation of raised bogs were

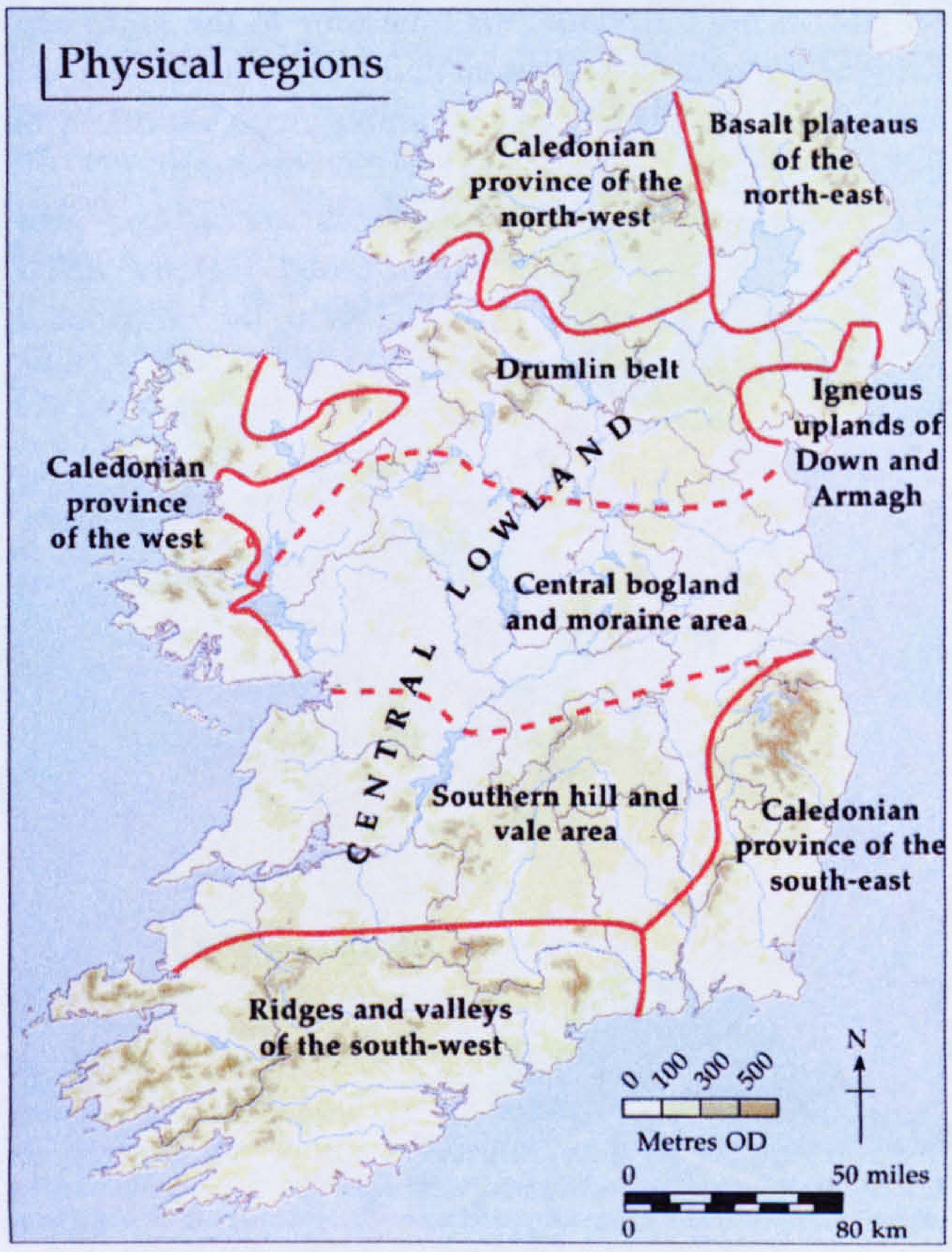


Fig. 3:1 The physical divisions of Ireland. Taken from Aalen *et al.* (1997).

present from about 10,000BC, i.e., during the early Holocene (Streefkerk & Casparie 1989). The bogs formed in clay-lined lacustrine depressions. A second prominent feature of the geomorphology of the central bogland zone is the presence of eskers. Midland eskers are long, sinuous mounds of gravels and sands formed between 18,000-16,000BC as the Irish Sea Glacier retreated. These were formed because of water movement which resulted in the transportation and deposition of sediment in sub-glacial tunnels and at tunnel mouths (Delaney 1997). Oriented for the most part east-west, the eskers have served as important routeways through the bog-flecked landscape since the island was first inhabited (Sheehan 1993). One such esker, known as the Cooldorragh hills, bounds the bog at Kilnagarnagh in the north (Fig. 3:2).

3:1:4 Climate

Ireland enjoys a temperate maritime climate as it lies in the path of the Atlantic Gulf Stream. The warming effects of the Gulf Stream and prevailing south-westerly winds tend to moderate the climate. Temperatures are lowest in January reaching a mean of

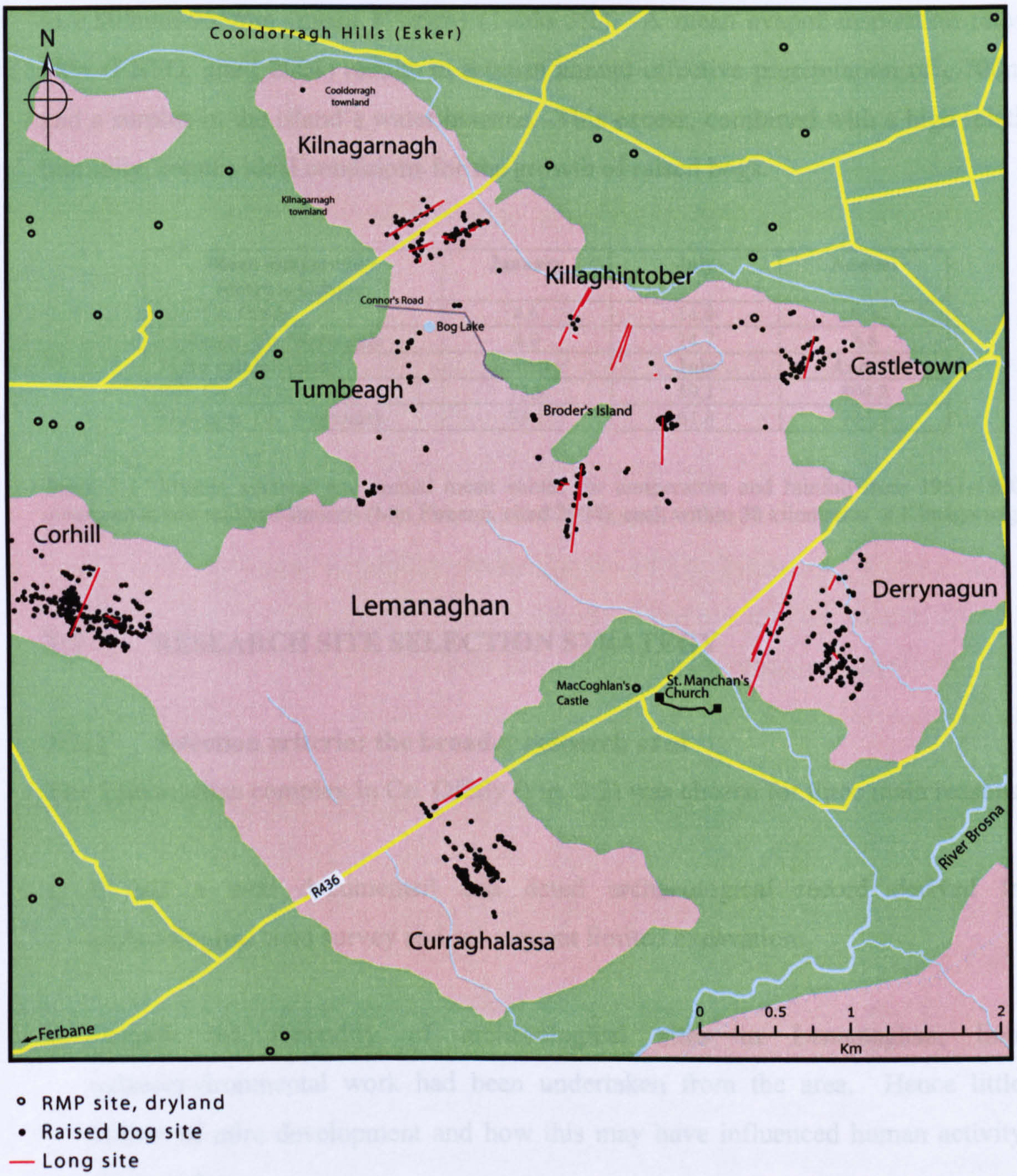


Fig. 3:2 The Lemanaghan Complex comprises of eight separate production areas or bogs. Bog names are derived from townlands. All known archaeological sites from the bog and the dryland are indicated.

c.5°C and are highest in July where they can reach a mean of *c*.15°C (Table 3:1). Ireland's mean annual precipitation is 1150mm though in the Midlands this figure falls to *c*.805mm-935mm (mean 870mm) (Table 3:1). A mean evapotranspiration rate of 38% (ENFO, cited 2004) results in a mean annual effective precipitation of *c*.700mm and a surplus in the island's water balance. This excess, combined with a high relative humidity, creates ideal conditions for the growth of raised bogs.

Mean temperature (degrees Celsius)	**January**	**July**	**Annual**
Birr, Co. Offaly	4.6	14.9	9.3
Mullingar, Co. Westmeath	4.0	14.7	8.8
Mean rainfall (mm)	**January**	**July**	**Annual**
Birr, Co. Offaly	75.9	59.1	804.2
Mullingar, Co. Westmeath	93.1	61.8	934.3

Table 3:1 Winter, summer and annual mean values for temperature and rainfall from 1961-1990 as measured at two midland stations (Met Éireann, cited 2004), each within 30 kilometres of Kilnagarnagh.

3:2 RESEARCH SITE SELECTION STRATEGY

3:2:1 Selection criteria: the broader research area

The Lemanaghan complex in Co. Offaly (Fig. 3:2) was chosen for three main reasons:

1. It had a well documented and dated archaeological record derived from archaeological field survey and subsequent limited excavation.

2. Despite the fecundity of archaeological sites in Lemanaghan, limited palaeoenvironmental work had been undertaken from the area. Hence little is known of mire development and how this may have influenced human activity in Lemanaghan.

3. Earlier participation by the author in multiple field surveys of Lemanaghan meant both the archaeology and the wider bog landscape were familiar and already known to be widely accessible.

3:2:2 The Lemanaghan Complex

Lemanaghan is a 1300ha industrial peatland (Fig. 3:2) subject to peat extraction by milling. Early nineteenth century records show the bog to have been almost a third larger then comprising 2961 Irish acres or 4797 English acres, the equivalent of 1940ha (Townsend 1811 cited in Trodd 2001). Today, eight separate production areas correspond to the individual bogs of which the complex is composed - Castletown, Corhill, Curraghalassa, Derrynagun, Killaghintober, Kilnagarnagh and Tumbeagh. Each area has been brought into production at different times since the mid-1950s (Trodd 2001). As of 2001 only two areas had not been subject to milling, Curraghalassa and Kilnagarnagh, with the latter entering production in 2003/4.

Surveys made in the early 1940s (Dubsky 1945) describe Lemanaghan, the largest open area of bog in the complex, as an expansive basin bog, the floor of which was almost entirely blue clay with the occasional occurrence of marl. Average bog depth was 6.7m with depths of up to 11.8m in places. Highly decomposed *Phragmites* peats covered the basin floor for up to 5 feet (1.5m) and these in turn were overlain by horizons of "Older" and "Younger" *Sphagnum* peats (Dubsky 1945). Bordering the basin occupied by this bog were smaller basins in which fen and raised bog also developed. Over time these areas of bog coalesced to form the greater Lemanaghan complex. The entire complex drains to the south in the direction of the River Brosna. Ordnance Survey maps from the 1830s show two bog rivers that rose in the central expanse of bog and ran southwards to the Brosna. Reclaimed callow, tracts of treeless fen peat flanking rivers and streams which was periodically inundated by water (Bellamy 1986), separates Lemanaghan from the river. Drainage and peat extraction have since reduced the depth of peat deposits across the complex. In the centre much of the ombrotrophic peat has already been removed and milling is onto fen peat levels.

Archaeological surveys carried out in Lemanaghan between 1993 and 1998 identified 743 sites of varying age, the earliest being a Bronze Age trackway in Kilnagarnagh bog dating to *c.*1500BC. A wide range of sites has been identified including plank built walkways, brushwood paths and a multi-period wooden and stone built roadway (IAWU 1997a, 1997b, 1998; O Carroll 2001a). The complex has also yielded some of the country's most recent significant archaeological finds. These include the partial remains of a medieval bog body (Bermingham & Delaney 2000), the earliest Irish (and potentially European) wooden crozier, *circa* mid sixth century AD (O Carroll 2001a), as well as an ornate metal crozier dating to the ninth century (Ryan 1991).

3:2:3 Selecting the study site

This thesis required a small raised bog with a known archaeological component. Given the size and the peat production history of the Lemanaghan complex (see Section 3:2:2), it was necessary to focus on a smaller area for further investigation. Three bogs were chosen for an initial assessment, Derrynagun, Curraghalassa and Kilnagarnagh. These bogs were selected because milling was either less intensive (Derrynagun) or had not yet begun (Curraghalassa and Kilnagarnagh). All of these bogs had a Bord na Móna drainage layout imposed on them at various stages in the 1980s.

Criteria for final selection of one of these bogs as the primary research site included:

- the size and accessibility of the bog.
- whether the bog was active, i.e., currently milled, or inactive - uncut or set aside, i.e., milling deferred either indefinitely or for a finite time.
- the potential for the preservation of intact biostratigraphic sequences and the survival of archaeological sites.
- the visibility, quality and accessibility of stratigraphic profiles and archaeological structures.
- the character of the archaeological record, i.e., number, type, chronology, complexity and distribution of archaeological structures.
- the location of the bog in relation to the overall hydrological catchment of the complex.

The following sections describe further each area chosen for assessment.

3:2:3:1 Curraghalassa

This raised bog lies in the southern part of the Lemanaghan complex (Fig. 3:2). It is accessed in the north via a public road, R436, and in the east and west by access routes running south along the bog flanks. In the early 1980s the bog covered *c.*80ha (200 acres), though this figure has diminished as peat cutting occurs annually on the bog edges. These are now entirely defined by peat faces most of which are still cut or active. Bord na Móna drains have been in place since the 1980s although milling has not yet commenced (as of 2003/4).

When subject to archaeological field survey in 1996, 137 archaeological sites, complexes and artefacts (150+ sites) were identified. These were generally distributed north of two mineral ridges, visible as small treed islands in the bog (IAWU 1997a, 2001). Sites have been dated from the sixth century AD to the post-medieval period. All the sites had been identified in the drain face with an absence of field surface exposures. In places the density of structures was such that individual structures were not easily discerned and frequently site classification proved difficult with the densest exposures recorded as archaeological complexes containing multiple structures of unclear site type (IAWU unpublished data).

Assessment in 2001 found the bog surface to be heavily overgrown with trees and saplings of *Quercus* sp., *Betula* sp. and *Picea* sp. as well as *Myrica gale* and multiple species of ericoids, Poaceae and dwarf shrubs. New *Sphagnum* moss growth was limited and generally confined to the drains. Since 1996, when the first archaeological survey was undertaken (IAWU 1997a), the drains had become overgrown thus reducing visibility of the drain faces, and hence the peat stratigraphy, as well as any archaeological exposures.

The inaccessibility of the drains and the complexity and increased obscurity of the archaeology meant this bog was considered unsuitable for further detailed study. A gross peat stratigraphic record of the bog, derived from extensive peat face exposures, could not be made without the drains being re-cut and ambiguous archaeological sequences would have been difficult to tie in with any peat and biostratigraphic records. In addition the density of archaeology was such that the relationship between structures and mire would be best understood by means of an integrated archaeological excavation and palaeoenvironmental investigation. Excavation did not form part of this research brief. Hence this bog was excluded from further detailed study with the exception of a perimeter walkover survey in which the peat faces in the west and south were cursorily surveyed (see Section 6:4).

3:2:3:2 Derrynagun

This, the largest of the three bogs selected for assessment, lies in the south eastern corner of the Lemanaghan complex (Fig. 3:2) and is readily accessible from the road, R436. It borders Lemanaghan Island in the west and low-lying pastureland in the east. To the south lies reclaimed callow and forestry plantations. As with all other bogs in the Lemanaghan group its margins have been cut since at least the nineteenth century. In the early 1980s the bog covered an area of *c.*120ha. Peat extraction, on an industrial scale, first began in Derrynagun around 1990. A typical Bord na Móna drainage layout had been imposed with drains running the length of the bog every 15m. Milling was generally confined to the north and west as much of the south and eastern parts of the bog now held *Picea* sp. plantations. These areas were not the subject of archaeological investigation and did not form part of the research assessment.

In 1994, when Derrynagun was subject to its first archaeological survey (IAWU 1997a), 111 archaeological sites were identified. In 1998 the bog was re-surveyed and this number had fallen to 64 due to destruction through milling (IAWU 1998). The sites were generally confined to the north and western parts of the bog (Fig. 3:1). Site types included trackways and smaller, shorter brushwood structures or platforms with dates from the Middle Bronze Age (1600-1200BC) to the Late Medieval Period (IAWU 1997b; O Carroll 2001a). The majority of brushwood structures lay close to the field surface. Between 1998 and 2001 no further peat extraction had taken place as the area was considered "set-aside" because of negotiations between Dúchas the Heritage Service and Bord na Móna regarding the archaeological mitigation of the sites present (Donal Wynne pers comm.).

In 2001 a walkover survey of Derrynagun found the drain faces both flooded and covered with loose peat. Where the drains were open, these were shallow with no more than 0.60m of peat stratigraphy visible. The distribution of archaeological sites was over a wide area and although many were clearly defined structures (substantial trackways crossing the bog) they presented complex sequences in terms of individual site construction and location, particularly in the north where multiple sites of diverse date had been constructed within a narrow corridor across the bog. Originally this area was of particular interest as the location and composition of the trackways may have allowed examination of the influence of trackways on mire development following on from work carried out in Corlea, Co. Longford (Casparie & Moloney 1994) and in Derryville, Co. Tipperary (Casparie 1998). However, the diffuse nature of the archaeological site distribution, the lack of good quality peat faces and the overall size of the bog meant Derrynagun bog was excluded from any further detailed survey.

3:2:3:3 Kilnagarnagh

Kilnagarnagh lies at the head of the Lemanaghan complex (Fig. 3:2). It is surrounded on three sides by esker deposits, supporting pastureland and in some places deciduous woodland and scrub. It is separated from the greater Lemanaghan complex by a minor public road located to the south that provides direct access to the bog. In 2003 construction of a new access route, which enters the bog in the north, was underway in preparation for peat extraction. Now around 50ha in extent (or *c.*1300m N-S by 600m E-W), because of centuries of domestic peat cutting on its margins, Kilnagarnagh was once larger. On its western margin, where turbary has removed peat, the cutaway margin is occupied by *Betula* sp. scrub or flooded cutaway. In the east there are small plantations of *Picea* sp. and a silt pond, i.e., a large sump designed to trap peat dust, while domestic peat cutting is ongoing in the north.

Peat depths at Kilnagarnagh, prior to the most recent drainage, were up to 8m (Bord na Móna unpublished survey data). The maximum depth recorded in 2001 was around 6m. The bog surface, though vegetated, is dry and accessible almost year round and is occupied by *Erica tetralix*, *E. cinera*, *Calluna vulgaris* and invading *Betula* sp. and *Picea* sp. saplings. Drains cut in the 1980s run between 1100m and 1300m in length and up to 1.20m in depth, thus providing a ready supply of accessible peat faces. The drains were open, largely un-flooded, and the peat stratigraphy could be readily distinguished in the weathered drain faces. Despite drainage since the 1980s, milling had not yet taken place. Thus, there was greater likelihood the bog had retained a complete record of its development. Milling over the entire bog began in 2003 following re-cutting of drains in 2002. The archaeological record from Kilnagarnagh comprises 19 sites, the most substantial of which is an oak plank-built trackway situated in the southern end of the mire. The others consist of small or single deposits of wood with the exception of a trackway discovered in 2003 (see Section 6:2).

3:2:3:4 Final Selection

Following assessment of each of the bogs described above, Kilnagarnagh was selected as the primary research site. It had the cleanest and most accessible peat faces with well defined and relatively simple archaeological sequences. It was also the smallest of the three bogs allowing more of this bog to be surveyed in detail than either Derrynagun or Curraghalassa. Their size, particularly Derrynagun, may have necessitated reducing the detail of the survey area and hence prevented detailed understanding of their development. In addition, the entire Lemanaghan system drains to the south, i.e., in the direction of Derrynagun and Curraghalassa, suggesting the potential for greater allogenic influence on the development of these two bogs to which Kilnagarnagh was not subject.

3:3 THE ARCHAEOLOGY OF THE LEMANAGHAN RAISED BOG COMPLEX

3:3:1 Introduction

Following large scale field surveys of industrial raised bogs in counties Longford (Raftery 1990; Moloney *et al.* 1993a, 1995), Offaly, Galway and Roscommon (Moloney *et al.* 1995), surveys of the Lemanaghan complex of raised bogs were carried out from 1993 to 1997 (IAWU 1997a, 1997b, 1998) with some areas re-surveyed in 1998. Early estimates of the number of sites identified from Lemanaghan vary from 600 to 650 (IAWU 1997a, 1997b), but a review of catalogue entries for this complex suggests that 743 sites have been identified though they do not all survive as peat extraction is ongoing. Site classification follows the IAWU with definitions detailed in Table 3:2 (Moloney *et al.* 1995). The range of site types encountered is listed in Table 3:3. This table excludes those sites situated in Lemanaghan bog itself (n = 27) as a site catalogue was not available; hence the total in Table 3:3 is given as 716.

Puddle togher	A short stretch of trackway laid down to cross a small area of localised wetness in a bog.
Togher	The Irish term for a predominantly wooden trackway.
Trackway	General term used to describe a construction crossing a bog.
Worked wood *in situ*	Wood in the bog which was deliberately deposited and has visible signs of tool marks present.
Worked wood not *in situ*	Wood displaced from its original setting displaying tool marks or other evidence of wood working.

Table 3:2 Site types as defined by the IAWU (Moloney *et al.* 1995, 203-204).

Other bogs in the region have also produced large numbers of archaeological sites. South of Lemanaghan the bogs of Clara and Mongan (Fig. 2:5) interrupt the industrial peatlands, serving as reminders of how Lemanaghan once appeared. There are no known archaeological sites from these bogs. Beyond Clara, lies the Boora complex consisting of nine separate bogs, four of which yielded twenty sites, including one densely packed complex of overlying discreet structures were identified (McDermott *et al.* 1998). Dates from the Late Bronze Age, *c.*1000BC, have so far been returned (*ibid.*). Immediately north of Lemanaghan is Bellair Bog in which twenty archaeological sites, including a narrow path comprised of longitudinal poles dating from the tenth century BC, were identified (IAWU 1997a). To the west, the bogs of Blackwater stretch out across northwest Offaly, Galway and Roscommon. Here, surveys identified 252 previously unrecorded sites bringing the total from Blackwater to 273 (Moloney 1995).

Dating of sites has been limited but sites from the Middle Bronze Age, the Iron Age and the Early Medieval periods are known (*ibid.*). To the east of Lemanaghan, the expanse of bogs collectively known as the Bog of Allen extends into Co. Kildare. Many of these bogs have been surveyed in the last three to four years and several hundred sites are now known (McDermott *et al.* 2002). While trackways are a feature of most bogs other site types and groups of sites are of interest. Settlement sites, platforms, log boats and possible barrows (see Section 2:4:5) reveal greater interest in mires then simply crossing them.

3:3:2 Site Classification & Representation

Just over 45% of all sites identified have been classified as deposits of worked wood *in situ*. A further 22% of sites lack evidence for wood working, which may indicate deposition was unrelated to human activity. This is a rather broad category as the variation in the character of deposits attests (IAWU 2001). It includes deposits of a single plank or a branch with a cut end, as well as sites with several elements. The deposits can be isolated or can occur in the vicinity of other sites. Deposits with multiple elements may lack structural coherence, or be insufficiently exposed to enable better definition of the type of site. Also included in this category may be the remains of structures which have been damaged by milling and thus upon discovery are no longer recognisable as a particular type of site. It may be that this site type is over-represented in the record because of limited exposure and poor preservation. Other surveys however, found this category accounted for more than a third of sites recorded. Of the 252 new sites identified in Blackwater (Moloney *et al.* 1995), 90 (*c.*35%) were small deposits of mostly worked wood (81 worked, 9 unworked). Despite the numbers in which they occur and the ambiguity surrounding their interpretation, sites classified as either worked wood or unworked wood are generally undated and have received little attention in the excavation projects carried out in the Lemanaghan complex from 1999-2000 (O Carroll 2002). In general, this type of site may be best viewed as 'background noise' related to the construction and use of other structures or as occasional deliberate or inadvertent deposits made because of activities of unknown nature.

Bog	Puddle togher	Togher	Find	Complex	Post row	Worked wood *in situ*	Unworked wood *in situ*	Worked wood *ex situ*	Unworked wood *ex situ*	No.
Castletown	14	4	0	0	0	43	11	9	1	82
Corrhill	16*	14	6	2	1	84	84	4	14	209
Curraghalassa	29	10	2	5	0	59	27	5	0	137
Derrynagun	25	8	3	0	2	65	6	1	0	110
Killaghintober	12	7	0	0	0	21	3	2	1	46
Kilnagarnagh	0	4	0	0	0	3	11	1	0	19
Tumbeagh	9	22	1	0	0	50	15	0	0	97
No.	89	69	12	7	3	325	157	22	16	**716**
						520				

% site type	14.6	9.6	1.6	1	0.5	45.5	22	3	2.2	**100%**
						72.60%				

* Corrhill puddle togher includes 1 hurdle
Tumbeagh counts exclude bog body
Total excludes sites from Lemanaghan: n.27. 716 + 27 = 743 sites in Lemanaghan complex

Table 3:3 Site classification & representation in the Lemanaghan raised bog complex.

Complexes make up 1% of the recorded archaeology in Lemanaghan (Table 3:2). This classification refers to high density occurrences of archaeological wood in which individual sites or structures cannot be distinguished because of limited exposure, or where the site density is such that a group classification is appropriate (IAWU 2001). In Curraghalassa one such complex, extending for more than 21m N-S and *c*.1m in depth, is bracketed by dates from the first century BC to the late medieval period. Here multiple artefacts, puddle toghers, hurdles and deposits of wood crowd the west side of a small dryland island or 'Derry' as they are known locally (Trodd 2001). Unlike longer sites, complexes of this nature point to activities other than a wish to cross the bog. Without further investigation, however, the reasons sites were placed repeatedly in particular parts of a bog will remain unknown though in the case of Curraghalassa a link with the nearby highpoint seems likely.

At 25% the second best represented site type in Lemanaghan is the togher or trackway (see Table 3:3) sub-divided here into puddle togher and togher. The former indicates a short structure generally no more than 3m in length, while the latter refers to any trackway of greater length. Nearly 10% of the sites from Lemanaghan are long sites ranging from 15m up to 700m. In this thesis the term trackway is used rather than togher to describe these sites. At the shorter end of this spectrum, trackways tend to be constructed of single or multiple-layered brushwood and/or roundwood, pegs may be present, and trackways tend to be wide enough for single file traffic (IAWU 2001). The most common interpretations of these sites is that they served to aid passage over parts of the bog which were otherwise difficult to traverse, i.e., where the bog was too wet (Raftery 1996) (intra-bog toghers), or that they were constructed in order to gain access to a particular part of the bog for reasons unknown (*ibid.*).

The longer trackways from Lemanaghan are mostly oak plank walkways, with one or two longitudinal planks forming a walking surface, which may or may not be supported by shorter transverse elements and/or pegs (Bermingham 1997; O Carroll 2001a). In the case of two medieval sites, multiple construction phases were evident each culminating in the laying down of flagstone surfaces (IAWU 1997a; O Carroll 1997). The length and positioning of the longer sites within the bog indicate that they were designed to link areas of dryland. A study of the distribution map, Fig. 3:2, implies that trackways were positioned to take advantage of the shortest crossing points; a feature known from other raised bog complexes characterised by trackway construction

(Raftery 1996). In Lemanaghan two dryland islands in the centre of the bog complex, now known as Broder's Island, were clearly targets for the trackway builders (Fig. 3:2) as they were natural 'stepping-stones' on any journey across the bog.

3:3:3 Chronology

Of the 743 sites recorded from Lemanaghan *c*.7%, (n = 59 dates from 57 sites), have been dated (Table 3:4, Figs 3:2 & 3:3). Arising out of the IAWU surveys in Lemanaghan, five "worked wood *in situ*" sites returned dendrochronological dates in the twelfth and tenth centuries BC and the sixth and seventh centuries AD (Table 3:4). A further five sites, classified as "platforms" when excavated (O Carroll 2002), have yielded dates in the tenth, fourteenth and seventeenth centuries AD. The classification of these sites as platforms is unclear, as the excavator has not distinguished between these platforms and sites of a similar nature classified as puddle toghers by the IAWU.

The majority of dates from Lemanaghan are from oak plank walkways, although a small number of brushwood structures have also been dated (Table 3:4). There is a bias towards sites capable of providing dendrochronological dates as these are favoured in terms of chronological accuracy. Bigger and more obvious sites also tend to attract more attention from archaeologists. The earliest site, a single plank walkway located in the northeastern corner of Derrynagun bog (= Leabeg 16, Fig. 3:2, Fig. 3:3), returned a dendrochronological date of 1547BC±9BC (Q9255). While little of the site survives today, when last traced in 1998 a fragmentary record of the walkway was made over 224m (IAWU 1998). It pre-dates the walkway spanning Kilnagarnagh by *c*.50 years

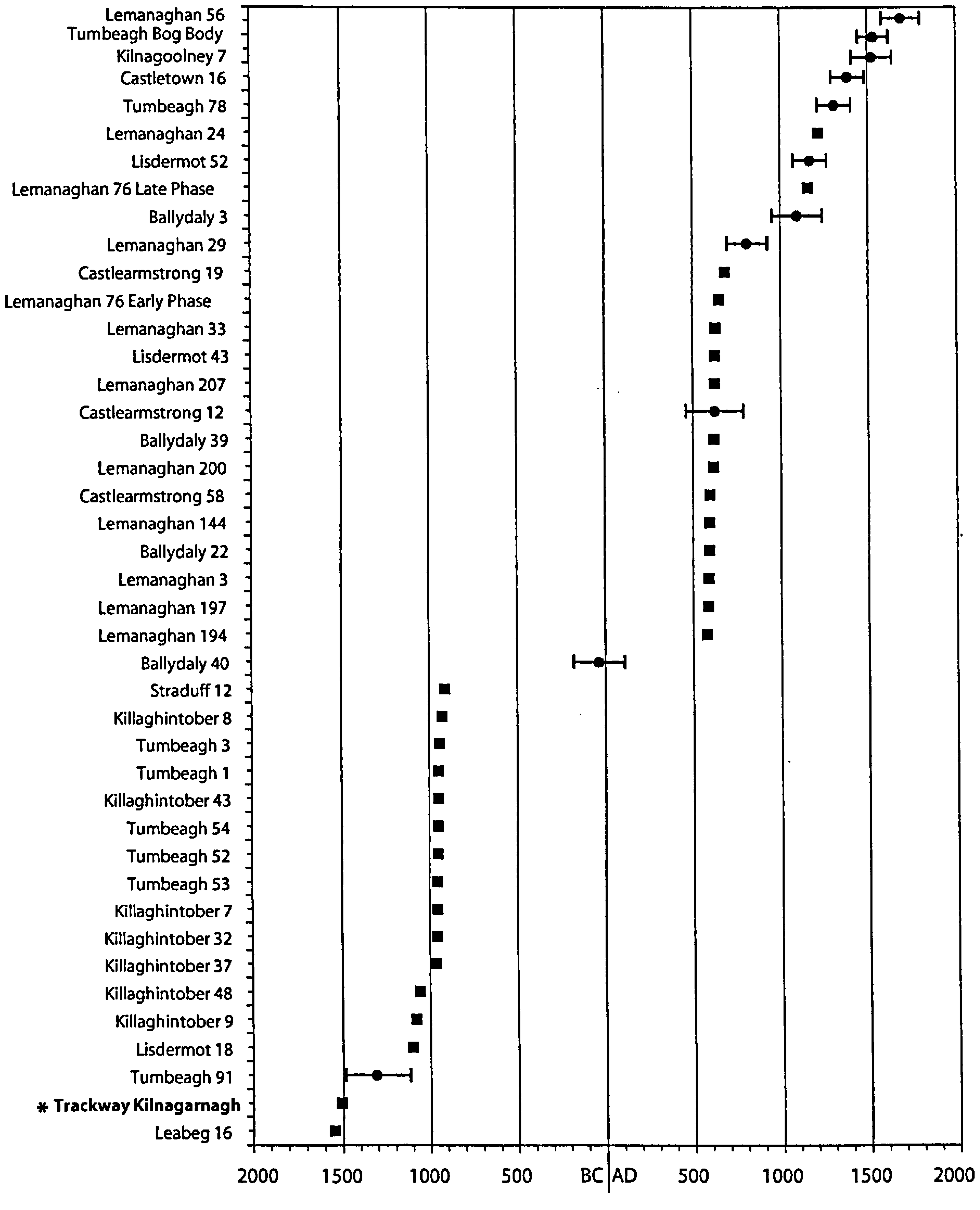
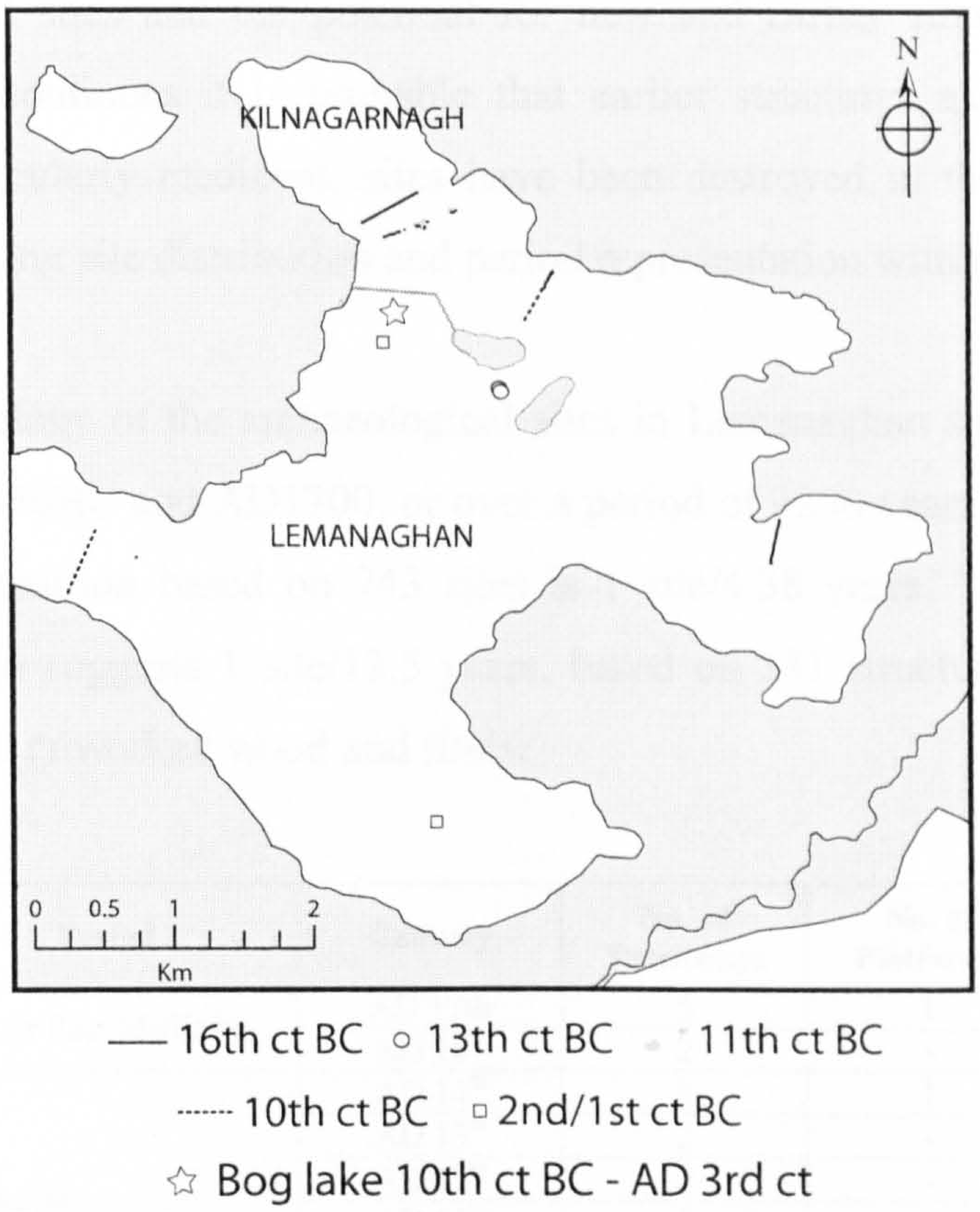


Fig. 3:3 Time-chart of sites from the Lemanaghan Complex.
The squares represent dendrochronological dates while the dots indicate sites dated by radiocarbon. All dates from IAWU (unpublished) except the Tumbeagh Bog Body (Bermingham & Delaney forthcoming).

(a)



(b)

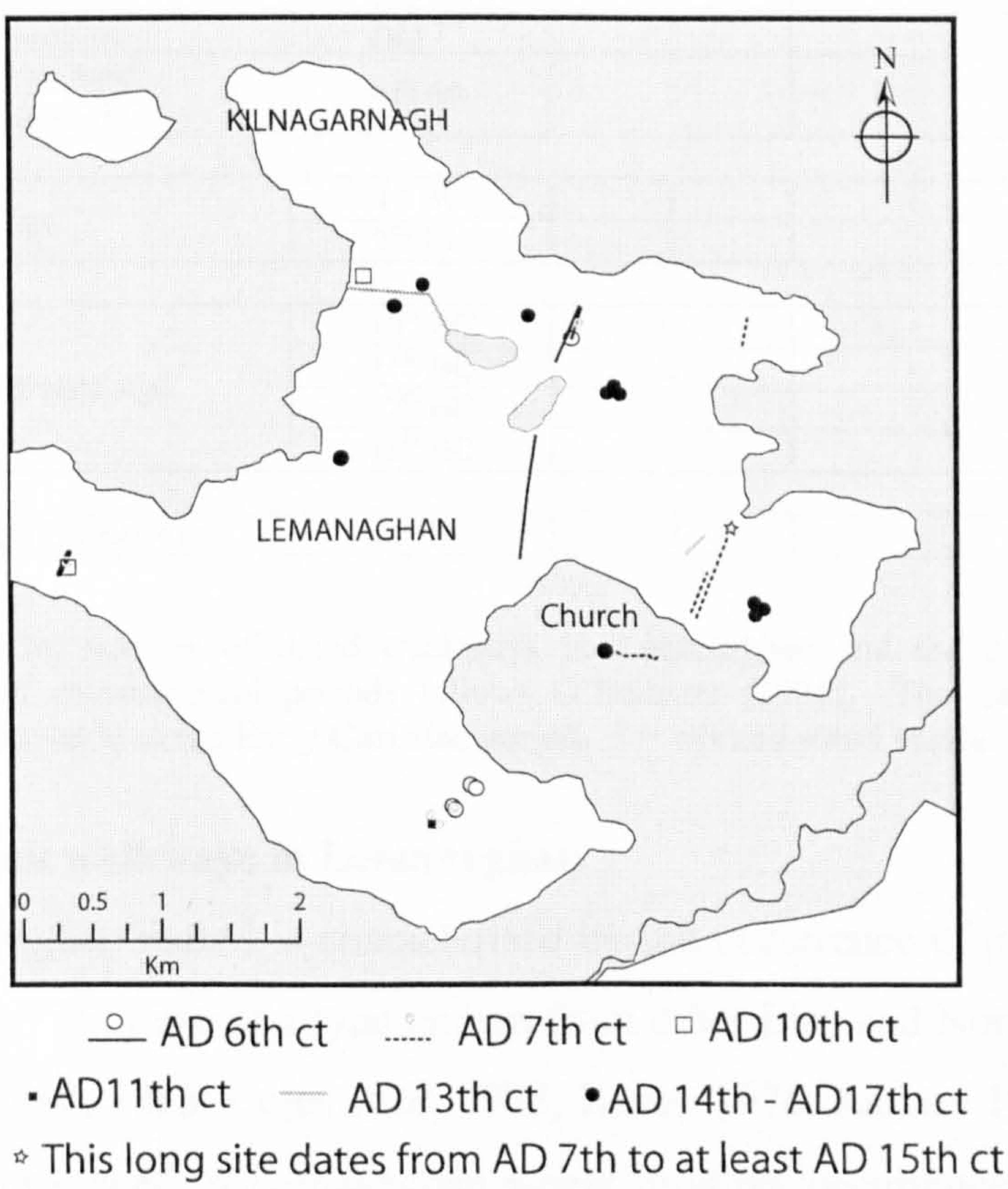


Fig. 3:4 Dated sites from Lemanaghan. Map (a) shows sites dating before 0BC. Map (b) shows sites post-dating 0BC. ct = century.

and is the earliest known structure in the Lemanaghan complex. Given the number of yet undated sites and the potential for new and earlier sites to be revealed as peat extraction continues it is probable that earlier structures exist within this complex. Later, particularly medieval, sites have been destroyed in those areas already milled further biasing site distribution and period representation within Lemanaghan.

The chronology of the archaeological sites in Lemanaghan shows deposits were made between 1550BC and AD1700, or over a period of 3250 years. A crude estimate of the rate of deposition based on 743 sites is 1 site/4.38 years. An estimate of trackway construction suggests 1 site/13.5 years, based on 231 structures excluding deposits of worked and unworked wood and finds.

Period	Century	No. of Trackways	No. of Platforms	No. of WWIS*
Late or Post Medieval	AD 17th	5	1	-
	AD 16th	2	-	-
Medieval	AD 14th	3	1	-
	AD 13th	2	-	-
	AD 12th	2	-	-
	AD 11th	2	-	-
	AD 10th	2	2	-
	AD 9th	1	-	-
Early Historic	AD 7th	7	-	1
Late Iron Age/ Early Historic	AD 6th	7	-	1
Iron Age	1st BC	1	1	-
	2nd BC	2	-	-
Late Bronze Age	10th BC	11	-	2
	11th BC	3	-	-
	12th BC	-	-	1
	13th BC	1	-	-
Middle Bronze Age	16th BC	2	-	-

Table 3:4 The number of dated trackways in Lemanaghan and the century in which they fall. Assignation of chronological periods follows O'Sullivan (2001). The Early Historic period is also frequently referred to as the Early Christian period. * = worked wood *in situ*.

3:3:4 Plank walkways in Lemanaghan

The Lemanaghan record is characterised by the occurrence of plank-built walkways or plank paths. They are of a type known from other Irish and North West European bogs (Casparie 1984, 1986; Coles *et al.* 1988; Hayen 1976; Raftery 1996) but within Ireland are best represented in Lemanaghan where multiple occurrences, albeit from different periods, are known. Elsewhere in Ireland this type of site generally occurs no more than once or twice within a given bog (Table 3:5).

While the Lemanaghan dates clearly show these sites must have been laid down by different generations, there is continuity in the type of site constructed which is not known elsewhere in regard to plank walkways. It would appear that early historic populations favoured this site type as did Late Bronze Age inhabitants of the area. This might imply a regional preference for plank walkways with origins in prehistory.

Site Code	Bog & County	Date	Source
OF-CHM 0016	Blackwater Co. Offaly	1625-1435calBC (GrN-21262)	Moloney *et al.* 1995
Derryfadda 23	Derryville Co. Tipperary	1590±9BC (Q9370) 1606±9BC (Q9369)	Cross *et al.* 1999
Cooleeny 22	Derryville Co. Tipperary	1517±9BC (code not cited)	Cross *et al.* 1999
Corlea 5	Corlea Co. Longford	587±9calAD (GrN-18616)	Raftery 1996
GA-KME 0009	Blackwater Co. Galway	Undated	Moloney *et al.* 1995
Corlea 50	Corlea Co. Longford	Undated	Moloney *et al.* 1993a
Cloonfore 4	Cloonfore Co. Longford	Undated	Moloney *et al.* 1993a
Cloonmore 7	Begnagh Co. Longford	Undated	Moloney *et al.* 1993a

Table 3:5 Instances of other plank walkways from Irish bogs. The sites are listed in chronological order.

Alternatively, this site type could be viewed as a standard response to the need to cross the bog easily, and repeatedly, within a given window of time. Plank walkways may be viewed as one of the least labour intensive site types for this purpose. They are relatively simple constructions, laid down in units of overlapping, longitudinal planks which may be supported at the ends by shorter cross-timbers and/or secured in the bog with pegs. Even simpler forms are known, namely longitudinal roundwood toghers composed of stretches of two to three longitudinally-laid poles placed side by side on the bog surface. One such trackway is known from Bellair Bog (IAWU 2001), just to the north of Kilnagarnagh with others recorded in Co. Longford (Raftery 1996). The Bellair track, dating around 925BC, is broadly contemporaneous with the Late Bronze Age plank paths from Lemanaghan. Raftery (1996) has suggested that differing site types arise, not merely because of prevailing environmental conditions and access to resources, but also because of the intended purpose of the trackway. In Lemanaghan the plank walkways perhaps reflect attempts at establishing a firmer route (both in the landscape and underfoot) through the bog than a roundwood site could offer.

By looking at the potential load bearing capacity of a site, via examination of the peat below a trackway and the degree to which it has been compressed, and the quality of the preservation of the wood, Casparie and Moloney (1996), and Casparie and Stevens (2001) have estimated the length of time a site may have been in use. In the first study, Casparie and Moloney (1996) examined an Iron Age corduroy road built of oak transverses lying on sleepers (Raftery 1990), and concluded that the site was in use for at most 10 years. At Derryville, Co. Tipperary a similar study concluded that a stone and gravel trackway, Killoran 18, had been used for a period of 20-40 years at the most (Casparie & Stevens 2001). Each of these sites is heavier and more robust than the plank walkways in Lemanaghan. They may therefore have sunk more quickly allowing them to become enveloped at a faster pace by the growing bog. Depending on the carrying capacity of the bog, it seems probable that a lighter site would not sink as rapidly as these larger structures. This suggests that a plank walkway could be in use for a longer period than heavier structures. However, it is self-evident that a plank path would decay faster than a stone roadway. Therefore, the walkway would have a shorter lifespan than a stone-built track and this might be reflected in the quality of preservation of the timbers sealed in the peat. An excavation of part of a 7th century AD plank walkway in Castletown bog, Lemanaghan, showed the wood was well preserved with only superficial decay (Bermingham 1997), a feature noted from other plank tracks (Casparie 1996). The longevity of plank walkways in Lemanaghan then was perhaps between 10-20 years, more than the corduroy road but less than the stone roadway. If this was the case then the various routes across the bog were quite probably only open for short periods.

There are indications that the local population attempted to 'cement' certain routes within the bog complex. A corridor across the north end of Killaghintober bog, immediately to the south of Kilnagarnagh, is characterised by the presence of at least six plank walkways with nine dendrochronological dates ranging from 1027BC to 925BC (IAWU unpublished data). Three sites produced two different dates indicating they were probably repaired or partially replaced. The true number of linear plank sites in the area is unclear as sites appeared to cross each other and milling had obscured connections between structures or parts of structures (IAWU unpublished data). There are at least three linear sites lying in close proximity to each other (Bermingham 2001) suggesting that the route was used frequently enough to warrant the repeated laying of wooden trackways.

Considerably later, and to the south, in Derrynagun and in Lemanaghan bog itself two multi-phase trackways reinforce the concept of the repeated use of particular routes. In these bogs, two plank walkways evolved into flagstone roads, both of which are still clearly visible and have obvious links with dryland (IAWU 1997a; 1997b). These roadways served the ecclesiastical centre at Lemanaghan and the medieval castles of the MacCoghlan families, the local Gaelic Lords (Bermingham forthcoming). They represent early precursors to the modern road, the R436, linking the village of Ballycumber and the town of Ferbane, and providing a cross-bog link between the River Shannon and the east.

3:4 ARTEFACTS FROM THE LEMANAGHAN RAISED BOGS

This study did not include a survey of artefacts known from the uplands surrounding the Lemanaghan complex with the exception of those townlands that fell in both bog and dryland. In most cases, examination of the topographic files of the National Museum of Ireland indicated that no finds were known from the dryland. Objects retrieved from Lemanaghan's raised bogs are listed below (Table 3:6).

The earliest finds, a flint scraper and a stone axe head, indicate a Neolithic presence in and around the bog complex although there are no archaeological sites dating to the Neolithic yet known from the area. The Bronze Age is the next period represented, with the items retrieved from bogs in the townlands of Cooldorragh and Kilnagarnagh of particular interest, as Kilnagarnagh bog lies inside these boundaries (Fig. 3:2). The Early Bronze Age copper dagger from Kilnagarnagh townland can only have been retrieved from the western edge of the bog, as this is the only part of the bog that lies within the townland boundary. The rest of the bog lies within the townlands of Cooldorragh and Tumbeagh. The dagger is short and tanged and of a type rarely found in Ireland but well-represented in Britain (Halpin 1984).

The later Bronze Age finds from Cooldorragh may have been retrieved from Kilnagarnagh but as this townland also covers part of Bellair bog, located *c.*700m to the north and abutting the esker on its northern slope, the objects may have originated from there. The artefacts point to a Bronze Age presence in the landscape which is reinforced by the Bronze Age archaeological structures in Kilnagarnagh bog (see Section 6:2).

Bog	Townland	OS	Object	Date
Curraghalassa	Ballydaly	15	Leather shoe	AD16th-17th
Corrhill	Lisdermot	15	20 silver coins	*c.*AD1300
Corrhill	Lisdermot	15	Leather shoe fragment	Medieval
Corrhill	Lisdermot	15	Leather shoe	Medieval
Corrhill	Lisdermot	15	Wooden bowl/platter	Medieval
Bellair	Bellair or Ballyard	7	Iron plough coulter & sock (NMI: 1977:2175)	Early Historic or later
Lemanaghan	Kilnagoolny	7	Silver & bronze crozier & shrine (NMI: 1977:2338)	Early Historic
Kilnagarnagh or Bellair	Cooldorragh	7	Leather shoe, Wooden bowl (NMI: 1933:762-3)	Early Historic
Castletown	Castletown	15	Leather shoe	AD684
Killaghintober	Castlearmstrong	15	Wooden crozier	AD596-7
Kilnagarnagh or Bellair	Cooldorragh	7	Bronze dagger (NMI: 1933:591)	Late Bronze Age 1200-600BC
Kilnagarnagh or Bellair	Cooldorragh	7	2 bronze axe heads, 3 bronze spear heads (NMI: 1933:592-6)	Late Bronze Age 1200-600BC
Kilnagarnagh	Kilnagarnagh	7	Copper dagger (NMI: 1931:312)	Early Bronze Age *c.*1800BC
Corrhill	Lisdermot	15	Flint side scraper	Neolithic
Corrhill	Lisdermot	15	Stone axe	Neolithic
Corrhill	Lisdermot	15	Textile fragment	Unknown
Corrhill	Lisdermot	15	Squared & dowelled timber	Unknown
Curraghalassa	Lemanaghan	15	Fragments of leather	Unknown
Derrynagun	Leabeg	15	Squared & dowelled shaft	Unknown
Derrynagun	Lemanaghan	15	Rubbing stone?	Unknown
Derrynagun	Lemanaghan	15	Perforated roundwood	Unknown
Tumbeagh	Tumbeagh	7	Textile fragment	Unknown

Table 3:6 Chronological list of artefacts recovered from the Lemanaghan raised bog complex. Sources: Halpin (1984), IAWU (2001), O Carroll (2001a, 2002).

The dagger also suggests the possibility of 'ritual' activities in the landscape as bogs and wetlands in general are known as favoured places in which votive deposits were made (van der Sanden 1996; Waddell 1998).

In common with the record of archaeological sites, the periods next best represented in the artefact record are the Early Historic and Medieval periods. The iron plough from Bellair (Table 3:6) suggests arable farming was taking place in the area. The object's dating range is, however, too wide to allow it be closely tied with local sites or with the palynological record for agriculture from this area (Weir forthcoming). The religious significance of Lemanaghan is reflected in the finds of sacred objects from the bogs. The earliest, a wooden crozier from Killaghintober bog which is the earliest crozier known from Ireland, was used as a peg in the assembly of a plank walkway running between the dryland and Broder's island (O Carroll 2002). The site predates the proposed foundation of the church at Lemanaghan by St. Manchán in AD645 (see Section 3:6:2) by around 50 years. It is possible that St. Manchán, a scholar of repute in his own time (Reynolds 1929), took over an earlier Christian centre, traces of which have not yet been revealed on the dryland. The wealth of this church is reflected in the later silver and gold reliquary known as the Shrine of St Manchán (Ó Floinn 1994) and a gold and silver crozier retrieved in two parts from Lemanaghan bog itself (Ryan 1991). Their recovery from bog suggests they had been lost or hidden in response to a threat. The construction of better roadways, for example, may have adversely affected the security of the monastery. The objects demonstrate that the church at Lemanaghan had access to great resources reflecting perhaps an economic status previously not present and one which dwindled over time. The circumstances behind the deposition of coins dating to the time of Edward I (IAWU 1997b; Bermingham forthcoming a) are also unknown. Their presence in the bog is a direct indication that the bog was accessible at the time of their deposition although the quality of access is unknown.

The artefacts retrieved from the Lemanaghan complex show that people were not only concerned with crossing bogs. It is possible the bog was viewed as a secure place for certain possessions. The prehistoric deposition of weapons, perhaps for ritualistic reasons, echoes the deposition of later Christian objects in the bog. Some items appear to have been inadvertently lost, in particular the single shoes generally recovered in association with archaeological structures.

3:5 DRYLAND ARCHAEOLOGY

3:5:1 Introduction

Increasingly, archaeological investigations in Ireland, particularly those associated with major infrastructural projects, are revealing many new sites in areas where numbers were previously low or sites were absent (Swan 2002; Newman 1997). Field survey, the increased application of geophysical survey, the monitoring of all ground works and testing in advance of development have "re-populated" the dryland landscape with evidence of earlier human occupation. The construction of a lead and zinc mine tailings pond in Derryville Bog, Co. Tipperary, offered the first opportunity to investigate the archaeology of both the raised bog and the surrounding upland. Surveys of the bog had identified 178 new archaeological sites (IAWU 1995) but few were known from the dryland. From 1996-1998 thirty-four archaeological sites, located on the upland fringing Derryville bog, were excavated. All but one was new, having come to light during topsoil stripping or field walking (Cross *et al.* 1999; Cross May *et al.* 2005). For the first time prehistoric habitation sites, possible cooking sites (including roasting pits), and a cremation cemetery, reflecting activity in and around raised bogs, were identified and investigated. At Lemanaghan, where 743 raised bog archaeological sites have been identified and only 25 dryland sites are known (see Section 3:3), the prehistoric period is most likely to be seriously underrepresented in the dryland archaeological record.

3:5:2 Dryland record Lemanaghan

On the upland surrounding the Lemanaghan raised bog complex, and on the island of Lemanaghan, twenty-five archaeological sites are known (Table 3:7, Fig. 3:2). In comparison to that of the raised bog, the dryland record is thus somewhat impoverished. There is an absence of clearly prehistoric sites and no site has been subject to excavation. Those sites to which a date can be ascribed are largely late medieval castle sites and St. Manchán's ecclesiastical complex situated on Lemanaghan Island. The remainder consist of ringforts, which can date from AD500-AD1200 (O'Brien & Sweetman 1997), earthen enclosures or earthworks to which neither function nor date range can be given, and one example of a crannóg - a lake settlement site - which could date anywhere from AD500-AD1600 (Fredengren 2002). In only one case can a direct link be made between a dryland site and a structure in the bog. This is a flag stone roadway (OF015-00411) extending from St. Manchán's Church into the bog at Derrynagun.

A continuous, and relatively well recorded, dryland archaeological sequence is provided by the ecclesiastical centre situated on the dryland island of Lemanaghan (O'Brien & Sweetman 1997). The church, named after St Manchán who founded it in the mid-seventh century AD, and its associated religious buildings stand in ruins having fallen out of use in the late seventeenth century (Ellison 1975). A graveyard lies within the grounds of the original monastic enclosure and burials still take place there. St Manchán is reputed to have died in AD664 or AD661 depending on which version of

SMR No.	NGR	Townland	Class	Date
OF007-047	21336 22879	Straduff	Earthwork	?
OF015-010	21320 22575	Ballylin	Enclosure	?
OF015-012	21470 22471	Kilcolgan More	Enclosure	?
OF007-042	21456 22912	Kilnagoolny	Enclosure	?
OF007-045	21308 22882	Straduff	Enclosure	?
OF007-016	21805 23130	Springpark	Crannog	AD500 - AD1600?
OF007-032	21649 23051	Killaghintober	Ringfort	AD500 - AD1200?
OF007-034	21705 23059	Killaghintober	Ringfort	AD500 - AD1200?
OF007-029	21389 23011	Kilnagarnagh	Ringfort	AD500 - AD1200?
OF007-030	21436 23047	Kilnagarnagh	Ringfort	AD500 - AD1200?
OF007-018	21946 23149	Moorock	Ringfort	AD500 - AD1200?
OF007-019	21944 23129	Moorock	Ringfort	AD500 - AD1200?
OF007-027	21303 23015	Rashinagh	Ringfort	AD500 - AD1200?
OF007-046	21318 22880	Straduff	Ringfort	AD500 - AD1200?
OF007-043	21468 22926	Tumbeagh	Ringfort	AD500 - AD1200?
OF015-00402-10	21712 22697	Lemanaghan	Ecclesiastical & secular complex	AD6th - AD17th
OF015-00411	21735 22690	Lemanaghan	Togher	AD6th - AD17th
OF015-01101	21460 22461	Kilcolgan More	Fortified house	AD16th
OF007-061	21389 22952	Kilnagarnagh	Castle	AD17th
OF007-037	21784 22990	Castlearmstrong	Fortified house	AD17th
OF015-00401	21707 22703	Lemanaghan	Tower house	AD17th
OF007-035	21819 23073	Parkaree or Boherfadda	Holy well	Historic
OF007-038	21797 23010	Castlearmstrong	Well	Historic
OF007-041	21348 22952	Rashinagh	Graveyard	Monastic?
OF007-060	21304 23006	Rashinagh	Castle	Post-Medieval?

Table 3:7 Dryland archaeology sites surrounding the Lemanaghan complex. Source: O'Brien & Sweetman (1997).

Irish Annals is accepted (O'Donovan 1837-1838) with the monastery established some 20 years or so earlier (Reynolds 1929). The construction of several plank walkways, dating from the middle of the seventh century AD, may be linked with the foundation and life of the monastery. The need to have more permanent or year round access to the island and the church settlement is best reflected in the evolution of the road running between the island and the dryland to the east (Fig. 3:2). The ability, however, of this road to provide year round access is dubious. A reference to the site relates that in AD1615 the old church of Lemanaghan was situated in the middle of a bog, impassable in the time of winter (Graves 1874). It is likely this island was the focus for prehistoric activity - the presence of earlier trackways demonstrates that the island was accessed, if not inhabited. The absence of earlier settlement is probably more a reflection of the lack of suitable investigation or site preservation than the actual absence of pre-existing occupation of the island.

3:6 ARCHAEOENVIRONMENTAL RECORDS FROM LEMANAGHAN

3:6:1 Introduction

Despite the known archaeological significance of the Lemanaghan raised bogs, the archaeoenvironmental research potential this area offers has been largely underexploited, with the exception of the excavation of human remains from Tumbeagh bog (Bermingham & Delaney 2000). Site-specific records exist, made during the course of Bord na Móna excavations and IAWU surveys but the data are limited by the parameters of the survey and the financial constraints of the excavation programme.

IAWU surveys provide an assessment of the archaeological content of a given bog and are designed to identify new sites exposed through milling. The record comprises a basic description, location and dimensional information (Moloney *et al.* 1995). In theory, all sites identified are then under the protection of the State and the developer, in this case Bord na Móna, is obliged to mitigate for the presence of archaeological sites. In practice sites are frequently destroyed or damaged prior to mitigation. Consequently, the IAWU has made efforts to gain an understanding of the composition and local environment (Bermingham 2001; O Carroll 2001b) of each site in case a site is destroyed prior to mitigation or preservation (McDermott 2001). There are limitations namely with regard to the number of chronological determinations obtained and limited follow-up excavation. A series of small-scale excavations of select sites carried out from 1999-2001 (O Carroll 2001a) has improved the situation. These projects included localised examination of wood species (data unavailable) and analysis of coleoptera (Reilly 2002) but in general lacked an integrated multi-proxy approach towards environmental reconstruction.

3:6:2 Wood species analysis

The first and most consistent aspect of the archaeoenvironmental record of raised bogs in which archaeology has been identified is wood species analysis (Moloney *et al.* 1993a). Species identifications are derived from samples of wood taken from each site discovered in the course of a survey (Moloney *et al.* 1993a, 1995; O Carroll 2001b), resulting in a list of species present from each site sampled from any given bog. Thousands of sites have been sampled and identifications made since the IAWU first began surveying in 1991 (*ibid.*). Quantitative analysis of this data is hindered as most sites are undated and follow-up investigations are either limited, being more like test excavation than full excavation (O Carroll 2002), or absent. In broad terms the data shows the range of wood species available for use in the vicinity of the bog and identifies preferences in selection with regard to site type, e.g. *Corylus* sp. (hazel) rods used in the construction of hurdles and *Quercus* sp. (oak) planks used for plank-built structures.

Without dates, examination of changes in species distribution and representation over time is not possible. It is therefore difficult to look beyond the individual site to the wider environment, the potential for which has been demonstrated by Caseldine *et al.* (2001, 2005) in Derryville, Co. Tipperary. Here, it was found that "prior to 1300BC… the tree species used for archaeological structures closely reflects the pattern of the natural woodland as inferred from environmental wood sampling and from pollen and coleopteran evidence" (Caseldine *et al.* 2001 108). Post-1300BC an increase in the use of *Corylus* sp. is taken as evidence for the rise of woodland management and the reduction in primary or sub-primary woodland.

The range of tree species from Derryville is similar to Lemanaghan. Interrogation of IAWU catalogues found that *Alnus glutinosa*, *Betula* sp., *Fraxinus excelsior*, *Corylus* sp., *Salix* sp. and *Quercus* sp. are the most commonly identified wood species regardless of date. Others represented include Pomoideae, *Taxus* sp., *Ilex* sp., *Sorbus aucuparia*, *Prunus avium/padus*, *Pyrus/Malus* sp., and *Crataegus monogyna/Malus* sp., but these occur less frequently. Since at least the Early Bronze Age, these trees have grown on the low hills that define the boundaries of the raised bog complex at Lemanaghan. Certain species may have grown in the bog margins and others on the dryland islands encircled by bog. Identification of natural wood samples from within Kilnagarnagh bog has demonstrated that *Alnus glutinosa*, *Betula* sp., *Quercus* sp., and *Pinus* sp. grew within the bog. The only archaeological wood identified from Kilnagarnagh was so far found to be *Quercus* sp.

The range of species represented in Lemanaghan is reduced if only dated sites with species identification data are considered (Table 3:8). Clearly then this archaeological complex would benefit from a wider wood species analysis and dating programme as the current picture is biased toward oak and generally plank built sites.

Date	Species
16^{th} ct. BC	*Quercus* sp.
12^{th} ct. BC	*Quercus* sp.
11^{th} ct. BC	*Quercus* sp.
10^{th} ct. BC	*Quercus* sp.
2^{nd} ct. BC - 2^{nd} ct. AD	*Betula* sp., *Alnus glutinosa, Fraxinus excelsior, Salix* sp., *Quercus* sp.
6^{th} ct. AD	*Quercus* sp.
7^{th} ct. AD	*Quercus* sp. *Alnus glutinosa, Fraxinus excelsior, Corylus* sp., *Betula* sp., *Salix* sp., Pomoideae
15^{th} - 16^{th} ct. AD	*Alnus glutinosa., Betula* sp., *Fraxinus excelsior, Prunus avium/padus*

Table 3:8 Tree species identified from dated sites in Lemanaghan (IAWU 2001). Where multiple species are listed it represents data from more than one site.

3:6:3 Peat stratigraphic records

Prior to this research project one large scale peat stratigraphic survey had been carried out within the Lemanaghan complex. This survey covered part of Tumbeagh Bog where the partial remains of a medieval bog body was discovered (Casparie forthcoming). A model of peat development was produced using standard radiometric radiocarbon dates and extrapolated dates. The accumulation of fen peat had already begun by 4225±225calBC (5417±90BP, Wk12086) though is likely to have started much earlier in the wider basin. The date was retrieved from the fen-mineral substrate interface, but not at the lowest point in the basin floor. Based on the presence of the remains of *Pinus* sp., interpreted as Boreal pine forest subsequently inundated by rising ground water, fen peat growth occurred from *c*.6000BC (Casparie forthcoming). Fen peat accumulation continued uninterrupted for several millennia until about 1000BC-900BC (date extrapolated from a nearby related horizon dated to 610BC±200calBC, 2540±60BP, UCD01108) by which time a bog lake had formed. Lake development was in two phases. Phase 1 dates from the mid-tenth century BC to the middle of the third century AD (255±175cal AD, 1800±60BP, UCD 01109), and was followed, probably within a few decades, by Phase 2. The lake finally discharged in the middle of the fifth century AD (470±130calAD, 1595±50BP, UCD 01110) (Casparie forthcoming). Ombrotrophic peat then accumulated over the lake zone. Fields of *Scheuchzeria palustris* and wet *Sphagnum* lawns dominated the raised bog formation until around the sixteenth century AD after which the sequence of development is unknown as the peat has been cut away.

In addition to the Tumbeagh survey a peat stratigraphic record was made of each archaeological site identified by the IAWU in the Lemanaghan complex in 1996 and 1997. The record was devised because of "[t]he necessity of expanding the physical context of a site beyond the terms 'bog' or 'raised bog'" (Bermingham 2001, 37). It was restricted to the immediate site environment thus producing a series of localised records which allowed consideration of the local conditions in which a site had been deposited. Occasionally the record was taken beyond the site, and the presence of spatial features such as hummock-hollow complexes, gullies, natural wood layers and horizons of allochthonous peat were noted. The record was however insufficiently detailed to allow consideration of wider bog development or the prevailing environmental conditions.

Excavation projects carried out by Bord na Móna in Lemanaghan did not include a comprehensive palaeoenvironmental strategy. Reports currently available that indicate a limited record was made of the local peat stratigraphy. At most, the records made show whether a site lay in an ombrotrophic or fen peat environment or if pools were present or absent (O Carroll pers comm.).

3:6:4 Coleopteran investigations from Lemanaghan

Peat samples from sixteen archaeological sites from the Lemanaghan complex have been subject to limited coleopteran analysis (Reilly 2002). All the samples, with exception of those from Tumbeagh (Reilly forthcoming), were focused on archaeological sites and not the broader environment and as such most findings can be considered localised in extent. Six samples were examined from six sites identified during the course of IAWU survey (*ibid.*), and the remainder come from small scale excavations carried out from 1999-2000 (O Carroll 2001a). The survey samples included a spot sample from below the Middle Bronze Age walkway in Kilnagarnagh bog. The insect assemblage was very small. It confirmed the ombrotrophic nature of the environment and the presence of *Eriophorum* sp. and *Calluna* sp. but was of insufficient size to derive greater environmental detail. Coleoptera from other sites within Lemanaghan implied that trackways had, in places, been laid across *Sphagnum*-rich stagnant pools with drier hummocks near by. Reilly (2002) takes this as an indication of the presence of mature hummock-hollow systems around 950BC in parts of Killaghintober and Tumbeagh bogs. Limited sampling and the absence of stratigraphic survey, however, make these data of limited use. Within a generally wet bog environment, dry areas can occur and within a dry bog environment localised areas of wetness can form. While the data hardly allows for extrapolation to the wider bog environment, some evidence of the nature of the surrounding dryland is present (*ibid.*).

Coleoptera from three sixth century AD sites included strong woodland indicators. From this Reilly (*ibid.*) infers the presence of oak-dominated deciduous woodland on the dryland margin from which the timber used in trackway construction may have been derived.

The most comprehensive coleopteran study from Lemanaghan incorporates samples deliberately selected to provide environmental reconstruction of a targeted site and the wider environment (Reilly forthcoming). Peat adhering to human remains which had once lain in Tumbeagh bog (Bermingham & Delaney 2000) was retained and subject to coleopteran analysis. The results implied the presence of wet pool peat at the location the body had lain. This corresponded well with the conditions suggested by examination of the peat stratigraphy at the site. A generally wet *Sphagnum* bog surface is implied, and a pool in which the lower legs of the bog body lay was identified (Casparie forthcoming).

In terms of the wider environment, the coleopteran analysis corroborates Casparie's reconstruction of this part of the mire from fen to lake to raised bog (forthcoming). Beetle taxa increase in diversity as the fen develops and minerotrophic conditions prevail. True aquatic species increase and there is an overall fall in taxa from other ecological niches as the lake develops. The presence of beetles favouring decayed and rotting vegetation coincides with the emptying of the lake when the lake floor and shore area dried out and were subject to increased decay. The development of an oligotrophic peat environment is then reflected in the insect assemblages (Reilly forthcoming). The integrated approach to the palaeoenvironmental work carried out at Tumbeagh has clearly enhanced the general understanding of the development of this bog but many questions remain.

3:6:5 Palynological analyses

A pollen sequence from Tumbeagh bog represents the only pollen record from Lemanaghan and one of the few taken in direct association with archaeological material from industrial raised bogs in Ireland (see also Caseldine *et al.* 1996; 1998). A peat monolith though ombrotrophic peat taken from immediately next to the human remains excavated in 1998 (Bermingham & Delaney 2000) was subject to pollen analysis by David Weir of Queen's University Belfast (Weir forthcoming).

The Tumbeagh sequence spans *c.*1800 years from the seventh century BC to the middle of the thirteenth century AD. The most abundant tree species present throughout the profile include *Betula* sp., *Quercus* sp., *Alnus glutinosa, Fraxinus excelsior* and *Ulmus* sp. with *Pinus* sp., *Taxus baccata, Sorbus* sp. and *Fagus sylvatica* occurring in 'trace' amounts, i.e. values ≤1%, at different times (the latter close to the top of the profile). Shrubs which occur occasionally or in trace amounts include *Salix* sp., *Ilex* sp. and *Hedera helix.* This list corresponds well with the list of taxa derived from wood species analysis, although the latter includes other taxa, such as *Prunus avium/padus* and Pomoideae. The pollen record shows the dryland was most likely source for the wood used in site construction. Given that wood used in Derryville was taken from the dryland fringing the bog (Stuijts 1998a, 1998b) this may have been the case also at Tumbeagh.

Around the beginning of the seventh century BC, the consistent presence of the anthropogenic indicator *Plantago lanceolata* and reductions in the values of *Ulmus* sp. and *Fraxinus excelsior* point to human activity on the nearby dryland. Weir (forthcoming) identifies two peaks in agricultural activity, primarily in the form of pastoral farming, around 460BC and between 280BC-60BC. Interestingly this coincides with a gap in the (dated) archaeological record from the Lemanaghan bogs (Fig. 3:3). From the first century AD agriculture is much reduced, and the local woodland regenerates and remains stable until the middle of the third century AD (Late Iron Age). Trees decline and there is a gradual intensification of agriculture around AD740-AD910. By this time the monastic settlement situated to the south on Lemanaghan Island was well established and served as an economic hub for the area as well as providing a religious focus (Bermingham forthcoming). The monastery's presence may have resulted in these landscape and agricultural changes. The pollen evidence suggests pastoral farming was dominant with cereal pollen occurring in two levels in trace amounts only. In contrast, other contemporaneous pollen sites in the east of Ireland show greater emphasis on cereal cultivation and more marked intensification in agricultural activity (Weir forthcoming). By around AD1000, tree cover is at its lowest with all woodland species reduced in value and cereal pollen has increased. though this trend is short lived. Towards the close of sequence from *c.*AD1180-AD1250 woodland taxa recover (*Ulmus* sp., *Quercus* sp. and *Fraxinus excelsior*) though a general increase in disturbance weeds, such as *Artemisia, Sinapis*-type, *Stellaria*-type and *Rumex*, prompts Weir to suggest the bog fringes may have become wetter and agricultural activity, though increasing, has moved further away from the bog.

To summarise, the pollen record from Tumbeagh suggests a continous but variable human impact on the dryland fringing the bog. Landscape change, due largely to human action, was taking place on the dry land from the Late Bronze Age/Early Iron Age and the scale of change increased over time.

3:8 CONCLUSION

The Lemanaghan bogs, including Kilnagarnagh, and the surrounding upland, do not present a continous archaeological record; rather some periods are better represented than others. Selected dating, limited preservation and the fact that new sites no doubt remain to be found are all factors. There is also little palaeoenvironmental work though there is some pollen data. However, consideration of all available archaeological and archaeoenvironmental evidence provides an overall impression of a relatively continous human presence in the area, with the dryland and wetland zones subject to differing levels of activity at different times. Little work has been undertaken to investigate the link between changes in the mire and the archaeological record of this area. The degree to which conditions on the bog may have influenced activity within this complex and its environs is explored in Section 10:4, utilising the results of the multi-proxy palaeoenvironmental study of Kilnagarnagh.

CHAPTER 4

RATIONALE BEHIND SELECTION OF METHODOLOGIES

4:1 INTRODUCTION

This thesis is concerned with the application of existing palaeoecological techniques and their utility in an Irish context rather than development of new approaches. Environmental proxies are routinely used as a means of characterising palaeoecological change in peatlands (Charman 2002). In this thesis gross peat stratigraphic survey has been used to map mire-wide changes in the evolution of the bog. Greater detail has been derived from the analysis of subfossil remains of testate amoebae and plant macrofossils (microstratigraphy). Investigation of the physical and chemical properties of peat has been limited to humification determinations. Chronological control is provided by AMS dating. In this chapter the rationale for choosing the methods utilised is presented. Chapter 5 provides a description of the applied methodologies utilised in the field and laboratory.

4:2 PEAT STRATIGRAPHY

A gross peat stratigraphic survey was considered an essential component of this research project as it would provide a general understanding of overall mire development both in time and space as well as serve as a foundation for the location and interpretation of higher resolution proxy approaches. Peat stratigraphic survey has a long history within peatland studies with studies dating from the seventeenth, eighteenth and nineteenth centuries (Barber 1981). Four reasons for undertaking peat stratigraphic surveys are listed below.

1. Examination of the mechanisms of mire formation and evolution with particular emphasis on the identification of internal and external controls on development (Walker & Walker 1961; Osvald 1970;Walker 1970; Casparie 1972; Moore & Bellamy 1974; Barber 1981; Rybníček 1984; Succow & Lange 1984; Streefkerk & Casparie 1989; Warren *et al.* 2002). Unlike many other peatland palaeoecological

studies the present research was carried out in an industrial peatland subject to regular and intensive drainage. The drains provided an opportunity to survey the peat stratigraphy of the bog in detail not available through coring buried strata alone.

2. Locating appropriate sampling sites and interpretation of microstratigraphic sequences (Barber 1981, 1985; Barber *et al.* 1998; Caseldine *et al.* 2001; Hughes & Barber 2004; Reilly forthcoming). Within raised bogs some locations, such as wet *Sphagnum* lawns and pool areas, are thought more likely to register climate-induced changes in hydrology (Barber 1981; 1985). Peat stratigraphic survey enables identification of optimum sampling sites and avoidance of peat formations which may provide a misleading picture of broader environmental change. Earlier work in Ireland has shown that patterns found in proxies such as pollen and testate amoebae were best explained by reference to the peat stratigraphic record (Caseldine *et al.* 1998). In some cases the magnitude of change implied by these proxies could not be explained in relation to either climate or anthropogenic factors; rather the internal dynamics of the system, revealed by stratigraphic mapping, were apparently responsible.

3. Description and interpretation of the landscape in which archaeological sites may be present (Casparie 1972, 1982, 1984, 1987, 1988, 2001, 2005, forthcoming; Casparie & Moloney 1994, 1996; Bermingham 2001; Casparie & Stevens 2001). The gross stratigraphic records allow the development of a bog to be mapped and thus the placement of any archaeological sites present within their contemporary landscape. This approach was taken at Derryville, Co. Tipperary (Casparie 2001, 2005), where more than 30 archaeological sites were excavated. The peat stratigraphic record served to clarify relationships between archaeological structures and enable identification of phases of mire use which were influenced by the character of the mire at different times (Cross *et al.* 2001; Cross May *et al.* 2005a). Application of a similar approach to a smaller bog such as Kilnagarnagh will allow for assessment of the value of this approach to smaller systems with lower archaeological site numbers.

4. Gross peat stratigraphic survey also allows peatlands to be viewed as landscapes which may then be reconstructed in 3D. Evolutionary and time-slice models of mire development can be constructed using peat stratigraphic data.

4:3 SAMPLING: SINGLE VERSUS MULTIPLE CORING

Four cores were taken for laboratory analysis from Kilnagarnagh. Barber (1981) and Barber *et al.* (1994) have suggested that a single palaeoecological profile can be representative of an entire site and thus be sufficient to allow identification of changes in climate. Other studies have suggested, however, that analysis of multiple cores is required to separate the effects of local hydrodynamics and climate (Barber *et al.* 1998; Charman *et al.* 1999) and thus allow better interpretation of biostratigraphic sequences. Multiple coring also allows assessment of spatial variability between records and may help explain differences in detail between same-site records through time (Hendon *et al.* 2001). As this thesis is partly concerned with the separation of external and internal processes affecting mire development multiple cores were taken for analyses. This approach is also in keeping with recent testate studies from mires in which the use of multiple cores can be viewed as a matter of routine (Caseldine *et al.* 1998, 2005; Charman *et al.* 2001; Chiverrell 2001; Hendon *et al.* 2001; Hendon & Charman 2004). Multiple cores would also provide a more detailed record of the environment in which archaeological sites may have been located. The criterion used to select each sampling location in Kilnagarnagh is outlined in Chapter 5:2:3.

4:4 TESTATE AMOEBAE

4:4:1 Introduction

Testate amoebae are considered useful hydrological indicators capable of enabling the reconstruction of past environmental conditions in peatlands (Tolonen 1986; Charman & Warner 1997; Woodland *et al.* 1998; McGlone & Wilmshurst 1999; Hendon *et al.* 2001; Booth & Jackson 2003; Wilmshurst *et al.* 2003). Moisture, i.e. depth to water table, is recognised as the fundamental control on assemblage composition and species distribution (Charman *et al.* 2000). Consequently changes in the character of fossil assemblages are likely to reflect changes in hydrology and thus surface wetness. The development of quantitative techniques in testate amoebae studies (Birks 1995; Woodland *et al.* 1998; Charman *et al.* 1999) has given testate studies a significant advantage over other hydrological proxy data such as humification and plant macrofossils. The latter provide semi-quantitative estimates of changing surface wetness. The application of transfer functions to fossil testate data allows the degree of change to be summarised in ecologically meaningful units, in this case water table depth in centimetres.

4:4:2 The ecology of testate amoebae

Testates are unicellular organisms that inhabit wet terrestrial and aquatic environments such as mires, wet forest soils and lakes. They are the most common group of unicellular animals living in surface peats (Tolonen 1986). In taxonomic terms they belong to the kingdom of Protozoa, free living single celled animals, which is estimated to be composed of possibly 100,000 species worldwide (Charman 1999). Testate amoebae are distinguished from other forms of Protozoa as they form an outer shell known as the 'test' which is preserved in fossilisation. Test morphology and size provide the basis for identification of fossil assemblages.

In peatlands, all testate amoebae taxa inhabit the water film of plants, such as Sphagna (Corbet 1973), and as a result are small, ranging in size from 10μm -250μm. Occupation of small water bodies is further facilitated by morphological adaptations such as flattened tests and modification of the size and orientation of the pseudostome - an aperture in the cell wall; some species possess a single aperture while others have two (*ibid.*). These adaptations help prevent desiccation and in combination with the external shell make the organism resistant to short term fluctuations in conditions, a useful feature when using them as hydrological indicators (Charman *et al.* 2001).

In peatlands, the zone occupied by testates bears a direct relationship to the depth to water table and in several countries modern studies have identified a vertical range specific to each region. For example, in Finland the depth to water table of living assemblages is 0.8cm-22.4cm, in Britain it is 1.89cm-10.31cm, while in continental Canada the identified range runs from 2.8cm-57.7cm (Charman *et al.* 2001). Despite the difference in the ranges between regions, different species of testate occupy similar positions along the hydrological gradient regardless of geography. For example, taxa from the genus *Arcella* consistently appear at the wetter end of the range from northern Europe and Canada. The relationship between water table and species distribution enables patterns of hydrological change to be identified within mires and as a result has been increasingly used over the last fifteen years as a means of identifying changes in mire surface wetness (see below).

4:4:3 Quantitative Testate Amoebae Analysis

The relationship between assemblage composition and water table depth and surface moisture is modelled by means of a transfer function which enables production of quantitative estimates of the depth to water table. Transfer functions have been developed for the UK, North America and New Zealand (Charman & Warner 1992; Charman 1997; Woodland *et al.* 1998) and are currently being developed for other sites within Europe including Ireland (see below). This thesis utilises the transfer function derived from modern UK testate populations (Woodland *et al.* 1998).

The ecological affinities of testate amoebae have been well established with testates recognised as cosmopolitan organisms that share a common set of factors governing species distribution, abundance and assemblage composition (Corbet 1973; Warner 1987; Charman & Warner 1992; Bobrov *et al.* 1999). Studies have shown that the transfer function derived from studies on UK bogs appears to work well across Europe (Woodland *et al.* 1998). Results from Derryville, Co. Tipperary, have demonstrated the applicability of the British derived transfer functions to Irish fossil material (Caseldine *et al.* 1998). Here individual proxies show a high degree of correspondence with one another. Moisture changes reflected in the plant macrofossil record generally agreed with those identified in the testate data. Testates also appeared to provide a better picture of palaeohydrological change than humification records, correlating well with the peat stratigraphical record (Caseldine *et al.* 1998, 2005). Clearly then, the combination of testate cosmopolitanism and inter-proxy correspondence supports the application of UK transfer functions to Irish fossil assemblages.

The applicability of this approach is currently being tested within the ACCROTELM Project (see Section 2:3:3 above). Modern data sets are currently being compiled from sites across Europe, including Ballyduff Bog, Ireland, which will allow the robustness of the UK transfer function to be tested and the development of a series of independent transfer functions. Developing new calibration data sets for different regions may broaden the range of modern analogues thus improving the potential precision of the transfer function (Wilmshurst *et al.* 2003). Nonetheless, for the reasons outlined earlier, the application of the UK transfer function to other sites can be viewed as reliable.

4:4:4 Limitations of testate amoebae analysis

Limitations on the utility of fossil testate studies include:

(a) the lack of modern analogues for some species, specifically *Difflugia pulex.*

(b) the possibility of differential preservation among tests.

(c) the absence of testates from fen peats.

These are discussed in detail below.

(a) Some species of tests have few modern analogues. The ecological preferences of *Difflugia pulex* are unclear as it rarely occurs in modern studies (Charman *et al.* 2001). Hence assigning a hydrological indicator value to this species for use in reconstructing water table depth is problematic. Based on associations with other taxa, Hendon (1998 cited in Charman *et al.* 2000) has suggested *D. pulex* indicates relatively dry conditions. A review of assemblage composition of testate stratigraphies from three other mires Coom Rig Moss, England (Charman *et al.* 1999), Derryville, Ireland (Caseldine *et al.* 1998), and the present study site Kilnagarnagh suggests that its distribution may be more complicated. The records suggest *D. pulex* is absent from very wet situations but is common in wet conditions. It is present where conditions are moving towards increased dryness, but is less abundant in very dry situations. This suggests it has a relatively wide tolerance but is absent from extremes, either very wet or very dry.

(b) Woodland *et al.* (1998) suggest that differential decay may not affect the composition of fossil testate assemblages from peatlands. Recent work undertaken in New Zealand (Wilmshurst *et al.* 2003) found poor overlap of species composition between modern and fossil testate samples. Less robust tests appear to be under-represented in the fossil assemblages, most likely as result of poorer preservation conditions, e.g., drier peat. The New Zealand study benefited from comparison of modern and fossil faunas from the same mire and serves to highlight the contribution of taphonomic considerations.

(c) Recent work on subfossil testate assemblages from mires has shown that high concentrations of testates are generally restricted to *Sphagnum*-dominated situations. Table 4:1 lists a number of studies in which testate concentrations were poor in non-*Sphagnum* deposits. These analyses are in keeping with earlier comments made by Tolonen (1986, 647) who stated that the "... abundant occurrence of 'useful' rhizopod species is concentrated in ombrotrophic mires ..." with *Sphagnum* peats more likely to return useful results. Given this and the lack of testates registered in fen levels from other sites (Table 4:1), the fen deposits at Kilnagarnagh were not subject to detailed investigation in terms of testates.

Site	Mire type	Core	Sediment type	Presence/Absence	Reference
Derryville, Co. Tipperary, Ireland.	Raised bog	DER18	Reed fen peat	TA absent or in low concentrations	Gearey & Caseldine in press
		DER18 (west)	Fen peat	TA absent.	
		DER23	Little *Sphagnum*. Record dominated by monocots.	TAs absent. Early stage of raised bog vegetation similar to underlying fen.	
		DER75	*Menyanthes* & *Scheuchzeria* peat and underlying fen peat.	TA absent.	
Raeburn Flow, Scotland	Raised bog	RBF	Macrofossils suggest *Eriophorum* dominated peat below 380cm.	TA absent. In countable numbers above 380cm where *Sphagnum* dominates.	Mauquoy & Barber 2002
Coom Rig Moss, Northumberland, England.	Intermediate raised-blanket mire	CRMI	Top 70cm *Sphagnum*. Remainder is monocot & ericaceous peat	TA present through out apart from lower very decayed sediment.	Charman *et al.* 1999
The Wou, Northumberland, England.	Oligotrophic valley mire	TW II	Predominantly monocotyledonous plants with silt, sand and woody horizons.	TA in low concentrations. Countable TA in overlying mixed *Sphagnum*-monocot. peat without minerogenic sediment	Hendon *et al.* 2001

Table 4:1 Ombrotrophic sites in which sub-fossil testate concentrations were poor in deeper non-*Sphagnum* deposits. TA = testate amoebae.

4:5 MICROSTRATIGRAPHY: PLANT MACROFOSSILS

Microstratigraphy here refers to the analysis of the vegetative components of peat, i.e., plant macrofossils. Macrofossils provide evidence for changes in mire plant communities through time enabling construction of records of vegetative change (Aaby 1976; Barber 1981). Changes in species composition and the proportions in which they occur imply changes in the ecological controls governing vegetation growth such as local and regional climatic conditions, moisture and nutrient availability (Nicholson & Vitt 1990). In raised bogs the occurrence and distribution of plants is strongly influenced by hydrology with different species having different hydrological requirements (Fig. 4:1). For example, *Sphagnum cuspidatum* is an aquatic species that tends to dominate pools. Less hydrophytic species such as *Sphagnum magellanicum* and *Sphagnum papillosum* occur at different stages in the development of hummocks (Hill 1978). Macrofossils can therefore provide evidence for variation in mire surface wetness (Barber *et al.* 1994; Chiverrell 2001; Mauquoy & Barber 2002).

It is then possible to use the environmental preferences of plant species to semi-quantitatively reconstruct changes in moisture levels on the bog surface (Barber *et al.* 1994). Detrended correspondence analysis (DCA) is applied to macrofossil profiles to identify and model the underlying controlling variable. Barber *et al.* (1994) showed that the distribution of plant taxa in relation to the axes reflected an environmental gradient governed by water level. Ericales and monocotyledons occupy the drier end of the scale with Sphagna occurring at the opposite end.

The use of macrofossils as wetness indicators is inhibited by the lack of absolute palaeo-indicator values against which estimates of wetness may be made. For example, the lack of modern analogues for species such as *Sphagnum imbricatum* means its past hydroecological preferences are less well understood than those of other Sphagna (Woodland *et al.* 1998); it may occupy a narrower hydrological range now than it did in the past (Stoneman *et al.* 1993). Secondly, difficulties in absolutely quantifying the wetness index derived from plant macrofossils (Charman 1997) mean that data derived from plant macrofossils aimed at reconstructing surface wetness may be difficult to interpret reliably.

In this thesis, microstratigraphy is used to supplement the hydrological proxy records derived from testate amoebae and peat humification determinations. The macrofossil remains analysed here are the sample residue retained after testate amoebae sample preparation (see Section 5:3:2). Other studies use larger sample sizes (*cf.* Hughes 1997; Hughes *et al.* 2000; Barber *et al.* 1998) as well as more sophisticated methods of analyses (*cf.* Dupont 1986). One advantage of the approach taken here is that it allows comparison of plant macrofossils and testate amoebae derived from the same sample. Where this approach has been used before it has been shown to be robust (Caseldine *et al.* 2005; Caseldine & Gearey 2005).

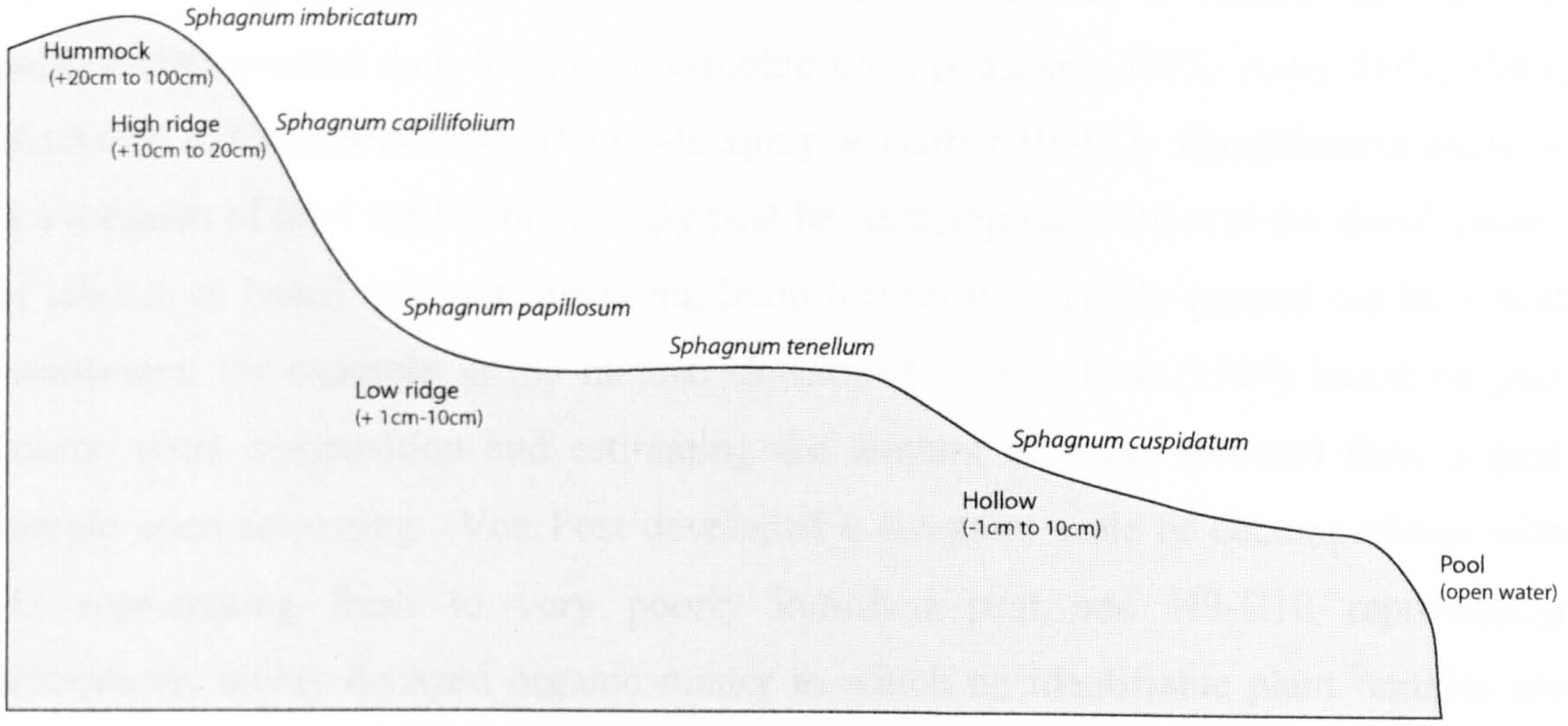


Fig. 4:1 Generalised distribution of microforms and the idealised distribution of *Sphagnum* species. Adapted from Lindsay (1995). The figures in brackets refer to position in relation to water table. + = above, - = below.

4:6 HUMIFICATION DETERMINATIONS

4:6:1 Introduction

Peat humification analyses have often been utilised as a means of deriving palaeoenvironmental data from ombrotrophic bogs (Casparie 1972; Aaby 1976, 1986; Blackford & Chambers 1991, 1993; Mauquoy & Barber 1999a). Humification analysis is a measure of how weakly or strongly peat has decomposed. Prior to the development of laboratory based methods, assessing humification was largely carried out by visual assessment, for example in the manner developed by von Post (1924) based on peat colour, plant composition and estimating the amount of water released from a peat sample upon squeezing. Von Post developed a ten-point scale of decomposition with H1 representing fresh to very poorly humified peat and H9-H10 representing amorphous, highly decayed organic matter in which no identifiable plant remains are visible.

Laboratory-based methods of assessing humification are concerned with measuring the proportion of humic acids in peat which are known to increase as peat decomposes (Aaby 1976; Blackford & Chambers 1993). In ombrotrophic systems decomposition is dependent on the degree of surface wetness of the bog. In literature concerning humification, water supply is cited as the primary control on decay (Blackford & Chambers 1991, 1993; Mauquoy & Barber 2002). Other important decay control factors include temperature, microbial and faunal populations and the type of plants inhabiting the bog (Charman 2002). Clymo (1983; 1991) has shown that where the bog water table is high, i.e., in anaerobic conditions, less decomposition will take place. It follows then that peat returning low humification values is likely to have been deposited during periods of high water table. Conversely where the water table is low, plant remains are more susceptible to decay as the availability of oxygen enables decomposition. High humification values therefore imply deeper water tables. In ombrotrophic bogs, surface wetness is determined by the level of effective precipitation, the balance between precipitation and the rate of evapotranspiration. As a result, measuring the degree of decomposition allows inferences regarding the palaeoclimate to be made.

The method of humification analysis most commonly in use is that of Blackford and Chambers (1991) refined from earlier work by Aaby (1986). It involves measuring the transmission of light through an alkaline extract of a peat sample at a wavelength 540nm. The results are expressed as percentage light transmission. Using this technique, Blackford and Chambers (1991) inferred wet shifts from five blanket bogs in England, Wales and western Ireland. The similar timing of the shifts, around the middle of the first millennium AD, was such that the authors concluded the shifts had been driven by climate forcing (*ibid.*). Other authors have also reached similar conclusions on the basis of wet shifts identified in humification data (e.g., Chambers *et al.* 1997; Gunnarson *et al.* 2003; Roos-Barraclough *et al.* 2004). In conjunction with plant macrofossil data, humification records from Coom Rig Moss and Felecia Moss, England, implied a series of broadly synchronous wet shifts which the authors concluded represented "[t]en periods of increased effective precipitation ..." (Mauquoy & Barber 1999a, 274). In a subsequent paper the authors again interpret these shifts and others identified from the raised bogs, Raeburn Flow and Bell's Flow, Scotland, as indicating climatic deteriorations (Mauquoy & Barber 2002).

4:6:2 Problems with colorimetric humification analysis

While humification analysis has become an established environmental proxy, there has been some discussion regarding the validity of the methods used (Blackford & Chambers 1993; Chiverrell 2001; Caseldine *et al.* 2000). The main difficulties considered have been differential decay rates between species, the poorly understood nature of the chemical processes involved in decomposition and, that the degree of correspondence between humification and other proxies is variable. Determining the degree of humification disregards the probability that the peat being analysed may be composed of plant species and parts of plants which decay at different rates. Clymo (1983) brings together the results of experiments undertaken by researchers in order to measure decay rates in multiple bog species. Based on the rate of weight loss (yr^{-1}) of dead plants, including *Eriophorum vaginatum*, *Calluna vulgaris* and *Sphagnum recurvum*, *S. cuspidatum* and *S. papillosum*, held within mesh bags on Moor House blanket bog, England, the experiments demonstrated differential decay rates across species and plant parts. *Eriophorum vaginatum* leaves and *Calluna vulgaris* shoots broke down more rapidly than *Sphagnum* shoots, while the roots of both *E. vaginatum* and *C. vulgaris* decayed at an even slower rate. Within the genus *Sphagnum* different species have been shown to break down at different rates. Johnson and Damman (1991) showed that *Sphagnum cuspidatum* loses mass at greater rate than *S. fuscum* despite *S. cuspidatum* inhabiting wetter hollows and *S. fuscum* forming hummocks. Belyea (1996) also found evidence for differential species effect decay between *S. capillifolium* forming hummocks, *S. papillosum* forming lawns and *S. cuspidatum* occupying hollows.

Chiverrell (2001) produced humification curves based on two adjacent cores from Site D, May Moss blanket bog, North York Moors. The data displayed differences that may have resulted from differential decay. He suggests that humification sequences may be microsite specific, reflecting differences in accumulation rates and therefore decomposition between microtopographic environments (*ibid.*).

Chambers *et al.* (1997) acknowledge that differential species decay could have implications for interpreting humification data but suggest using multiple proxies can account for any likely bias. They argue correspondence between proxies, in their case pollen and peat humification from Talla Moss, Scotland, negates the potential effect of differential species decay. The proxy data indicate that major changes in humification are not accompanied by similar shifts in the composition of the local vegetation. Hence, the authors contend, it is unlikely major changes in humification result from local vegetational change and thus shifts in humification can be considered allogenic in origin.

While rates of decay of different plants are thus reasonably well understood, the chemical processes involved in the transformation of dead plants into peat remains an area of great complexity. Clymo (1983, 161), in reviewing various methods of assessing humification and the lack of detailed agreement between resulting data sets, refers to peat as "a mixture of still largely unknown chemical substances". Recently Caseldine *et al.* (2000) have suggested that the complexity of the chemical transformations involved in decay, which are poorly understood, may limit the applicability of humification analysis. In addition, the use of sodium hydroxide (NaOH) to extract humic acids from the peat may introduce contaminants and 'skew' data.

It is assumed the colour of the NaOH peat solution reflects the quantity of humic acid present and therefore the degree of decay (Blackford & Chambers 1993). However, it has been suggested that the procedure causes changes in the humic acids present and resulting measurements reflect these transformations rather than the quantity of humic acid associated with decomposition of the peat (Caseldine *et al.* 2000). Indeed Blackford and Chambers (1993) noted the reluctance of some researchers to accept NaOH as an extractant because NaOH peat solutions contained contaminant, non-humic material and the extraction procedure produced additional compounds (Hayes 1985). What exact variables are reflected in a humification curve are therefore unclear as both differential decay processes as well as the 'standard' NaOH extraction procedure may have contributed to the nature of the curve. Caseldine *et al.* (2000) suggest that humification curves may reflect major wet shifts in surface wetness only and smaller changes are a product of "noise in the humification signal" caused by the NaOH extraction process.

The above problems meant extensive analysis was not undertaken on all cores from Kilnagarnagh with analysis confined to one core, K101 (see Section 7:2:3). It was considered that other proxies would provide more reliable results.

4:7 RAISED BOG EVOLUTION & SURFACE MODELLING

In landscape reconstruction studies, digital elevation models (DEMs) can aid the presentation and interpretation of variable and changing landscapes. Over the last 10-15 years interpretation of archaeological sites and landscapes is increasingly undertaken with the aid of surface models (Newman 1992, 1997; Westcott & Brandon 2000). These tools have for the most part been employed in dryland archaeological situations with little attention paid to their use in wetland environments. Recent work by O'Sullivan (2001) included hypothetical DEMs of a prehistoric landscape in the Shannon Estuary. In general, however, the application of DEMs in the archaeological or palaeoecological study of mires is in its infancy.

Creating DEMs of mires, however, could serve as a useful means of portraying the dynamism and multi-dimensional character of such systems. Stratigraphic surveys have typically been employed to establish basin morphology and the general sequence of mire evolution, with results presented in two dimensions as cross-sections with depth plotted on the y-axis and distance on the x-axis (Walker & Walker 1961; Casparie 1972; Barber 1981; Almquist-Jacobson & Foster 1995; Warren *et al.* 2002). Research concerned with mire evolution has also involved the presentation of stages in peatland development in 'plan' view. Nicholson and Vitt (1989) used peat stratigraphic survey results and dating evidence to map peatland initiation, infilling and paludification of a former lake basin in western Canada. Anderson *et al.* (2003), examined the role of terrestrialisation and paludification in the growth and expansion of peatlands and imposed stratigraphic data on basal contour maps, thus emphasising the relationship between topography and peat formation in a 2D view.

With the increasing availability and accessibility of Geographical Information Systems (GIS) software this relationship and other issues of mire ontogeny can now be modelled in a more visually effective manner. Chapman and Gearey (2002) have produced topographic models of the pre-peat landscapes of two lowland raised bogs in England to identify areas where the earliest peat formation occurred and those parts of the landscape which may have remained as dryland for longer. The study aimed to highlight the potential for predicting locations for archaeological sites within both mires by modelling basal morphology using DEMs. Although this study did not attempt to model different phases of evolution of the mire surface through time it clearly shows the potential for the use of DEMs in relation to raised bog development.

This thesis advances the utility of DEMs in mire-related palaeoecological and archaeological research. Here DEMs are used to model major phases in the ontogeny of the raised bog at Kilnagarnagh. The production of these models and the parameters guiding that production are described in Section 5:5:3 with results presented in Section 8:3.

CHAPTER 5

METHODS

5:1 INTRODUCTION

This chapter provides a description of the applied methodologies beginning with field methods. This is followed by a description of laboratory techniques, data analysis and finally data modelling. The criteria behind the selection of the study site have been described in Section 3:2:3.

5:2 FIELD METHODS

Fieldwork comprised of two seasons undertaken in the summer of 2001 and 2002 with a further follow-up visit to the site in 2003. There were five main elements to the fieldwork programme:

1. Selection of the research site based on assessment of three potential sites by means of walkover survey (see Section 3:2).
2. Survey of representative gross peat stratigraphy involving examination of peat faces, peat cores and the sub-surface contour.
3. Core sample site selection and retrieval.
4. Archaeological survey involving re-location of known sites and identification of any new sightings.
5. GPS location of all data/sampling points.

5:2:1 Gross peat stratigraphy

The approach taken developed out of archaeological survey strategies used in raised bogs, with particular reference to Casparie (1972) and Barber (1981). A second walkover survey of the primary research site Kilnagarnagh allowed for the selection of three drains that would serve as the primary peat stratigraphic and coring transects through the bog (Fig. 5:1). This preliminary survey also enabled an overall impression of the bog's stratigraphy and large scale peat formations to be gained.

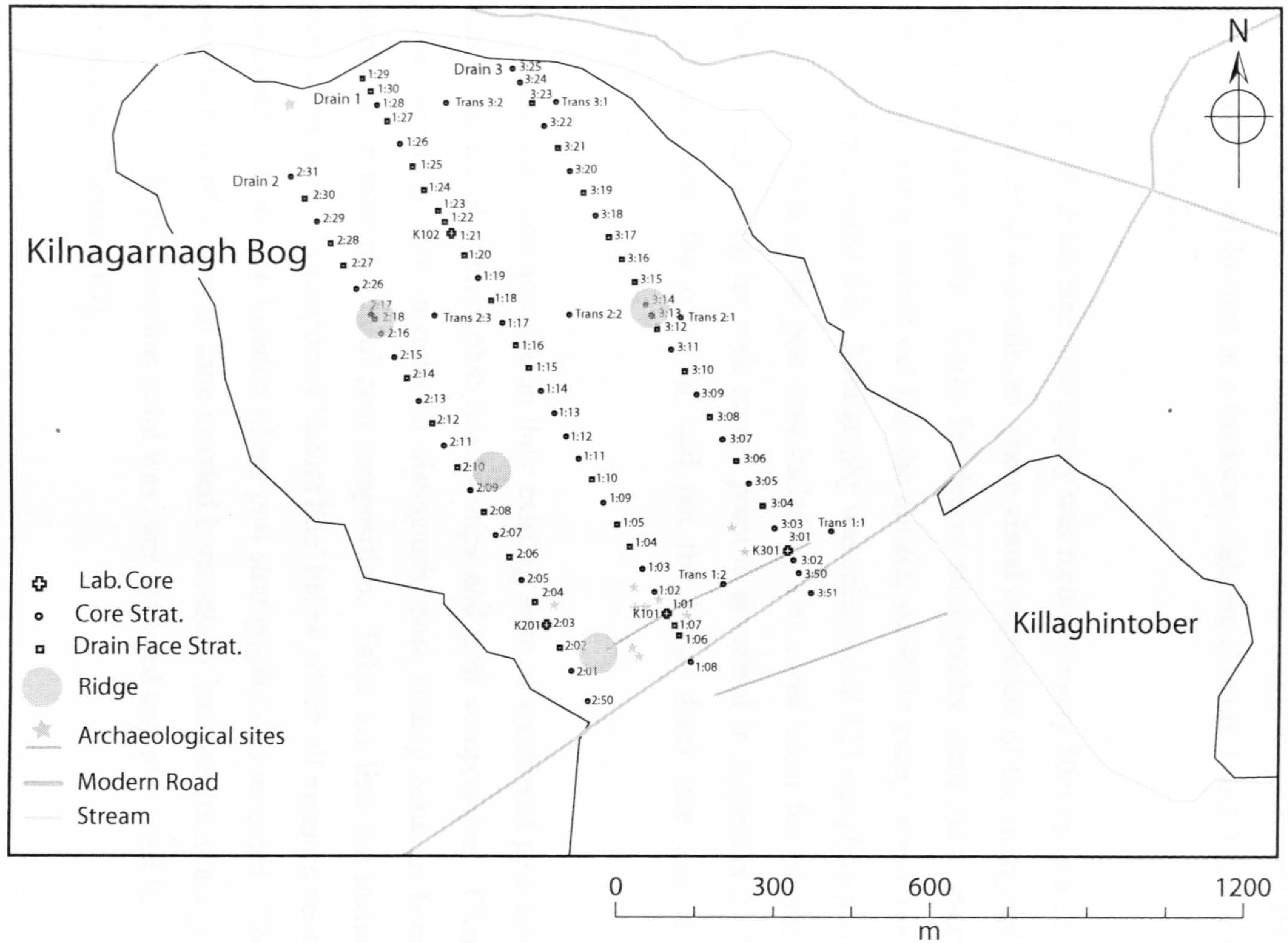


Fig. 5:1 Map of Kilnagarnagh showing all survey points and archaeological sites.

The interval between the main drain transects was *c.*180m-250m and allowed for a relatively even distribution of the stratigraphic record across the width of the bog as well as incorporating any archaeological sites within the survey framework. Transects were labelled Drain 1, 2 and 3. Survey points were recorded as a sub-set of a drain, e.g., Drain 1:13, Drain 2:26. The survey moved from south to north with the first survey point in each drain located at a trackway sighting (Drains 1 and 3) or in line with the trackway (Drain 2).

In each transect, drain face stratigraphy was recorded every 50m up to a depth of 1.40m. The survey interval was reduced where visual inspection of the stratigraphy warranted higher resolution study. Cores for deeper stratigraphy were made every 100m and coring was usually carried out into the mineral substrate except where the character of the deposit prevented this. Stratigraphy was recorded at 121 sampling points, of which 62 included cores to the peat base including four cores taken for laboratory analysis. The stratigraphic log for each survey point is presented in Appendix 2. Where cores were made only the core log, and not the initial drain face log, is included in Appendix 2.

Peat faces were first assessed in their existing state as weathered peat faces provide a clearer picture of stratigraphic relationships and peat composition. Cleaning with a shovel was then used in order to distinguish more clearly between horizons and to enable closer examination of peat composition. Table 5:1 lists the items recorded at each survey point. A temporary 'datum line' below which all measurements were taken was established at each location where peat stratigraphy was recorded. The datum line took the form of a bamboo cane inserted horizontally into the drain face just below the field surface. In all cases this point was later surveyed and converted to a level relative to Ordnance Datum (OD).

Peat types were identified in the field and were described in terms of colour, degree of humification and the obvious plant macroscopic remains with reference to Casparie (1972), Phillips (1980), Barber (1981), Hammond (1981) and Bellamy (1986). A brief description of the major sediment units is given below. Assessing the degree of decomposition or level of humification of raised bog peats followed Casparie (1972) and von Post (1924). Casparie (1972) describes humification as being poor, moderate or high. These categories equate to von Post's 10-point scale of decomposition as follows: poor = H1-3, moderate = H4-6, and high = H7-9. H10 represents amorphous

Details recorded at each survey point
• depth of the record
• depth to water table
• number of individual horizons present
• thickness and where required distance over which a horizon or sequence occurred
• the nature of boundaries between horizons, i.e., sharp, gradual, indistinct
• colour, either weathered or fresh
• the rate of oxidation, i.e., slow, rapid
• the degree of compaction, e.g., whether loose, very loose, compact, very compact, friable or crumbly
• peat type as reflected by the main plant constituents present, the proportions in which they occur and the degree of decomposition

Table 5:1 Details recorded at each peat stratigraphic survey location.

peat, which was not identified in Kilnagarnagh. The level of humification is evaluated through visual examination and assessment of the amount of identifiable plant matter in the peat, in conjunction with the squeeze test. On the other hand the degree of decomposition of fen peats was recorded descriptively, as opposed to comparing it to a scale. Descriptive terminology included well or very well decomposed, compact or very compact, loose or very loose, some or no visible plant parts.

5:2:2 Core site selection & sample retrieval for laboratory analysis

Two primary objectives of this research are (a) to establish the pattern of mire evolution and (b) to examine the environmental context of human interaction with the mire as expressed by the presence of archaeological sites (See Section 1:4 above). Taking cores for laboratory analysis facilitates high-resolution investigation of mire deposits and of changes in the nature of the deposits through time. The stated aims determined the number of cores, their distribution and the depth of sequences retrieved. Sample site selection followed interrogation of the peat stratigraphic and archaeological records made in 2001. Using the results of the gross peat stratigraphic survey to identify optimum coring locations would allow for assessment of large-scale spatial variability between sequences across the mire. Hand-drawn cross-sections of the primary transects were used to pinpoint the location of the cores. Each core was retrieved using 5cm by

50cm Russian corer with sequences taken from the modern field surface. At each location, a clean peat surface was prepared from which coring took place.

Four coring sites were selected. Three were located in the south (K101, K201 & K301) while the fourth (K102) lay near to the mire centre in the north (Fig. 5:1). Two long and two short cores were retrieved (Table 5:2).

Core	Length	Analysis
K101	5.91m	Testate amoebae, Plant microstratigraphy AMS, Humification
K201	5.62m	Testate amoebae, Plant microstratigraphy, AMS
K301	3.5m	Testate amoebae, Plant microstratigraphy, AMS
K102	4m	Testate amoebae, Plant microstratigraphy, AMS

Table 5:2 Length and range of laboratory analysis carried out on each core.

Criteria governing core location and length included:

(a) the quality of the peat stratigraphy, i.e., identification of deposits best suited to environmental reconstruction.

Palaeoecological investigations of past environmental conditions are typically conducted in ombrotrophic peatlands because of the dependence of these systems on meteoric moisture (Ingram 1983). Fens fed by groundwater sources do not offer the same potential for broader palaeoenvironmental reconstruction (Moore & Bellamy 1984). For this reason, the emphasis was on the retrieval of ombrotrophic peat sequences though all cores extended into the upper fen deposit in order to ensure recovery of the fen-bog transition.

Barber (1981) has suggested that different microtopographic environments are more climatically sensitive than others. In particular, lawn-hollow-pool situations are more likely to reflect hydrological changes reflective of climate change. Where possible other later studies have deliberately selected areas where these features prevail (e.g., Barber *et al.* 1998; Mauquoy & Barber 1999a). In Kilnagarnagh, the peat stratigraphic record revealed that pools occurred more commonly on the eastern side of the mire. Hence, one core (K301) was taken from this area.

(b) the presence or absence of archaeological sites and the need to provide a high resolution environmental context for such sites.

The absence of known archaeology in the centre and north might be explained by examining a sequence from this part of the mire. Core K102 was located with this issue in mind. In contrast cores K101, K201 and K301 were deliberately sited in relation to a Bronze Age plank walkway that extends from east to west across the southern end of the mire. K101 and K301 were taken through the line of the trackway. K101 was located at part of the track that had provided a dendrochronological date for the walkway, and hence a potentially useful chronological marker. K301 was sited at the trackway's eastern end where it appeared to differ structurally, comprising roundwoods rather than planks (see Section 6:2:2). A core from here might explain why the character of the site appeared to change at the eastern extremity. K201 lay beyond the west end of the trackway. As there was no visible stratigraphy in this location the core was sighted off the line of the site where a more detailed peat stratigraphic record was available.

(c) the need to establish the chronology of major mire evolutionary stages such as initial fen peat growth and the change to ombrotrophy.

Two long cores (K101 & K201) were taken in order to recover a complete sequence of peatland development and facilitate dating of the basal peat deposit. The cores were excavated where the peat deposits were deepest as these were assumed to represent the earliest peat formation in the basin. K101 included the recovery of the peat and mineral substrate interface. The base was not retrieved at K201 as the presence of wood prevented its recovery. Dating of fen peat initiation was thus confined to K101.

5:2:3 Archaeological survey

An IAWU survey of Kilnagarnagh Bog completed in 1996 identified 18 archaeological sites (see Section 6:2). All sites were re-located in 2001 in a repeat survey, and were located using GPS survey. A custom-made field sheet was used to record any archaeological features encountered (see Appendix 3). The sheet was adapted from survey record sheets used in surveys carried out by the IAWU (McDermott 1995; Bermingham 2001).

The archaeological survey concentrated on those areas where archaeological features were already known. Sightings were flagged using labelled bamboo canes. Following re-location of all known material, the survey concentrated on obtaining greater definition of the plank walkway. Every drain was examined for the presence or absence of the site. This investigation extended the walkway by 150m at its eastern end and in places additional sightings were identified within the known length of the site. Drains 1 and 3 include trackway sightings in their record but the trackway did not appear to extend as far as Drain 2. New sightings were not identified in the west; the last sighting lay over a ridge in the mineral substrate.

In 2003 while inspecting active face banks in the northern end of the bog a new archaeological structure was identified (see Section 6:2:4). Details of the discovery were passed on to the state authority, *Dúchas* the Heritage Service. The site consists of a series of oak planks exposed in a privately cut bog peat face fringing Kilnagarnagh bog in the north. Its composition is similar to that of plank built trackways found in Irish bogs. The site could not be accessed directly owing to flooding of the cutting at the base of the peat face, the depth of overlying peat (*c*.1.5m), and the overgrown and unstable nature of the bog in this area. As a result a level OD was not obtained for the site and its NGR was established using a hand-held GPS. There are no other archaeological sites visible in the vicinity.

The discovery of a new site in 2003 highlights one of the main limitations of the recognition of archaeological sites in bogs. Many more sites may be present in the bog but their presence may be hidden because the overlying peat is uncut or intact. In common with many Bord na Móna bogs the view in Kilnagarnagh is limited to the upper metre of peat and the field surface except at the bog edges where deeper peat faces are found. The occurrence of one metre deep drains every 15m increases the opportunities for the identification of archaeological sites across the bog but any finds below this level remain hidden.

5:2:4 GPS survey

Using a Leica GPS 121 individual data points were recorded in 2001 and 2002. The data were tied into the Irish National Grid and Ordnance Datum, corrected to Malin Head, using survey data derived from surveys of the Irish Archaeological Wetland Unit. Survey data was then processed in Leica SkiPro 2.5 for use with ESRI® ARCGIS™ 8.2.

5:3 LABORATORY METHODS

A standard pattern Russian corer (50cm x 5cm) was used to recover the cores in contiguous overlapping lengths of 50cm. These were placed in split plastic piping and wrapped in Clingfilm. The cores were then stored in a cold store at 4°C. Each of the four cores was subject to testate amoebae and plant macrofossil analysis with chronological control provided by AMS determinations. Colorimetric humification analysis was conducted on samples from Core K101.

5:3:1 Testate amoebae

A sampling resolution of 8cm was adopted for each core. Following analysis of the fen deposits of core K101, in which testates were found to be minimal or absent, analysis was confined to the ombrotrophic sediment of the remaining three cores.

Preparation of the testate samples followed the methods outlined by Charman *et al.* (2001) which allows for retention of macroscopic plant remains which can be studied separately. In this way each proxy is derived from the same sample thus maintaining a direct relationship between the two data sets.

Preparation:

1. A 1cm^3 sample of peat was placed in a beaker with 100ml of distilled water.
2. Three tablets of *Lycopodium clavatum* were added, which served as an exotic marker enabling quantitative rhizopod analysis.
3. The sample was boiled (100°C-150°C) for around 10 minutes to encourage its disaggregation.
4. The sample was washed through a 350μm coarse sieve and back-sieved through a 10μm mesh. The organic matter trapped in the coarse sieve was retained for macrofossil analysis.
5. The residue from back-sieving was washed into centrifuge tubes which were centrifuged for six minutes at 6000rpm and again in smaller vials for three minutes at 3000rpm. This was necessary in order to reduce the amount of distilled water in the sample (water used to wash the sample from the sieve to the tube) and ensure easy transfer of the residue into stoppered vials.

For counting, samples were slide mounted and viewed using an Olympus BH-2 at magnification of x100 and x400. Initially water was used as a mountant but water-mounted samples quickly dried and glycerol was used instead (Charman *et al.* 2000). Identifications were made with reference to Charman *et al.* (2000) and web based resources such as *BioImages: The Virtual Fieldguide* (cited 2001-2003) and the Protozoa Gallery (*Micrographia* cited 2001-2003). The minimum number of testates counted per level was 150. Where necessary multiple slides were counted to reach 150 individuals unless, despite examination of three or more slides, the required threshold was not reached. Samples with low counts were excluded from subsequent numerical analysis.

5:3:2 Microstratigraphy: plant macrofossils

Macroscopic plant residue retained from the preparation of samples for testate analysis (see Section 4:5) was examined using a Leica MZ6 microscope at a magnification of x25. Macrofossil content was assessed on two scales: the relative percentage of the different groups of macrofossils and the percentage of the leaves of different Sphagna species present (Barber 1981; Caseldine *et al.* 1998, 2005). The categories distinguished were *Sphagnum* (leaves & stems), undifferentiated monocotyledons, *Calluna* rootlets and leaves, *Eriophorum*, wood and UOM (unidentified organic matter). The proportions in which these occurred was estimated based on a percentage of the total organic matter present.

Subsequent analysis concentrated on the identification of Sphagna. Where present, one hundred individual Sphagna leaves were extracted for identification and mounted in glycerol. Where large-leaved Sphagna dominated care was taken to ensure small-leaved Sphagna were also extracted. The leaves were viewed using an Olympus BH-2 microscope at a magnification of x100. Identifications were based on differences in cell morphology and position between the larger hyaline cells and the smaller green or photosynthetic cells and were made with reference to Daniels and Eddy (1990) and Hill (1978). Within the sections *Acutifolia* and *Cuspidata* there was no attempt at lower taxonomic division with the exception of *Sphagnum cuspidatum.*

5:3:3 Humification

The preparation of samples follows that of Aaby (1986) and Blackford & Chambers, (1993) and currently serves as the ACCROTELM protocol for humus determination outlined by Chambers (2004).

Preparation:

1. Thirty six samples were extracted from K101 at 8cm intervals. The interval was the same as that used when sampling for testate amoebae analysis. As *c.*1cm^3 of peat had already been removed for testate analysis the thickness of the sample taken ranged from 1-2cm which provided between 5-7g of wet sediment.
2. The samples were oven dried overnight at 70°C. Once dry they were ground and a 0.2g sub-sample extracted.
3. The extract was placed in a 200ml flask, with 100ml of freshly mixed 5% NaOH. At this point the time was recorded. From the addition of the NaOH to the recording of the percentage (%) transmission the experiment was completed within 4 hours.
4. The mixture was brought to the boil on a hot plate and then simmered for 1 hour.
5. The samples were allowed cool and then topped up to 200ml mark with distilled H_2O and shaken thoroughly.
6. Each sample was then filtered through Whatman (Qualitative 1) Paper.
7. 50ml of the filter solution was poured into a 100ml flask and diluted with 50ml of distilled H_2O.
8. The diluted filtrate was then well shaken before being inserted into a UV Vis Spectrophotometer in order to measure the % transmission at 540nm wavelength.
9. The spectrophotometer was zeroed for each sample at 100% using distilled water.

The samples should all have less than 100% transmissivity. The range of values encountered ranged from 8.4% to 48.9%. Higher values are indicative of poorly humified peats, and lower percentages are indicative of well humified peats.

5:3:4 Chronological control

Nineteen samples were taken from the four cores and submitted to the University of Waikato Radiocarbon Dating Laboratory, New Zealand for AMS determinations. The dating programme was funded by Bord na Móna Energy Ltd. Sample selection was based on identification of the zone boundaries derived from the testate sequences with peat taken from either immediately above or below the relevant boundary. Where possible only *Sphagnum* remains were selected for dating (Speranza *et al.* 2000) except in the case of the basal peat sample and samples from around the fen-bog transition. Samples were oven dried overnight, visible contaminants such as roots or fragments of wood were removed and approximately 1g of dried peat was submitted for analysis. The samples were subject to chemical pre-treatment; they were washed in hot 10% HCl, rinsed and dried. The results are expressed in yrs BP and BC/AD (Bowman 1990) (Table 7:1) and calibration follows Stuiver and Polach (1998).

5:3:5 Age-Depth models

Age-depth models were constructed for each of the cores in this study for two reasons:

(a) to enable estimation of rates of peat accumulation (expressed here as yrs/cm).

(b) following from (a) the models serve to estimate the duration and timing of testate and plant microstratigraphic zones not constrained by radiocarbon dates.

Models were constructed using linear interpolation (Bennett 1994) and represent an approximation of the true age-depth relationship. Within palaeoecological studies this type of age-depth model is a simple and frequently used method. Bartlein *et al.* (1995) have shown that age-depth models must be created using calibrated radiocarbon dates. Use of uncalibrated dates assumes that variations in the rate of accumulation will cancel out the 'wiggles' in the calibration curve. This assumption is invalid and consequently calibrated dates are used.

Use of calibrated dates however introduces a different level of complexity associated with the width of confidence intervals. Calibration of radiocarbon dates into calendar ages can result in intervals covering a few hundred years thus compromising the accuracy of palaeoecological reconstructions. To counter this Bennett (1994) suggests plotting the mid-point of calibrated dates against depth. The mid-point between the pair of calendar ages enclosed by the 95% confidence interval (2σ) is taken as an estimate of the calendar age. The standard deviation of this age is derived from halving the distance between this age and either of the bracketing ages.

Linear interpolation offers a simple means of providing time control for sediment sequences, however, there remains a degree of uncertainty attached to age estimates that affects the precision of the age-depth model (see Section 2:2:3). Refining radiocarbon-based chronologies has produced a body of research in its own right some of which has already been discussed. 'Wiggle'-match dating is being increasingly employed as it produces narrow confidence intervals and hence improved accuracy of a given chronology (Kilian *et al.* 1995; Kilian *et al.* 2000; Blaauw *et al.* 2003). Telford *et al.* (2004) point out that its level of accuracy may be artificial as it relies on the assumption that rate of sedimentation was constant. A similar assumption, regarding the rate of arboreal pollen influx, may undermine the approach of Speranza *et al.* (2000) (see Section 2:2:3). The advances in converting radiocarbon ages to calendar ages do not prohibit the use of liner interpolation as a means of estimating dates for microfossil assemblage zones or changes in environmental conditions. Here, 'wiggle'-match dating was not undertaken as this method requires a higher number of closely spaced dates then currently available.

The age-depth models presented here are derived from dated sequences retrieved from a heavily drained bog. This means that the upper peat deposit has been compacted and as a result, the depth of peat separating dated samples is artificially low. This has implications for estimating rates of peat accumulation as rates are likely to be inflated with too many years per centimetre suggested.

Streefkerk & Casparie (1989) present a model of acrotelm shrinkage derived from a system of drainage similar to that employed by Bord na Móna (see Section 2:1:7). Deepening drains annually by *c.*0.30m in five years causes the upper peat deposit to compact by *c.*1.17m. After the first two years when the rates of shrinkage are typically high (up to 40%) the peat deposit shrinks by *c.*0.20m per year. Deeper peats are not affected in the same way, here compaction is considerably less. At Kilnagarnagh peat depths prior to drainage were 8m (see Section 3:2:3:3). In AD2001, the maximum peat depth was 6m showing, based on the model referred to above, that the mire had shrunk vertically by around 2m with the greatest degree of compaction occurring in the upper metre of peat. Calculating the rate of peat accumulation between dated horizons from Kilnagarnagh is therefore problematic, particularly where deposits were subject to compaction or retardation in antiquity (see Section 8:3:4) and age estimates for changes in the biostratigraphic records should be considered carefully.

This has knock-on implications for the use of extrapolated dates in providing a chronological framework for otherwise undated changes in mire or fossil stratigraphies. As stated above, compaction of the peat deposit due to drainage is greatest in the upper peats (see Section 7:1:1) and declines as peat depth increases. Thus, age estimates for the timing of changes in mire stratigraphy from deeper peats may be better then those from higher deposits though all assume a constant rate of accumulation between dated horizons.

5:4 ANALYSIS & PLOTTING

5:4:1 Testate amoebae

Testate counts were recorded using shareware software developed by Keith Bennett, Polltax3, using a Psion Series 3mx (Bennett 2003). The files were then transferred to PC and amended for analysis and plotting using *psimpoll* 4.10 (Bennett 2002). Zones were applied to each testate sequence by means of visual inspection with zone boundaries avoiding sample levels. Sub-zones were applied where there was a minor but possibly significant change within a generally consistent assemblage. This method was favoured over numerical zonation, such as cluster analysis using CONISS (Bennett 1996), as the testate stratigraphy is relatively straightforward and the sequences short.

5:4:2 Microstratigraphy

The results of the microstratigraphic analysis were plotted using *psimpoll* 4.10 (Bennett 2002). The percentage of *Sphagnum* leaves is expressed as a percentage of the *Sphagnum* component of the total peat components. Initially, the testate zones were applied to the microstratigraphic sequences producing a reasonably close fit, but there were some important differences. Zonation based on gross stratigraphic boundaries was also attempted but this did little to clarify or aid interpretation of the microstrat sequences. Instead the plant macrofossil data was zoned independently based on visual inspection.

5:4:3 Statistical analysis

A transfer function is a mathematical equation that formalises the relationship between species and the environment. It enables reconstruction of an environmental variable from fossil biological data such as testate amoebae, diatoms and foraminifera (Birks 1995). Analysis of modern testate communities has shown that species representation is closely related to the depth of the water table (Charman & Warner 1992; Woodland *et al.* 1998; Bobrov *et al.* 1999). A transfer function is used to reconstruct this parameter based on the species composition of the fossil assemblage. Dan Charman, using a transfer function developed by Woodland *et al.* (1998), produced the water table reconstructions from Kilnagarnagh. The results are presented in Chapter 7.

Ordination techniques, typically detrended correspondence analysis (DCA), are commonly used to establish the link between species and environment (Birks 1995). DCA describes a pattern in the species-environment data that may be best explained as an ecological gradient. In the case of testate amoebae, this may be a hydrological gradient (ter Braak 1985). DCA is applied in order to reduce the complexity within a data set in order to elucidate the relationships between taxa and the environment. Where a data set is not particularly complex however, for instance where too few taxa are present, the application of DCA may be inappropriate.

DCA was undertaken on the testate data set from Kilnagarnagh but the results were unsatisfactory. The dominance of a small number of key taxa, the rare or sporadic occurrence of many others meant the hydrological gradient in the data set was already apparent and this could not be improved upon by the application of DCA. The removal of the rare taxa from the data set reduced the overall number of taxa submitted for analysis and negated the need for DCA.

5:5 MAPPING

5:5:1 Maps

The base map of the Lemanaghan area (Fig 3:2), including the Kilnargarnagh extract (Fig. 5:1) were derived by digitising and georeferencing the relevant parts of OS sheets 7 and 15 using ESRI® ARCGIS™ 8.2. All survey points were then added and thus located in relation to the Irish National Grid.

5:5:2 Peat stratigraphic cross-sections

Results of stratigraphic surveys are generally displayed in cross-section diagrams (Walker & Walker 1961; Casparie 1972; Hu & Davies 1995). These allow a 2-dimensional view of the major stratigraphic horizons and the most significant spatial formations within the mire. Representation of the results from Kilnagarnagh largely follows Casparie (1972) with adaptations to this system by the author. Other systems, such as Troels-Smith (1955), tend not to be applied in gross stratigraphic studies of this sort as they fail to "adequately express the variation in the boundaries between different strata or the variation in content" (Barber 1981, 57).

In this case there were two main stages to the production of the peat stratigraphic diagrams. Initially drawings were made by hand using drawing film and pencil. These drawings were used in designing the core sampling strategy. For final presentation digital images were produced. As a suitable stratigraphic drawing programme was not available the diagrams were created using Adobe Illustrator with peat stratigraphy symbols newly constructed. A stacked column graph was used for the basis of each diagram with a vertical exaggeration of x50. The x axis shows distance in metres while the y axis is in metres Ordnance Datum. The units within each column were derived from the depth of individual peat horizons. Each unit was then filled with the appropriate peat symbol. Stratigraphic horizons were linked using horizontal lines. These horizons were then filled with the appropriate symbols in order to produce a continous impression of the gross stratigraphy. The results are presented in Chapter 6, Figs 6:4-6:6.

Distribution maps of most significant peat horizons and formations were also generated using Adobe Illustrator. These allow visualisation of the various peat deposits in plan view and served as a precursor to the production of models of overall mire development utilising DEMs (see below). The distribution maps are presented in Chapter 6, Figs 6:7-6:13.

5:5:3 Creation of the Kilnagarnagh DEMs

Burrough (1986) defines a DEM as any digital representation of the variation in surface elevation. Similarly, Wheatley and Gillings (2002) define a DEM as a model of continuous variation over a land surface. The raw data required to generate surface models typically consist of point data comprising x, y and z co-ordinates where x and y equate to longitude/latitude or national grid references, easting and northing, and z refers to height OD (Ordnance Datum).

Two types of DEM that are most commonly used in landscape reconstruction are Triangular Irregular Network (TIN) and Raster models. TIN are produced by linking points to form triangles with elevation or z-values stored at nodes. This in effect produces a sheet of connected triangular faces which represent the modelled surface. TIN are typically used for high precision modelling of smaller areas and require high resolution source data. In addition they can have a rather angular appearance providing a 'chunkier' rather than a smooth, more natural image.

Raster DEM comprise a layer consisting of a grid or a regular array of cells of equal size in which each cell represents part of the land surface (Burrough 1986). Every cell has a value which equates to the elevation of the area on the ground represented by that cell. These values can be real or estimated. Estimated values are derived via interpolation, i.e., a missing value is estimated by taking an average of known values from neighbouring points (nearest neighbour). Interpolation allows a continuous curve to be drawn through all known data points; in this case the centre point of each cell is connected to its surrounding neighbours. In this way a surface can be generated.

In this thesis the objective is to create a series of surfaces which can provide as good a representation of the available data as possible. Complex modelling of a particular variable, such as hydrology or the distribution of particular plant species for example is not required. The type of model generated is also determined by the nature of the input data, which in this case (see below) is widely spaced rather than high resolution regularly spaced data. For these reasons Raster DEM were favoured over TIN.

A variety of spatial interpolation methods can be used to generate DEM. These fall into three main categories: linear interpolations which involve drawing straight lines through data points; cubic splines which involve drawing a curve through data points and lastly, statistical interpolation (Burrough & McDonnell 1998). In this thesis a general purpose interpolation method known as a spline was selected. Splines were chosen as they can be produced quickly, providing visually effective results while retaining small-scale variation (Wheatley & Gillings 2002). The creation of a smooth surface was also a factor in selection. Mire basin floors have smooth gently undulating surfaces and splines can reflect this quality better than the faceted surface derived from TIN. Spline interpolation generates a raster layer composed of identically sized cells. Conceptually, splines perform like a rubber sheet which is overlaid on a grid of points. The elevation of points comprising the grid is known and the rubber sheet is fitted to the elevation data. A mathematical function minimises overall surface curvature which results in a smooth surface that passes exactly through all the input points (*ibid.*).

ARCGIS provides two spline options: regularised and tension. These are used to control the nature of the spline surface. Regularised splines create a smooth gradually changing surface incorporating values that may lie outside the range of the sample data. The tension method follows the data points more closely thus reducing the likelihood of introducing further error such as sinks and peaks. The Kilnagarnagh models were generated using the tension spline method.

For the purposes of this research project a Leica GPS was used to gather the point data and the models were created using ESRI® ARCGIS™ 8.2 software. Kilnagarnagh is represented by regularly spaced data. This sample data was constrained by the limitations imposed on it by the peat stratigraphic survey. The survey area as defined by the Bord na Móna boundary measures approximately 8.4km sq. One hundred and twenty-one data points were collected along three longitudinal transects through the mire, i.e., along the same drains subject to peat stratigraphic survey (Fig. 5:1). The sampling interval was generally 50m although this was reduced in places with greater surface variability, e.g., where sub-peat mineral ridges were clearly present. Between transects, i.e., from east to west, the sampling interval was wider, between 180m-250m. To reduce this interval three transverse transects were made producing an additional seven data points. Transects were evenly distributed over the length of the mire, with one in the north, a second in the middle and a third across the mire's southern end. This reduced the east-west survey interval in places to 125m. This additional point data served to reduce the gaps over which the spline interpolation was made. However, the layout of the survey data means the density of data from north to south in the mire is higher than the density of data from east to west. As a result there is reduced level of detail and so a greater generalisation in the surface between transects, i.e., interpolation is required over larger gaps in the input data which may affect the accuracy of the interpolated surface.

The sample data was manipulated using ESRI® ARCGIS™ 8.2 software. DEMs of the basin floor, the top of the fen, a highly humified *Sphagnum* surface, a poorly humified *Sphagnum* surface and the modern mire surface were produced via spline interpolation (see Appendix 3). ESRI®ArcScene 8.2 software was then used to produce draped DEMs with a vertical exaggeration factor of 10 applied to each surface. The results are presented in Chapter 8, Figs 8:1-8:8.

CHAPTER 6

SURVEY RESULTS

6:1 INTRODUCTION

This chapter begins by describing the results of the archaeological field survey. The details of the gross peat stratigraphic survey are then presented. The chapter concludes with a brief description of a survey of the peat faces fringing Curraghalassa bog which lies at the southern end of the Lemanaghan system (Fig. 3:2).

6:2 THE ARCHAEOLOGICAL SURVEY OF KILNAGARNAGH BOG

The first archaeological field survey of Kilnagarnagh bog, undertaken in 1996, identified 18 new archaeological sites (IAWU 1997b). In 2001, all of the sites were re-located. The archaeological survey then focused on one site, an oak plank walkway which traversed the southern end of the bog. In 2003, during the course of fieldwork associated with this research, a new structure was discovered bringing the number of archaeological sites known in the bog to nineteen. All but the latter lie in the southern end of the bog, in close proximity to the modern road (Fig. 5:1).

The results of the archaeological survey are described in four parts. The first part details sites exposed on the bog surface, the second and third sections describe a plank walkway and associated flanking deposits of wood, and the fourth details a new structure identified in 2003.

6:2:1 Archaeological exposures on the bog surface

Of the sites identified in 1996, six lay close to or on the field surface, and of these four consisted of either single or a few pieces of brushwood while the remaining two were more substantial. Classified as toghers (see Table 3:2), these two sites each measure around 30m in length and between 0.70m-1.70m in width. They are of light construction, consisting of no more than five pieces of brushwood or heavier roundwoods at each exposure. At each sighting the pieces were parallel and all lay horizontally. The sites share a NE-SW orientation and lie 6.3m apart. Neither has been dated but given their position at the top of the mire they are likely to be relatively recent in date, most likely within the last 100 years given that the wood was not waterlogged but was well preserved.

6:2:2 A wooden walkway

Running across the southern end of the bog is an oak, plank-built walkway (Fig. 5:1) which has been dated to 1509±9BC or later (Q9291). The description presented here is based on a combination of the 2001 re-survey of the site and the IAWU survey first made in 1996 (IAWU 2001). Oriented ENE-WSW the site is primarily composed of longitudinal, oak planks laid end to end and secured in place using pegs set in mortises cut into the ends of the planks (Fig. 6:1). At some sightings the site consists of two parallel planks or a plank with some roundwood or brushwood also present. The additional sightings in 2001 consisted of roundwoods and smaller split timbers rather than oak planks. There was no evidence for the use of transverse timbers either as substructural or superstructural components. The site ranged in width from 0.12m to *c.*0.68m.

Fig. 6:1 View of trackway from west in Drain 1 at survey point 1:01 (photo: IAWU 1996).

When first identified in 1996 site length was recorded as 337.50m (IAWU 2001). Re-survey in 2001 increased site length to 445m, extending the site at its eastern end. This may not however be the full length of the site as the absence of drains and the presence of a large water-filled sump, which lies to the east on the line of the site, prevented further investigation at the time of the survey. The 2001 survey identified the trackway's western landfall lying among trees situated on a sub-peat ridge (Fig. 6:2). Landfall was not identified in the east; the site was present in the last open drain but could not be traced beyond this point.

The drains in place in Kilnagarnagh offer access to the site every 15m. Despite their presence the site was not located in a number of drains in the east suggesting the possibility of gaps in site construction. The first gap is 32m, and is followed by two breaks, each around 46m long, with a fourth extending for *c.*32m (Fig. 6:2). These absences do not appear to be a product of the survey as each drain was investigated, by probing and cleaning the drain base and faces carefully. The drains, which are only *c.*1.5m in width, may cut through parts of the site where it was less substantial and therefore removed when the drains were cut. Alternatively the gaps may reflect real breaks in the site that originated in antiquity.

Three detailed records of the gross peat stratigraphy in which the site was situated were made; two at locations where whole core samples were taken - K101 close to the site's mid -point and K301 at the easternmost sighting of the trackway. The third record was made at the westernmost sighting (Fig. 5:1). At K101 and K301 the site lay within relatively homogeneous poorly humified *Sphagnum* peat (Unit H, see Section 6:3:7) with some *Eriophorum* and *Calluna*; an *Eriophorum* tussock underlay a plank at K101. Drain face stratigraphy at K101 showed the trackway to have been constructed across a hummock-hollow complex (Unit H2) (see Section 6:3:9). In the east, the site lay deeper in the peat and was more difficult to relate to spatial features in the mire although the hummock-hollow complex was visible in the drain face stratigraphy above the site. In the west the trackway lay close to the field surface in wood peat (Unit E2) (see Section 6:3:6). Around 130cm of peat had developed over a ridge in the mineral substrate on top of which *Pinus* sp. had grown; the remains of more than ten tree stumps and associated root systems were visible.

It is suggested above the trackway ran across a hummock-hollow complex. That the surface on which the trackway was laid was irregular is perhaps supported by the undulating profile of the trackway as shown in Fig. 6:2. Shorter profiles from other trackways, such as sites excavated in Mountdillon, Co. Longford (Raftery 1990), reflect the uneven nature of the bog surface on which trackways were constructed. In

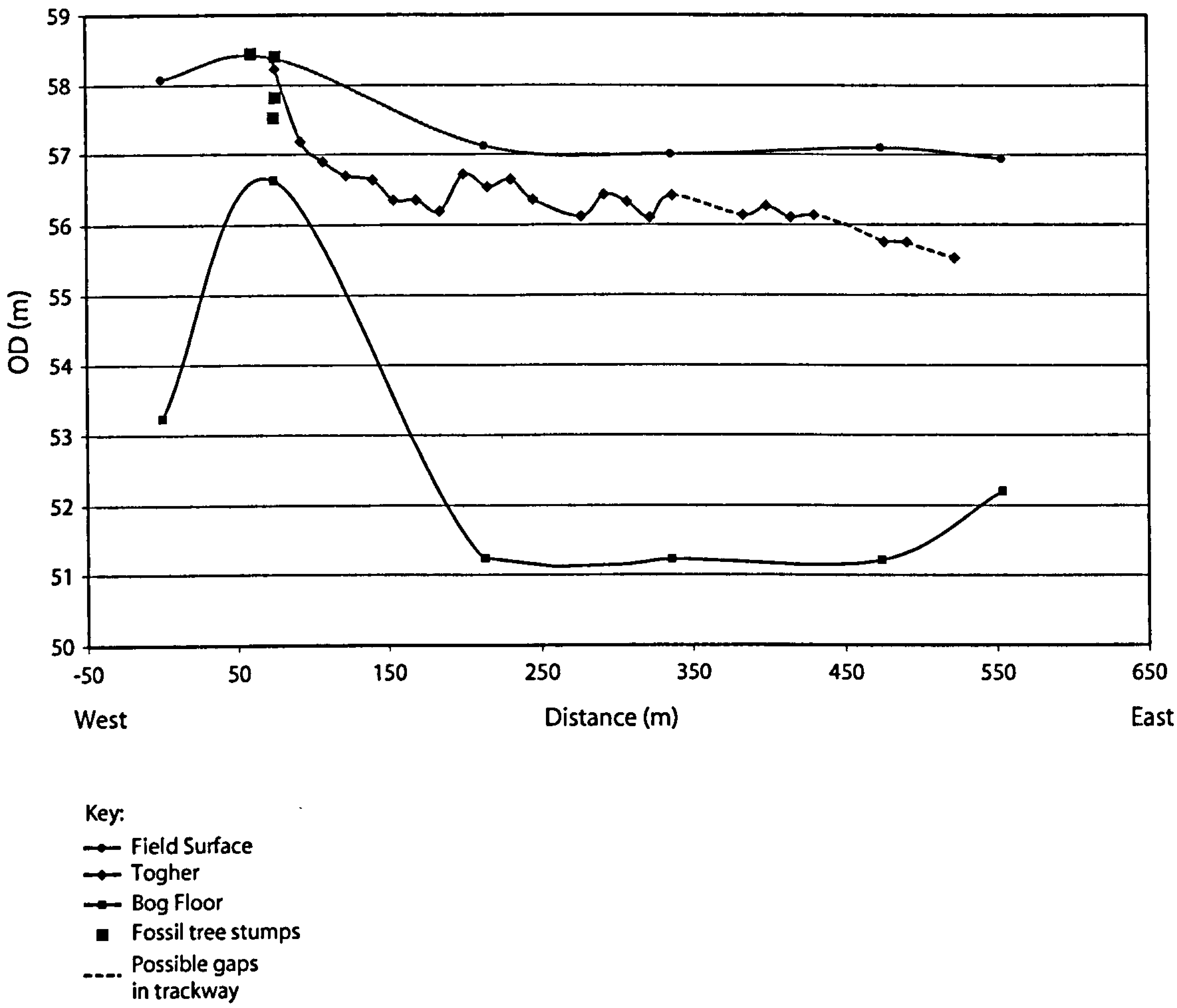


Fig. 6:2 West-East cross-section of southern end of mire showing trackway in profile.

several bogs, trackway builders frequently attempted to create a level surface by infilling hollows and pools with wood before the walking surface was laid, e.g. the Abbot's Way, Somerset, England (Coles & Orme 1976); Corlea 1, Co. Longford, Ireland (Raftery 1996); Lengener Moor XV (Le), Lower Saxony, Germany (Casparie & Moloney 1994).

At Kilnagarnagh, with the exception of the western end over the ridge, the trackway profile contrasts markedly with the shape of the basin floor and the mire surface. It has been suggested that the latter probably mimics the basal geometry because of compression related to extensive drainage (see Section 6:3:1). Compression may have had an effect on the profile of the trackway. Spatial features such as hummock and hollows were identified in Kilnagarnagh on morphological grounds, i.e., convex hummocks and concave hollows were clearly visible in the drain face (se Section 6:3:9). The softer hollow peats may have shrunk more than the firmer hummock peat causing exaggeration of the hollow profiles. Nonetheless, despite compression of the overall peat deposit, an indication of the topography of the earlier mire surface is preserved. Thus it seems likely that the trackway profile reflects the shape of the bog surface at the time of site construction.

6:2:3 'Flanking' deposits

Nine deposits of worked and un-worked wood, consisting of one to three pieces of brushwood without any particular arrangement or design, were also identified. Tree species represented include *Fraxinus excelsior*, *Corylus* sp., *Alnus glutinosa*, *Ilex* sp., *Salix* sp., *Quercus* sp. and *Betula* sp. (IAWU 2001). These deposits flank the Bronze Age walkway, lying between 10m-88m from the trackway (Fig. 5:1). A further two deposits, both of single planks, lie somewhat closer to the walkway, between 3.5m-5.5m distant.

6:2:4 A new site

The sites described above occupy a narrow strip across the southern end of the bog. Prior to 2003 these sites represented the only archaeological evidence from Kilnagarnagh bog. In July 2003 a new oak-plank structure was identified in privately cut bog fringing the main body of the bog in the north (NGR: 214797 231102) (Fig. 5:1). In this area the peat faces are up to 3m deep; at the location of the site the peat face is *c.*2.20m deep. This could not be accessed directly owing to flooding at the base of the peat face and because of the depth of overlying peat, *c.*1.5m. There were no other archaeological features visible in the vicinity.

The site has been classified as a togher or trackway based on its composition and similarity to other plank-built trackways known from Irish bogs (Raftery 1996). Composed of *c.*5 parallel, horizontal, cleft oak timbers, some roundwoods, and one peg, it is *c.*2m wide, *c.*0.5m deep and runs back into the peat face at an angle of *c.*45º (Fig. 6:3). An IAWU follow-up visit in December 2003 identified timbers on a lower opposing bank as *in situ*, thus implying a NW-SE orientation and a known length of *c.*3m (Moore & Stanley 2003). A level OD was not obtained. The site lies about 56m south of a 60m contour to which the bog used to extend; reclamation and peat cutting have removed peat between the site and the lower slopes of the esker forming this contour. The absence of OD data prevents estimating the location of its northern landfall. The site is undated but metal tool marks identified on some loose timbers suggest a date range from the Bronze Age to the medieval period (*ibid.*). The structure is situated in ombrotrophic peats. It is overlain by *c.*1.5m of poorly humified *Sphagnum* peat and sits at the interface between two major peat horizons: poorly humified *Sphagnum* (Unit H, see Section 6:3:9) and highly humified *Sphagnum* (Unit F, see Section 6:3:7).

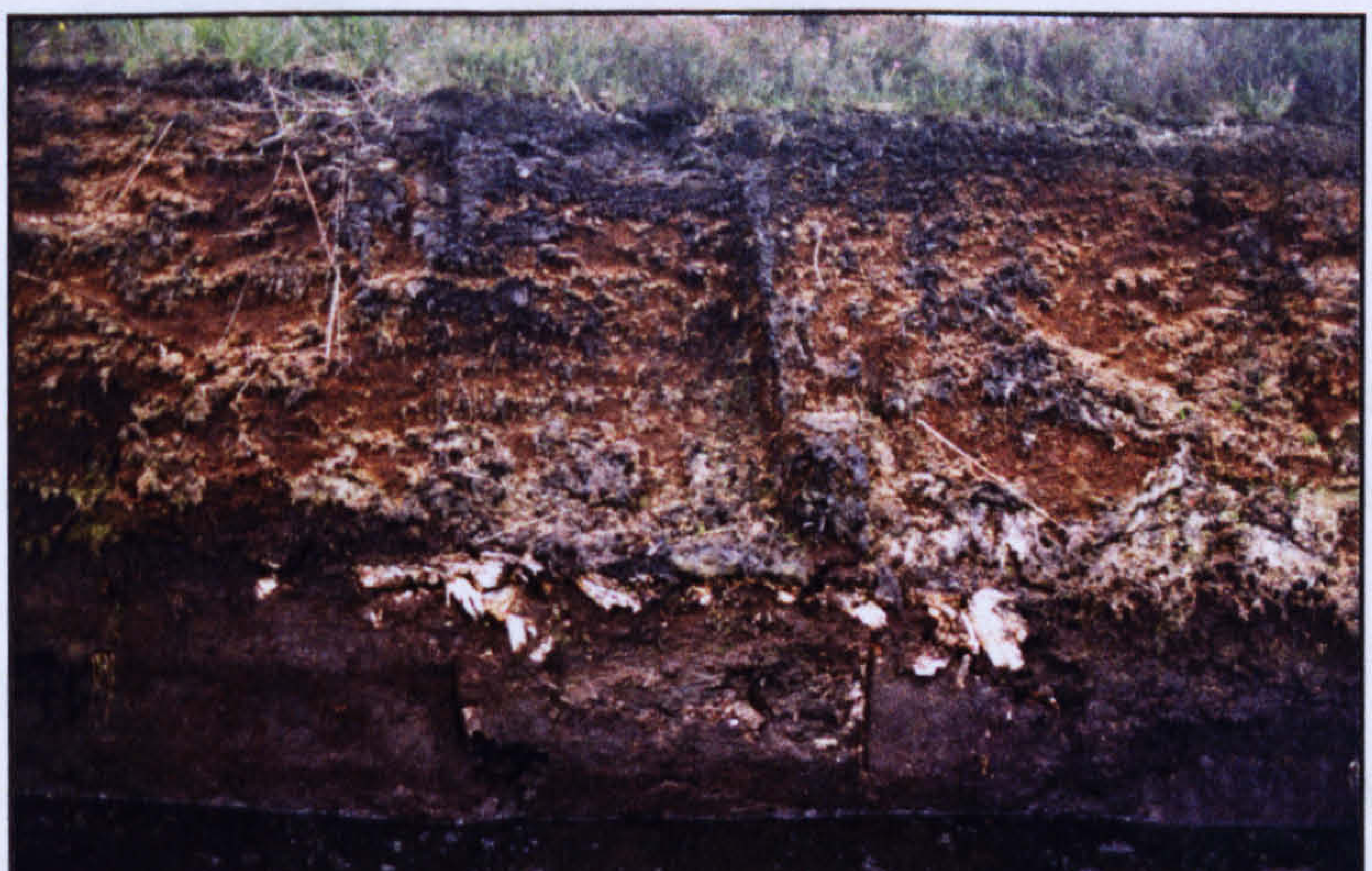


Fig. 6:3 View from north of trackway discovered in Cooldorragh townland in AD2003. The trackway is *c.*2m in width and the peat face is *c.*2.20m high.

6:3 GROSS PEAT STRATIGRAPHY

6:3:1 Introduction

The gross stratigraphic record from Kilnagarnagh derives from a combination of drain face and coring records made in 2001 and 2002. Table 6:1 details the number and type of stratigraphic records made. Each stratigraphic survey point is described in Appendix 2. Individual records have been combined here to present a mire-wide description of the most significant peat-forming environments (Figs 6:4-6:6). This description was supplemented with records made during the initial walkover surveys and general observations made over the course of two field seasons. Eleven depositional environments, referred to here as Units and labelled A-K, were identified. These are composed of a variety of sediment types defined below. More than one of type of sediment can occur within each of the forming environments identified.

Number of stratigraphic records	
86 drain face stratigraphic records	
62 cores into deep stratigraphy	49 longitudinal transect cores
	9 transverse cores
	4 sampling sites – 2 long & 2 short cores

Table 6:1 The number and type of stratigraphic records made in Kilnagarnagh bog.

Definition of sediment units

The text in brackets refers to the individual depositional environments.

Mineral substrate (Unit A)

Glacio-lacustrine deposit in the form of homogenous, sticky blue to blue-grey clay. In places, the mineral substrate consists of bands of laminated clay and fine-grained sand.

Intermediate deposits (Unit B)

Lying between the mineral substrate and the basal peat. This deposit was either organic silt (Unit B1), or a calcareous marl deposit (Unit B2).

Sedge peat (Unit C)

Sedge peat is distinguished by the presence of Cyperaceae rhizomes, most probably of *Carex*. They are less than 10mm in width, flattened and yellow-brown in colour. Sedge-rich peats can be either yellow-brown or yellow-black; oxidation tends to take

PAGE

NUMBERING

AS ORIGINAL

FIG. 6:4

DRAIN 1

KILNAGARNAGH, CO. OFFALY

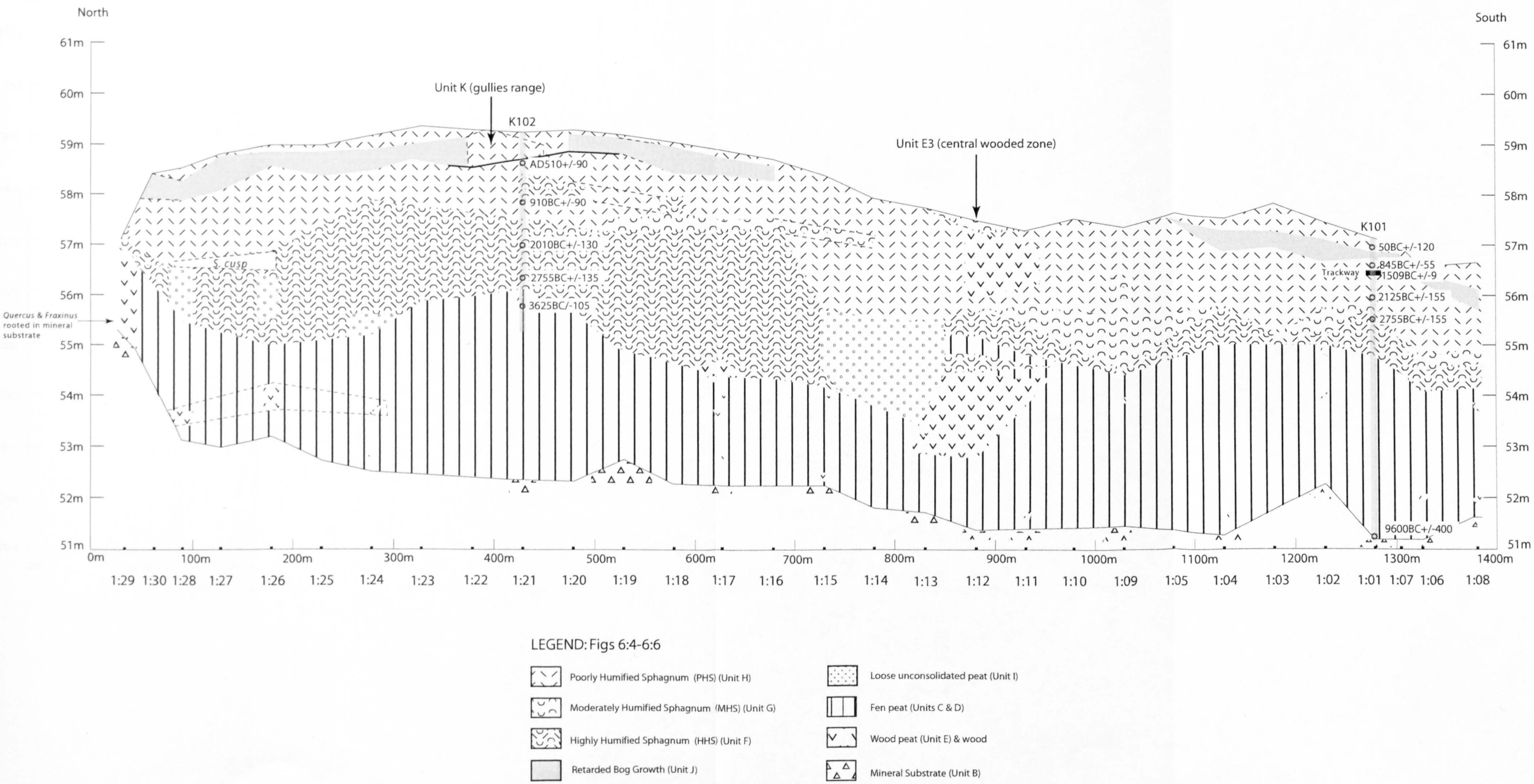


FIG. 6:5
DRAIN 2
KILNAGARNAGH, CO. OFFALY

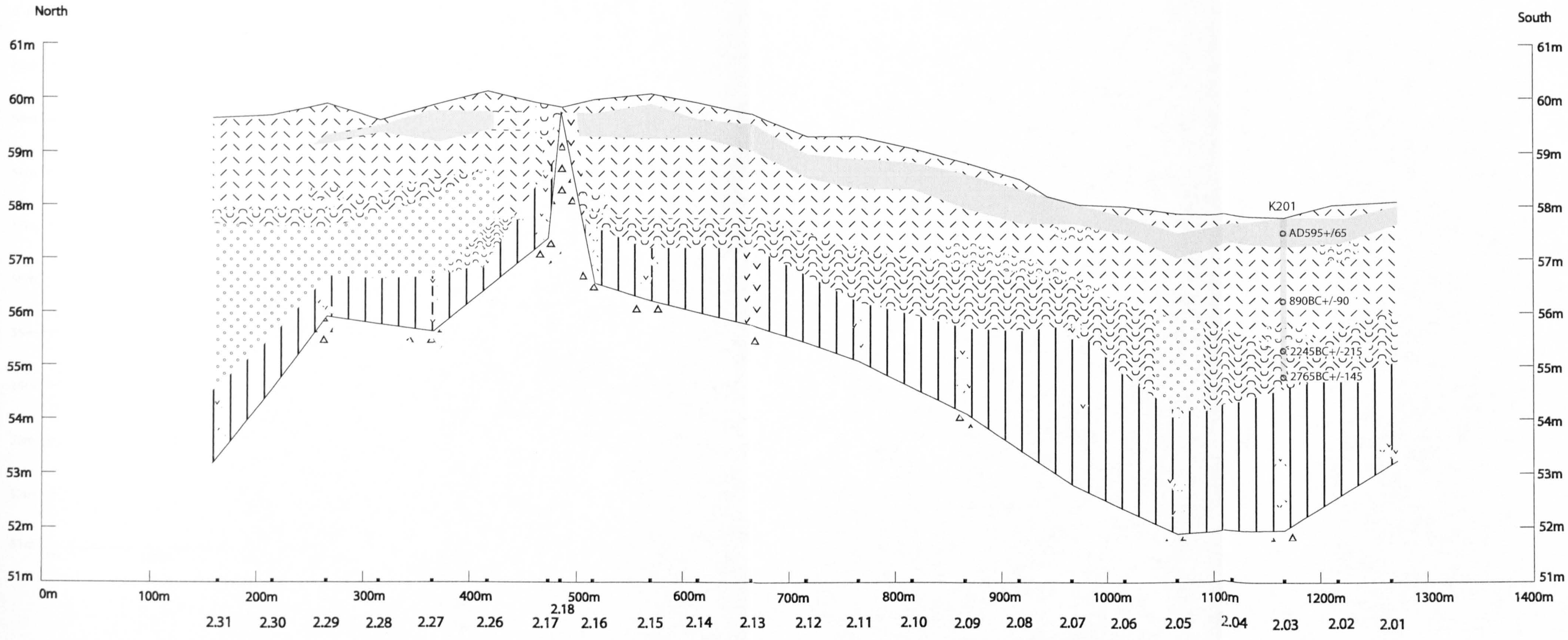
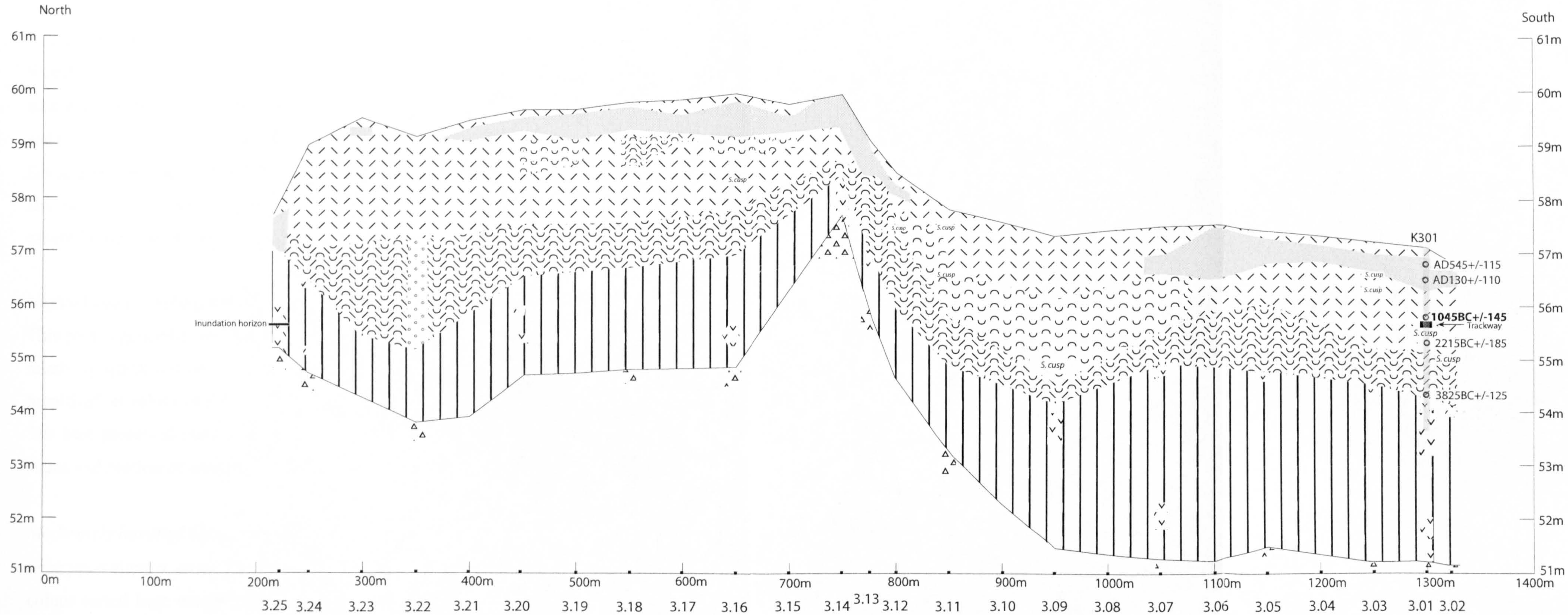


FIG. 6:6

DRAIN 3

KILNAGARNAGH, CO. OFFALY



place rapidly. The remains of *Phragmites* reed, wood and the orange, flat, circular seeds of bog bean (*Menyanthes trifoliata*) also occur within sedge-dominated peat.

Reed peat (Unit C)

Reed peat is characterised by the presence of *Phragmites australis* rhizomes that survive as flattened, yellow-brown strips *c*.20-40mm in width. When dry these strips appear papery. The peat matrix is generally well decomposed and oxidise rapidly from yellow to yellow-black. The remains of sedge, wood and *Menyanthes trifoliata* can occur within reed peat.

Wood peat (Unit E)

Wood rich peat or wood peat is generally characterised by fragments of roots, twigs bark and leaves within a dark, friable organic matrix. In places the remains of trunks and root systems survive sometimes rooted in the mineral substrate. Sedge, reed, moss, Ericales and monocotyledon remains can also occur within wood rich peat. Wood can also occur within other peat types. Wood was not identified to species in the field except in the case of *Pinus* sp., *Quercus* sp., *Fraxinus excelsior* and *Alnus/Betula* sp.

Highly humified Sphagnum *(Unit F)*

This peat is generally unstructured, red-brown to brown in colour, undergoing rapid to relatively quick oxidation upon exposure. Where the sediment corresponded with humification values of H7-H9 it was recorded as highly humified *Sphagnum* (HHS). The best preserved plant remains within this peat were *Eriophorum vaginatum*, the stems and rootlets of ericoids and wood remains.

Moderately humified Sphagnum *(Unit G)*

Sphagnum clumps, stems and leaves were visible providing this peat with structure. Its colour varied from orange to dark brown and in general oxidisation occurred rapidly. Moderately humified *Sphagnum* measured from H4-H6 on the von Post scale. Other plant components, such as *Eriophorum vaginatum*, *Sphagnum cuspidatum* and ericoid remains were also present.

Fresh to Poorly humified Sphagnum *(Unit H)*

The remains of *Sphagnum* plants are very well preserved retaining both structure and composition. Humification values range from H1-H3. Its colour can vary; in deeper deposits, it has a rich orange colour and is slow to oxidise. It is visible in hummocks and in lawns. As with the other *Sphagnum* peat types the remains of *S. cuspidatum*, *Eriophorum*, *Calluna* and wood remains can be present.

Sphagnum cuspidatum

Distinguished in the field by its bright yellow appearance, its humification is generally low though higher values are also present. *S. cuspidatum* can occur with an amorphous, greasy, algal mud that is yellow to green in colour.

6:3:2 Unit A: The mineral substrate

Of the 62 cores made into deep stratigraphy, 46 revealed a clearly defined mineral substrate-peat interface. Thirteen cores lacked information either because coring was obstructed, generally by wood, or because sediment was not retained in the auger chamber. Occasionally where the underlying deposits were softer up to 50cm of mineral deposits were recovered, normally *c.*10cm was retrieved.

The basal deposit consists of sticky, plastic blue to blue-grey clay. For example, at survey point 1:9, *c.*50cm of homogenous plastic blue clay was recorded. In other places laminated clay and sand bands are present, e.g., at survey points 1:8, 1:13, 3:22 and 3:25.

The interface between the mineral substrate and the overlying peat deposits is clearly defined. The transition is generally sharp with peat lying directly on the mineral substrate. In a number of locations, an intermediate horizon is present between the peat and the sticky blue clay. This is described in Unit B.

The stratigraphic survey revealed that the basin morphology is not simple. Ridges in the mineral substrate occupied the eastern and western flanks of the basin though they did not appear to extend as far as the centre of the basin. The ridges varied in height and in extent (Figs 6:4-6:6). The basin floor along Drain 1 has a number of gentle ridges of a lesser magnitude than those identified elsewhere which do not rise above 53m OD (Fig. 6:4). It is possible that such small-scale variation exists elsewhere in the basin but this would require a high-resolution basin contour survey. When compared with the magnitude of other ridges these features are unlikely to have influenced mire ontogeny to the same extent. In contrast, the presence of more prominent ridges is evident in the undulating surface topography of the mire. Recent drainage had resulted in compaction of the peat deposit with the result that the mire surface mirrored the wider topographic variation of the basin floor. In Drain 2, there is a ridge just below the mire surface at *c.*60m OD. A drain cuts through the top of this ridge exposing it in profile (Fig. 6:5). To the east of Drain 2, two further ridges drop off towards the mire centre. The plank trackway described above ran off the edge of the ridge east of survey points 2:01 and 2:02 (Fig. 6:2). Survey points 2:09 and 2:10 lie just to the west of a second ridge. Its presence can be discerned for *c.*35m into the mire before it falls away. A ridge in Drain 3 (Fig. 6:6), between 700-800m lying at *c.*58m OD defines the northern limit of the lower part of the basin on its eastern flank.

The basin floor dips from northwest to southeast (Figs 6:4-6:6). It falls from approximately 53m OD (taken from the base of slope of the northern basin edge) to 51.2m OD at 1300m, a distance of over 1200m (Fig. 6:4). This provides a gentle gradient with the basin floor dipping 1.5mm every 1m or 1.8m over 1200m. On the eastern and western flanks of the basin greater changes in elevation occur. The profile from Drain 2 (Fig. 6:5) shows that from *c.*250m to 520m (excluding the apex of the ridge at 500m) the basin floor lies between 55.5m OD and 56.5m OD. It then drops to *c.*52m OD around 1100m, which equates to a drop of 7.8mm every 1m, more than 5 times the fall off in the mire centre. In Drain 3 (Fig. 6:6) north of the ridge at *c.*750m, the basin floor lies between 53.8m OD and 55m OD. South of the ridge, it falls from 55m OD to *c.*51.2m OD (the same OD as the centre of the basin) over *c.*150m (32mm every 1m) lying at this level OD for another 350m.

6:3:3 Unit B: intermediate deposit

In several places, an intermediate deposit marked the transition from clay to peat. This deposit was either an organic-rich sediment (but not peat) (B1, Table 6:2), or a calcareous deposit (B2, Table 6:3). Its upper and lower boundaries were generally very distinct.

Sub-unit B1 is distributed across the middle of the basin floor, in the northeast corner and in the south eastern end of the basin (Fig. 6:7). It comprises either an organic silt or mud and ranges in thickness from *c.*1cm-5cm.

At four locations (Fig. 6:7, Table 6:3), sub-unit B2, a calcareous deposit underlies the basal peat in some of the lowest points in the basin. This Unit is interpreted as lake-marl (see Section 8:3:3)

Location	Description	OD
1:06	Mud base	51.19m
1:11	Light brown mix of fen peat and clay, *c.*5cm thick	51.40m
1:15	Organic silt, *c.*2cm thick, sharp boundary	52.25m
1:17	Dark grey organic clay "old surface', *c.*3cm thick	52.24m
1:19	Organic grey-yellow silt, *c.*2cm thick	52.76m
2:13	Organic silt	55.76m
2:17	Organic silt	57.36m
2:26	Organic silt	56.45m
3:50	Organic mud over sticky blue clay	-
3:05	Organic silt with plant fibres	51.49m
3:14	Yellow sticky clay with organic inclusions	57.70m
3:22	Organic silt, *c.*2cm over sticky blue clay	53.77m
3:24	Organic mud, *c.*5cm thick	54.70m
3:25	Slight organic top, *c.*1cm thick, to mineral soil	55.16m

Table 6:2 Transect locations where an intermediate horizon, B1, was identified.

Location	Description	OD
1:13	Smooth, yellow marl, 11cm thick overlying sand	51.73m
1:19	Marl, 22cm overlying fine sand	52.76m
Trans 1:2	Marl, 22cm overlying sand	51.23m
3:51	Marl, 30cm Killaghintober bog	-

Table 6:3 Locations where calcareous deposit, B2, was identified.

6:3:4 Unit C: Basal peat

The objective in surveying the basal peats was to identify the peat-mineral substrate interface and the character of the junction with the overlying peat deposits. Less attention has been given to the interrogation of the basal records in comparison with ombrotrophic levels as the former concern a system dependent on ground water rather then precipitation and offer less potential for broader environmental reconstruction (Streefkerk & Casparie 1989). In addition, identification of well-defined spatial features based on coring data alone can be difficult, though examples where this was possible are included below. Instead, the basal peat record serves to show the heterogeneity of the peat forming system itself and hints at the range of vegetation communities that combined to form a variable mire landscape over the course of its development. The basal peats are treated here as a single formation unit, but one in which there is internal variation.

This is a complex unit representing the lowermost peat deposit in the mire. It was identified in all transects and its distribution is mire wide with the exception of areas of very high ground, e.g., ridge apexes Drains 2 and 3, and northern slope of the basin, Drain 1. This unit was thickest along the central transect, Drain 1 (Table 6:4) reaching its greatest thickness in the southern end of the basin (Fig. 6:4). It was shallowest in Drain 2 (Fig. 6:5) which lies close to the western edge of the mire, nearer the upland on higher ground (Bottom 51.90m-59.72m OD, Top of basal peats 53.98m-58.73m OD).

Transect	No. of cores	Thickness of deposit	Mean thickness	Transect length
Drain 1	16	380cm-187cm	270cm	1333m
Drain 2	14	44cm-285cm	147cm	1228m
Drain 3	51	92cm-365cm	214cm	1172m

Table 6:4 Unit C: Basal peat deposits

This unit is primarily represented by well decomposed sedge-dominated peat. Other elements or potential sub-units include horizons of sedge and reed peat, reed peat, and peat lacking in obvious macrofossils. Both reed and wood are also present as random fragments within the overall peat matrix. Boundaries between sub-units were also variable, ranging from distinct (e.g., from wood rich peat to sedge or reed peat) to peat types grading progressively into one another (e.g., between sedge peat and reed peat). The distribution of these sub-units and the density in which they occur is highly variable across the mire, making them difficult to display graphically. It also hinders identification of related horizons within Unit C. For this reason, the description has not been divided into sub-units and only the very dense wood-rich horizons have been depicted (Figs 6:5 & 6:8).

The heterogeneous nature of Unit C includes differences in colour and compaction. Peat with high reed content tends to be yellow, while sedge-rich peats can be either yellow-brown or yellow-black. Thin black layers (≤5mm), frequently associated with reed levels occur within otherwise yellow-brown matrices. Sedge rich peat can be very compact but it is also present as a soft, loose and friable deposit. In general, oxidisation of newly exposed peat occurs rapidly, with yellow peats changing to black within seconds. Where the peat is already dark (reflecting earlier oxidation) further oxidation is slow.

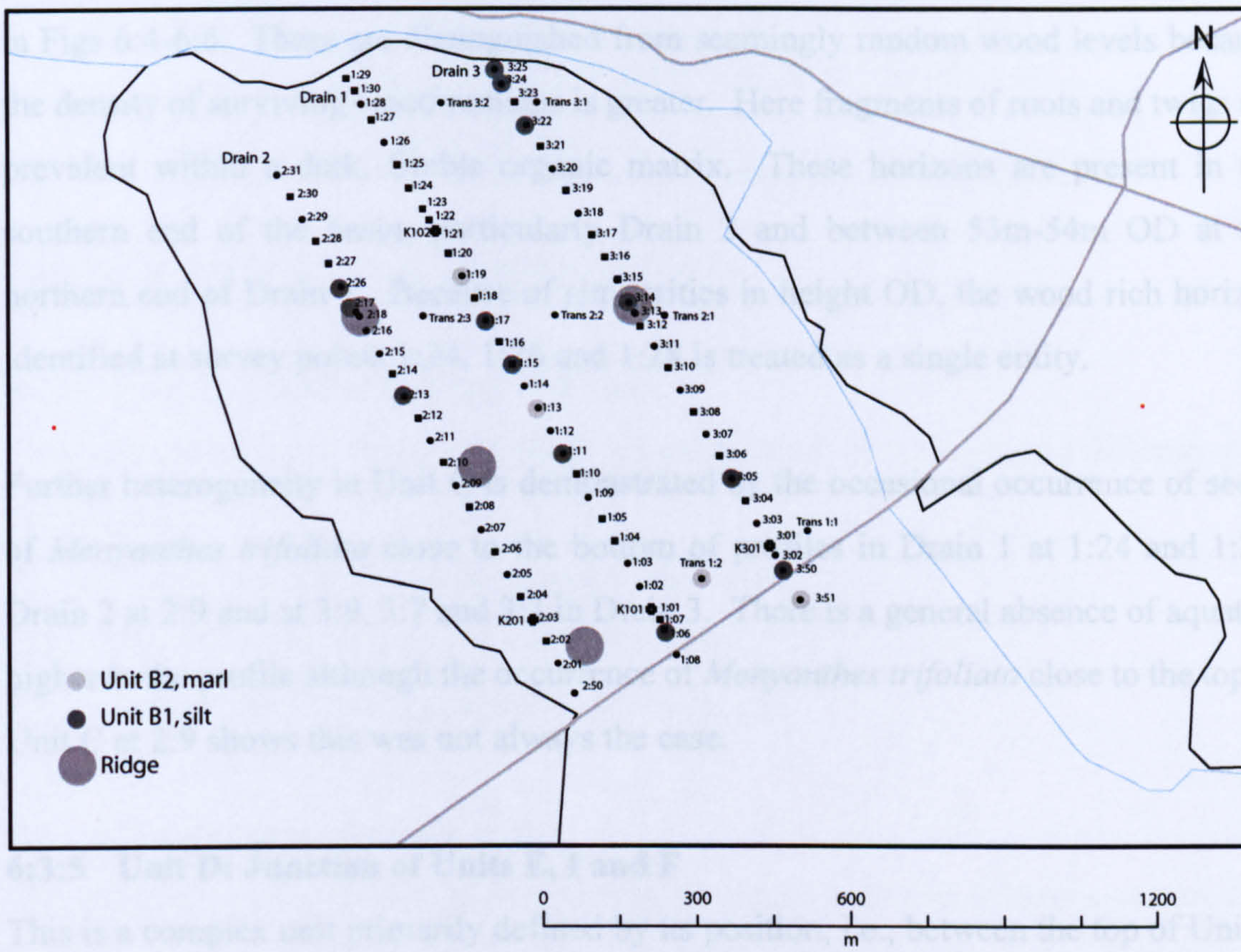


Fig. 6:7 Distribution of Units B1 & B2, Kilnagarnagh Bog, Lemanaghan, Co. Offaly.

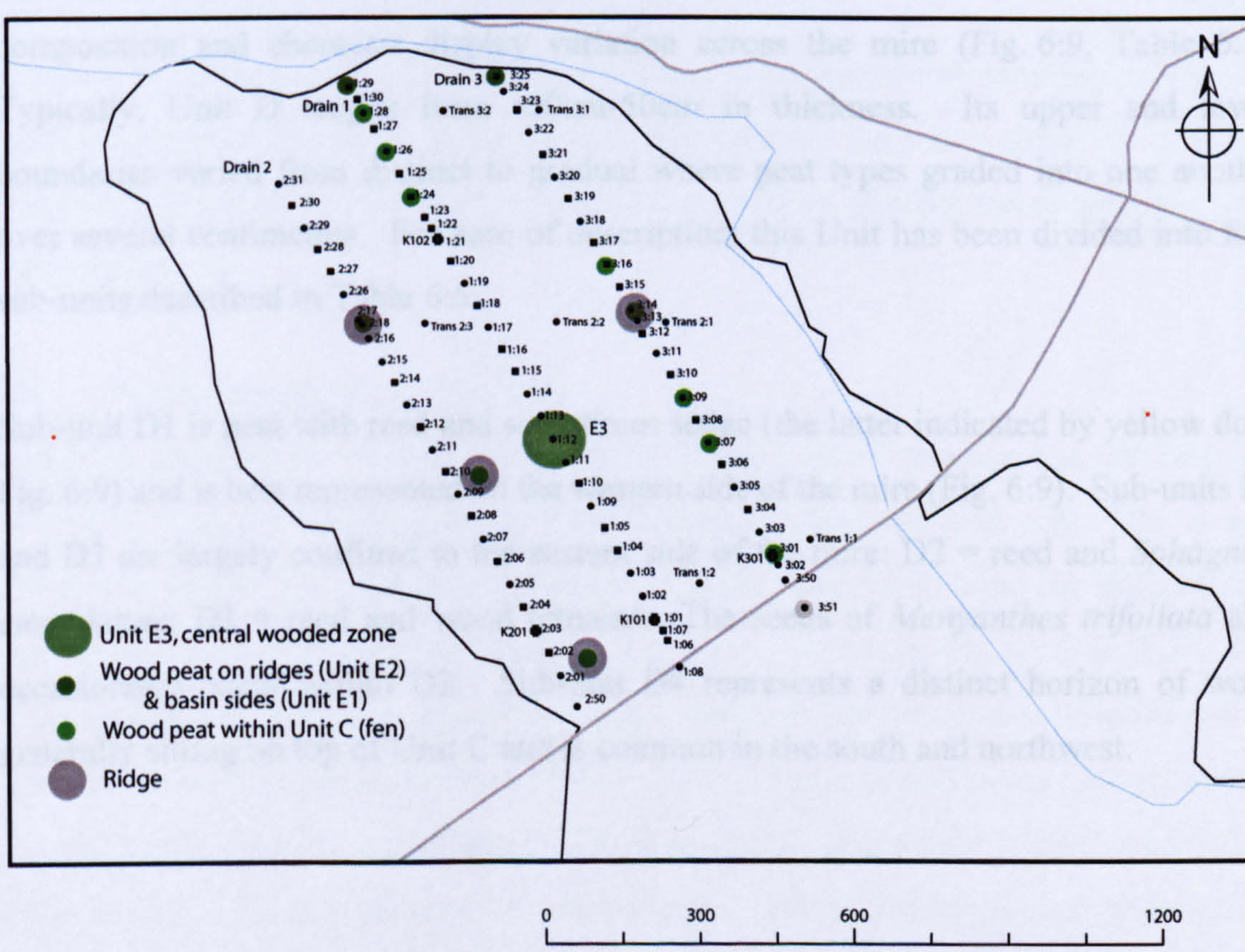


Fig. 6:8 Distribution of wood peat (Units C & E), Kilnagarnagh Bog, Lemanaghan, Co. Offaly.

Lying within or on top of Unit C are horizons of wood rich peat which are distinguished in Figs 6:4-6:6. These are distinguished from seemingly random wood levels because the density of surviving wood remains is greater. Here fragments of roots and twigs are prevalent within a dark, friable organic matrix. These horizons are present in the southern end of the basin, particularly Drain 3 and between 53m-54m OD at the northern end of Drain 1. Because of similarities in height OD, the wood rich horizon identified at survey points 1:24, 1:26 and 1:28 is treated as a single entity.

Further heterogeneity in Unit C is demonstrated by the occasional occurrence of seeds of *Menyanthes trifoliata* close to the bottom of profiles in Drain 1 at 1:24 and 1:28; Drain 2 at 2:9 and at 3:9, 3:7 and 3:3 in Drain 3. There is a general absence of aquatics higher in the profile although the occurrence of *Menyanthes trifoliata* close to the top of Unit C at 2:9 shows this was not always the case.

6:3:5 Unit D: Junction of Units E, I and F

This is a complex unit primarily defined by its position, i.e., between the top of Unit C (basal peat) and the bottom of Units F and I, and was recognised in 38 of the 45 cores made into deep strata. Gaps in the sediment sequence at seven survey points meant its identification here was problematic. Unit D is found mire wide although its composition and character display variation across the mire (Fig. 6:9, Table 6:5). Typically, Unit D ranges from <10cm-50cm in thickness. Its upper and lower boundaries varied from distinct to gradual where peat types graded into one another over several centimetres. For ease of description, this Unit has been divided into four sub-units described in Table 6:5.

Sub-unit D1 is peat with reed and sometimes sedge (the latter indicated by yellow dots, Fig. 6:9) and is best represented on the western side of the mire (Fig. 6:9). Sub-units D2 and D3 are largely confined to the eastern side of the mire: D2 = reed and *Sphagnum cuspidatum*; D3 = reed and wood remains. The seeds of *Menyanthes trifoliata* also occasionally occur within D2. Sub-unit D4 represents a distinct horizon of wood generally sitting on top of Unit C and is common in the south and northwest.

Sub-unit	Description
D1	Well decomposed organic matrix with minor reed and/or sedge
D2	Reed and pool peat
D3	Reed peat with wood
D4	Natural wood horizon (i.e., non-archaeological wood)

Table 6:5 Description of sediment sub-units within Unit D.

6:3:6 Unit E: Wood peat/wood rich peat

This unit can be sub-divided into three sub-units based on location and differences in composition:

E1. Wood peat situated on the slopes of the basin.

E2. Wood peat occupying the mineral ridges.

E3. Wood peat located in the centre of the system.

E1. Wood peat on slopes (Fig. 6:8)

The northern slopes of the mire basin at survey points 1:29 and 3:30 was occupied by wood peat. At 1:29 the *c.*120cm deposit was exposed in a perimeter drain. Here the peat was black, friable and dominated by detritus including fragments of bark, leaves, roots and twigs. This overlay remains of trees that were rooted in the mineral substrate.

At survey point 3:25 a wood rich horizon *c.*26cm in thickness with noticeable sedge and reed components lies close to the base of the peat on the rising slope of the basin. Within this horizon at 55.47m OD a thin horizon, *c.*1cm, of white minerogenic in-wash was visible.

E2. Wood peat on ridges (Fig. 6:8)

Ridges in the mineral substrate identified in Drains 2 and 3 and near the southern end of Drain 2 were covered by between 80cm-120cm of wood peat (Fig. 6:8). The remains of tree trunks and root systems were exposed in the drain faces or on the field surface. On the slopes of the ridge in Drain 2 (between survey points 2:13 to 2:17, Fig. 6:5), fragments of leaves, twigs and wood are abundant and the amount of wood present increases steadily towards the apex of the ridge. The peat is high in reed remains and is yellow, rather than black, in colour. The wood peat lying on the upper slopes of the ridge in Drain 3 is similar (Fig. 6:6) but contains *Sphagnum cuspidatum* and *Calluna* levels. Close to the southern end of Drain 2 the wood peat is black, friable, dominated by bark, twig and leaf fragments but lacking in reed or sedge.

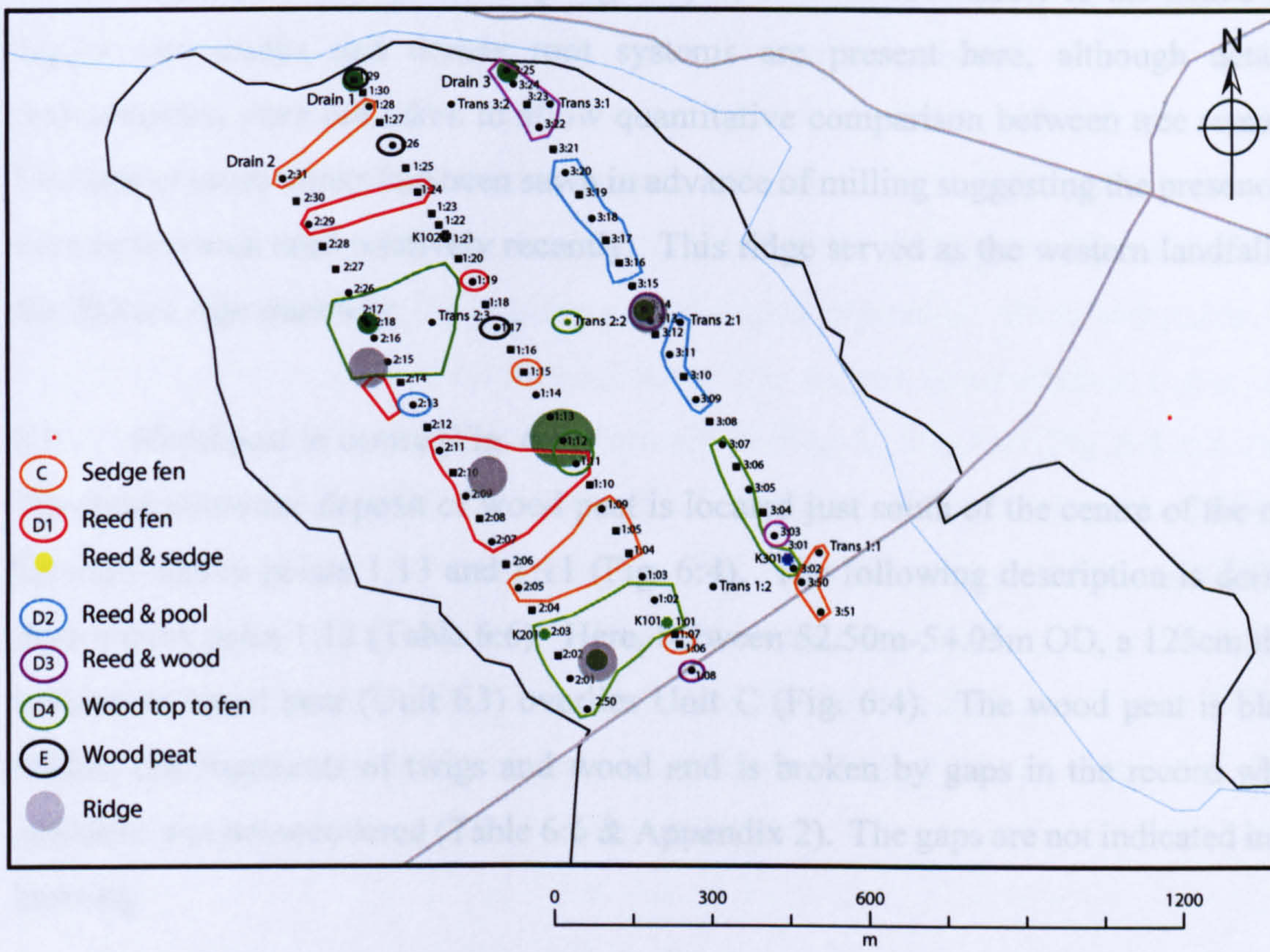


Fig. 6:9 Distribution of sub-units D1-D4 that comprise the Fen-Bog Transition inclusive of Units C & E (Fig. 6:8). Kilnagarnagh Bog, Lemanaghan, Co. Offaly.

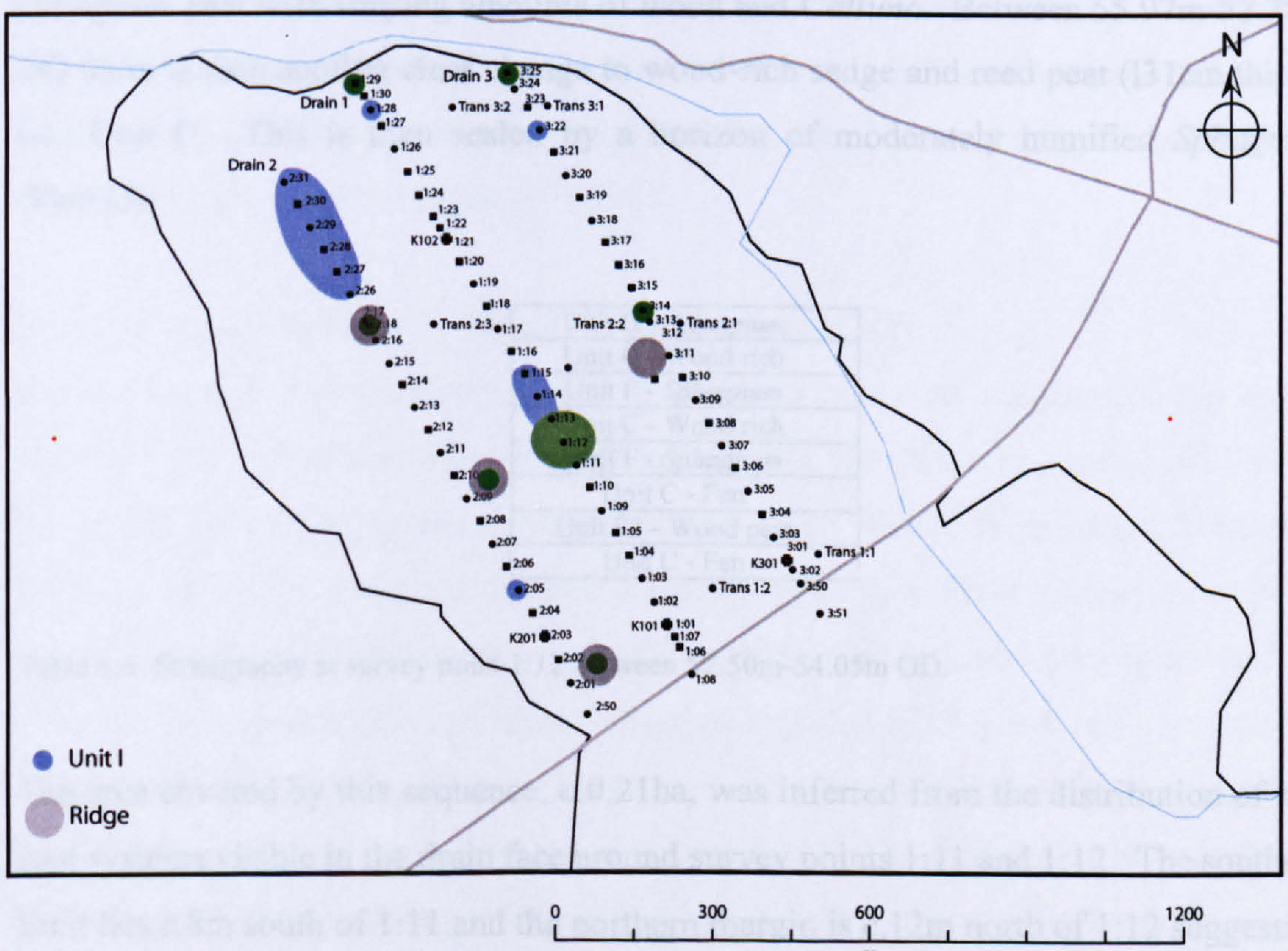


Fig. 6:10 Distribution of Units E & I (Fig. 6:8). Kilnagarnagh Bog, Lemanaghan, Co. Offaly.

The peat matrix is derived from *Sphagnum*; its remains are visible to the naked eye. Bigger tree trunks and denser root systems are present here, although detailed measurements were not taken to allow quantitative comparison between tree remains. The tops of some trunks had been sawn in advance of milling suggesting the presence of trees in this area until relatively recently. This ridge served as the western landfall for the Bronze Age trackway

E3. Wood peat in centre (Fig. 6:8)

The most extensive deposit of wood peat is located just south of the centre of the mire between survey points 1:13 and 1:11 (Fig. 6:4). The following description is derived from survey point 1:12 (Table 6:6). Here, between 52.50m-54.05m OD, a 125cm thick horizon of wood peat (Unit E3) overlies Unit C (Fig. 6:4). The wood peat is black, friable, has fragments of twigs and wood and is broken by gaps in the record where sediment was not recovered (Table 6:6 & Appendix 2). The gaps are not indicated in the drawing.

The sequence here is complicated by the presence of other peat types. Sub-unit E3 is overlain by alternating deposits of sedge peat with reed, similar to Unit C and, *Sphagnum* peat with varying amounts of wood and *Calluna*. Between 55.97m-57.28m OD there is then another clear change to wood-rich sedge and reed peat (131cm thick), i.e., Unit C. This is then sealed by a horizon of moderately humified *Sphagnum* (Unit G).

Unit G - *Sphagnum*
Unit C - Wood rich
Unit F - *Sphagnum*
Unit C - Wood rich
Unit F - *Sphagnum*
Unit C - Fen
Unit E3 - Wood peat
Unit C - Fen

Table 6:6 Stratigraphy at survey point 1:12 between 52.50m-54.05m OD.

The area covered by this sequence, *c.*0.21ha, was inferred from the distribution of tree root systems visible in the drain face around survey points 1:11 and 1:12. The southern limit lies *c.*8m south of 1:11 and the northern margin is *c.*12m north of 1:12 suggesting this zone extended for *c.*70m north-south. Observations from adjacent drains (*c.*15m to east and west) suggest it extended beyond these drains, giving it a minimum width of *c.*30m. The edges of the zone were defined by reed beds easily identified by the weathered and flattened reed rhizomes exposed in the drain face.

6:3:7 Unit F: Highly Humified *Sphagnum* (HHS)

This unit is highly humified *Sphagnum* peat (H7-H9). It is generally red-brown to brown in colour, undergoing rapid oxidation upon exposure. Both herbaceous and lignaceous remains occur in variable amounts The deepest accumulations occur in the middle of the northern half of the mire between 54.50m-57.50m OD (Fig. 6:4) where the deposit reaches up to 270cm in thickness. In the east, where the deposit occupies a similar elevation (between 55.20m-57.50m OD), it has a maximum thickness of 130cm though this decreases steadily as the basin floor rises to the south (Fig. 6:5). In the southern half of the mire, Unit F is between 25cm-150cm in thickness (Figs 6:5 & 6:6) and deepens as the basin floor drops. In the centre, Unit F has an undulating upper surface and a maximum depth of 75cm.

The unit appears to be mire-wide, albeit discontinuous where it is interrupted by the presence of another major peat unit, e.g., Unit I. The most extensive gap is in the northwest (*c.*200m in length) with a smaller gap (*c.*100m) close to the centre of the mire immediately north of the wood peat unit E3 (Fig. 6:10). Additional gaps are found in the north and southwest (survey points 1:28, 3:22 and 2:05). Topography has also limited the accumulation of Unit F in places, for example, on the upper slopes of the ridge in Drain 2 at survey points 2:16-2:17.

6:3:8 Unit G: Moderately Humified *Sphagnum* (MHS)

This unit comprises moderately humified *Sphagnum* peat with humification (H) values from H4-H6. Its colour varied from orange to dark brown and in general oxidisation occurred rapidly on exposure. Other plant components, such as *Eriophorum*, *Sphagnum cuspidatum* and *Calluna* remains, were present, appearing as shallow horizons or, in the case of herbaceous plant remains, in small tussocks. Unit G is an intermediate horizon between the Unit F, highly humified *Sphagnum* and Unit H (Fig. 6:4), poorly humified *Sphagnum*. In contrast to Units F and H this unit is limited in its distribution and does not form a continuous unit across the mire (Fig. 6:11). The distribution of Unit G may therefore be partly a product of the difficulty of distinguishing it in the field and the resolution at which the survey was undertaken.

Its greatest representation is in the southern half of the mire where it appears to extend across the width of mire between 900m-1100m. Unit G is located immediately south of the wooded zone, sub-Unit E3, and the mineral ridge identified in Drain 3. It increases in thickness from west to east from *c.*40cm to *c.*120cm and lies higher in the west and east than in the centre. Just to the north of the mire centre Unit G is also present. It is shallow, reaching no more than 40cm in thickness and there are no similar horizons to the east or west.

6:3:9 Unit H: Poorly Humified *Sphagnum* (PHS)

This unit is primarily composed of poorly humified *Sphagnum* peat with humification values of HI-H3 (see Section 5:2:2). It was recorded from both coring and drain face survey and, as a result it was possible to identify spatial features in the top 130cm of peat (se below). Up to 240cm of this peat unit is present continuously across the mire. It is generally thicker in the centre becoming shallower towards the east and west. The exposed top of Unit H had weathered, appearing as fluffy and yellow, while deeper deposits ranged from orange to dark brown in colour. Other components within this unit include herbaceous and ericaceous plant remains, the former mainly as tussocks of *Eriophorum*, as well as horizons of more humified *Sphagnum*. Horizons of homogenous PHS are between *c.*10cm and 100cm in thickness. In general the deeper parts of this Unit are more homogeneous but this may be influenced by the limitations of coring as opposed to drain face investigation.

Conditions allowed for the growth of *Sphagnum cuspidatum*, best represented in the east and southeast (Fig. 6:6). Locations where *S. cuspidatum* lay up to 5cm-15cm thick are indicated in the profile drawings. Typically, however, *S. cuspidatum* peat is present in thin narrow layers (1m-2m in width), occasionally laminated, and sometimes with pool algae. Small scale, localised variability within Unit H is also reflected in the arrangement of differently humified horizons. For example, at survey point 1:13 Unit H is distinguished by a series of intercalating layers of poorly and moderately humified *Sphagnum* peat. North of this homogenous poorly humified *Sphagnum* dominates.

An arc is used to define the distribution of major variation within Unit H identified in the upper 130cm of peat (Fig. 6:12). South of this arc, there are clear undulations in the stratigraphy (sub-unit H2) with laminated deposits of differently humified *Sphagnum* and *Sphagnum cuspidatum*, *Calluna* and *Eriophorum* present locally.

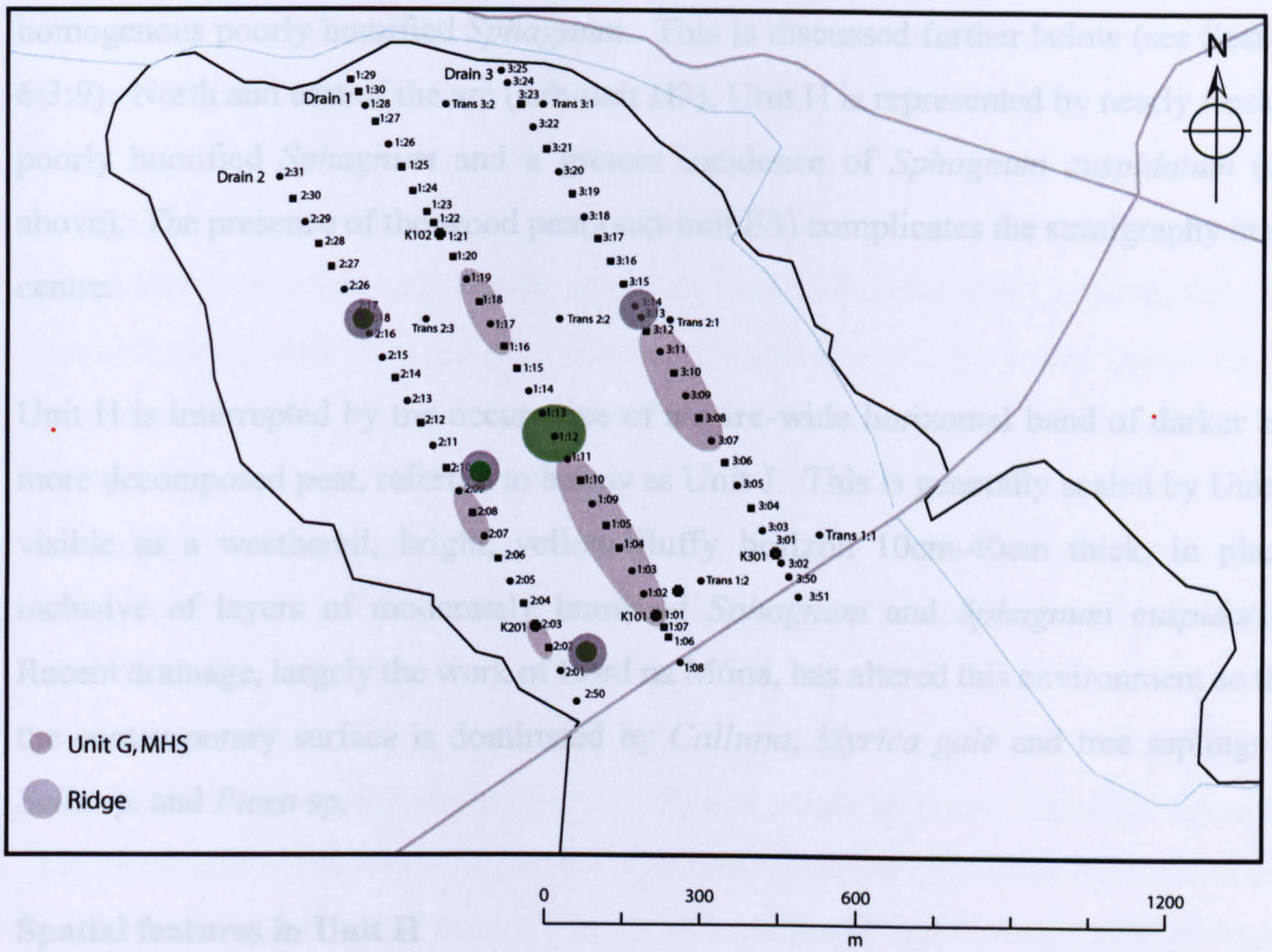


Fig. 6:11 Distribution of Unit G, Kilnagarnagh Bog, Lemanaghan, Co. Offaly.

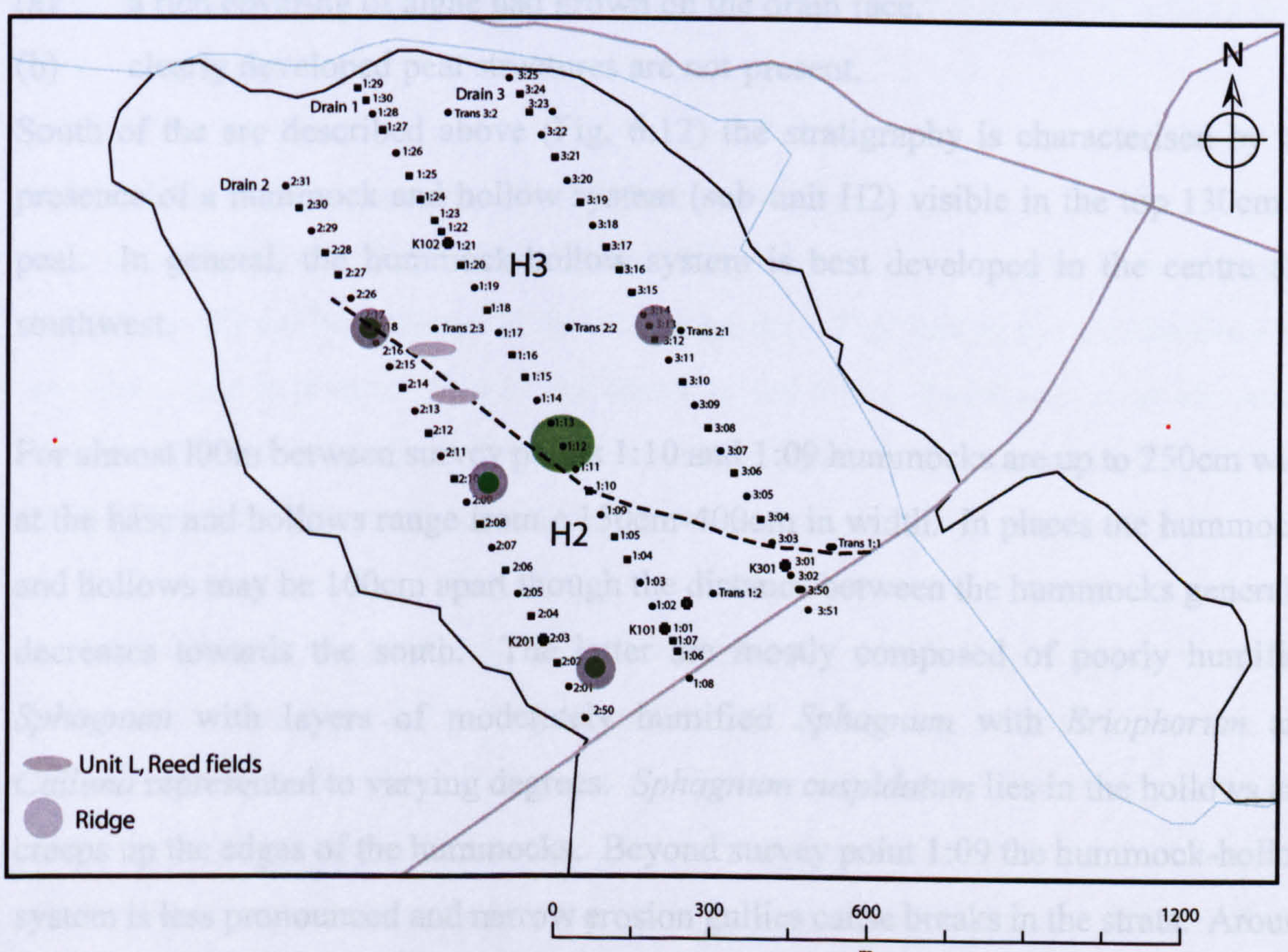


Fig. 6:12 Distribution of Units L & H with distribution of H2 (hummock-hollow) and H3 (lawn) indicated. Kilnagarnagh Bog, Lemanaghan, Co. Offaly.

Occasionally small gullies interrupt the strata, which is generally preceded by relatively homogenous poorly humified *Sphagnum*. This is discussed further below (see Section 6:3:9). North and east of the arc (sub-unit H3), Unit H is represented by nearly fresh to poorly humified *Sphagnum* and a greater incidence of *Sphagnum cuspidatum* (see above). The presence of the wood peat (sub-unit E3) complicates the stratigraphy in the centre.

Unit H is interrupted by the occurrence of a mire-wide horizontal band of darker and more decomposed peat, referred to below as Unit J. This is generally sealed by Unit H visible as a weathered, bright, yellow fluffy horizon 10cm-40cm thick, in places inclusive of layers of moderately humified *Sphagnum* and *Sphagnum cuspidatum*. Recent drainage, largely the work of Bord na Móna, has altered this environment so that the contemporary surface is dominated by *Calluna*, *Myrica gale* and tree saplings of *Salix* sp. and *Picea* sp.

Spatial features in Unit H

It was difficult to identify spatial features in the upper peats of the northern end of the mire (with the exception of Unit J, see below) for two reasons:

(a) a rich covering of algae had grown on the drain face.

(b) clearly developed peat structures are not present.

South of the arc described above (Fig. 6:12) the stratigraphy is characterised by the presence of a hummock and hollow system (sub-unit H2) visible in the top 130cm of peat. In general, the hummock-hollow system is best developed in the centre and southwest.

For almost 100m between survey points 1:10 and 1:09 hummocks are up to 250cm wide at the base and hollows range from *c.*150cm-400cm in width. In places the hummocks and hollows may be 100cm apart though the distance between the hummocks generally decreases towards the south. The latter are mostly composed of poorly humified *Sphagnum* with layers of moderately humified *Sphagnum* with *Eriophorum* and *Calluna* represented to varying degrees. *Sphagnum cuspidatum* lies in the hollows and creeps up the edges of the hummocks. Beyond survey point 1:09 the hummock-hollow system is less pronounced and narrow erosion gullies cause breaks in the strata. Around 130m to the south, the hummock-hollow system is composed mostly of hummocks of poorly humified *Sphagnum* with less moderately humified *Sphagnum* present. Over the last 100m, towards the southern end of the mire, the system is more pronounced with hummocks lying *c.*5m apart. Thin layers of *Sphagnum cuspidatum* occupy the hollows between the hummocks.

In the southwest the hummock-hollow system is well defined around survey point 2:04 over *c.*60m, with hummocks mostly of poorly humified *Sphagnum*. Towards the end of Drain 2 the system is replaced by low hummocks or ridges in the peat. Similar formations were identified in the southeast between survey points 3:01 and 3:02 where they provide a gently undulating base for Unit J that had in places slipped and cracked on the slopes of the "hummocks" (see Section 6:3:11). In addition, numerous narrow *Sphagnum cuspidatum* layers (1m-2m in width) occupied small pools or the base of shallow "hollow-like" features.

In the northwest (around survey point 2:29) low ridges of poorly humified *Sphagnum* peat, 5m-6m in width and with gentle slopes, are separated by shallow depressions *c.*3m in width. *Sphagnum cuspidatum* occupies the "hollows" and *Calluna* and *Eriophorum* are present in the ridges but not in large amounts. In the area of the mineral ridge at survey point 2:16, breaks in the stratigraphy and slipped layers suggest the occurrence of local erosion that contributed to the difficulty of identifying spatial structures in this area.

6:3:10 Unit I: Loose unconsolidated peat

Unit I consists of very loose, unconsolidated deposit of water and peat. In several places the peat could not be retained in the core chamber. This unit is most extensive in the northwest and is present close to the centre of the mire. It also occurs as an isolated feature close to the northern and southwestern margins of the mire though the absence of flanking deep cores at these locations may mask its extent.

In the northwest Unit I extends for *c.*250m on top of Unit C (Fig. 6:8) and reaches its greatest thickness of *c.*300cm deepening as the ground surface lowers to the north. The top of Unit I is marked by a change to consolidated, highly humified *Sphagnum*. Close to the centre of the mire a similar though shallower deposit forms the northern boundary of the wooded zone represented by Unit E3 (Fig. 6:4). Here, the unit is 150cm-177cm in thickness and at one location, survey point 1:13, its base comprises soft, mud-like peat *c.*30cm deep. It is sealed by a deposit of poorly humified *Sphagnum*.

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6:3:11 Units J & K

Lying within the upper metre of peat is a very distinct horizon that in the weathered drain faces was easily distinguished from the underlying poorly humified peat Unit H (Figs 6:13, 6:14). This horizon is generally evident across the mire as a dark band 5cm-70cm in thickness, with sharp upper and lower boundaries that can be horizontal or undulating and irregular. It was considerably more desiccated than the peat lying above or below it, displaying in places polygonal and vertical drying cracks. Its distribution was interrupted by the presence of ridges in the mineral substrate and in the centre by the wooded zone, Unit E3 (Fig. 6:15). Its contours follow that of the underlying basin, probably a reflection of the drained and compacted nature of the peat. It typically occupies higher elevations in the east and west than in the centre of the mire.

In the north, in the centre, Unit J is visible as an undulating and weakly developed horizon over *c.*350m defined by a basal layer of dark highly humified *Sphagnum* overlain by shallow layers of less humified *Sphagnum* peat and *Sphagnum cuspidatum.* From survey point 1:23 Unit J is distinguished by two well-humified dark bands separated by shallow, laminated layers of less decomposed *Sphagnum.* The lower band is generally more distinct reaching up to *c.*12cm in thickness, and is more heavily oxidised.

Unit J's distribution is then broken by a zone occupied by gullies (Unit K) that interrupts the main stratigraphy over *c.*70m. The best-defined gully is at survey point 1:22 between 58.60m-59.33m OD. This gully is 73cm deep and *c.*4m wide at the base represented by *c.*9cm of highly decomposed black peat with abundant *Calluna* remains. Stratigraphically this occupies a similar position to the lower band of Unit J described above. The gully became infilled with poorly humified *Sphagnum* retained only on the gully slopes as the gully was truncated by a later narrower gully represented by a layer of *Sphagnum cuspidatum* *c.*9cm thick overlain by *c.*50cm of poorly humified *Sphagnum.* At survey point 1:21 (between 58.8m-59.10m OD) the two gullies are each represented by highly humified gully bases.

Beyond the gully zone, a thin highly decomposed dark layer extends up to survey point 1:19 forming the base of Unit J over 50m (Fig. 6:4). This layer is 2cm-10cm in thickness with little structure and vertical drying cracks. It lies beneath alternating shallow layers of poorly humified and moderately humified *Sphagnum.*

In the west, the northern margin of Unit J lies between survey points 2:30 and 2:29 (Fig. 6:6) where it is relatively shallow. It extends for *c.*120m but is interrupted by the ridge at 2:18. South of this ridge Unit J is generally defined by two dark highly decomposed layers of *Sphagnum* peat which vary from black to dark brown in colour.

In the northeast Unit J is difficult to discern (Fig. 6:6). Rather, there are peat deposits lying at the same position in the profile that may represent its northeastern margin. At survey point 3:25, two bands of highly humified *Sphagnum* separated by poorly humified *Sphagnum* were recorded although 30m to the south, at 3:24, the bands were absent. From around survey point 3:21 a highly to moderately humified *Sphagnum* horizon is visible as a weathered black band, better developed in some places than in others. It ranged in thickness from 10cm-26cm. From survey point 3:20 it is generally thicker, *c.*24cm-41cm, and is visible as a weathered, cracked band of shallow, successive layers, in places overgrown by *Eriophorum*.

The character of Unit J changes south of an arc formed between survey points 2:18, 1:19 and 3:19 (Fig. 6:15). In the west, south of the ridge at 2:18, its upper and lower surfaces are irregular and undulating. It generally appears as two highly decomposed layers separated by shallow horizons of highly, moderately and poorly humified *Sphagnum* (Fig. 6:14). Between 2:07 and 2:06 the upper layer is discontinuous, very decomposed and mud-like and, in places, dried out in small blocks. The lower layer is visible as a yellow-black horizon with a grey bottom. From survey point 2:05 to 2:04 a series of hummocks (Unit H2) cause breaks in Unit J.

In the east Unit J is particularly well defined around survey point 3:15 (Fig. 6:6) reaching *c.*42cm in thickness. The upper layer is 16cm in thickness and composed of cracked and highly humified *Sphagnum.* The bottom layer is distinguished by its mud-like composition and has weathered white-grey. The entire unit is underlain by *Sphagnum cuspidatum.* From 3:15, Unit J respects closely the contours of the underlying relief and rises gently in the direction of the ridge. On top of the ridge, the double horizon is not present. On the ridge's southern slope distinctive, dried and cracked, dark layers extend to survey point 3:12 where Unit J is visible as a black-yellow smooth layer (highly decomposed and oxidised), 10cm in thickness and overlain by *Sphagnum cuspidatum.* This layer may equate to the upper phase identified north of the ridge. It extends just to the south of survey point 3:12 after which for

Fig. 6:13 Unit J is visible as a dark undulating band lying beneath a bright, poorly humified *Sphagnum* peat deposit (Unit H). Photo: 2001.

Fig. 6:14 The drains were re-cut in 2003 and the surface vegetation was removed. Unit J is visible as a desiccated and cracked undulating horizon bounded above and below by brighter coloured peat in this photograph. Photo: 2003.

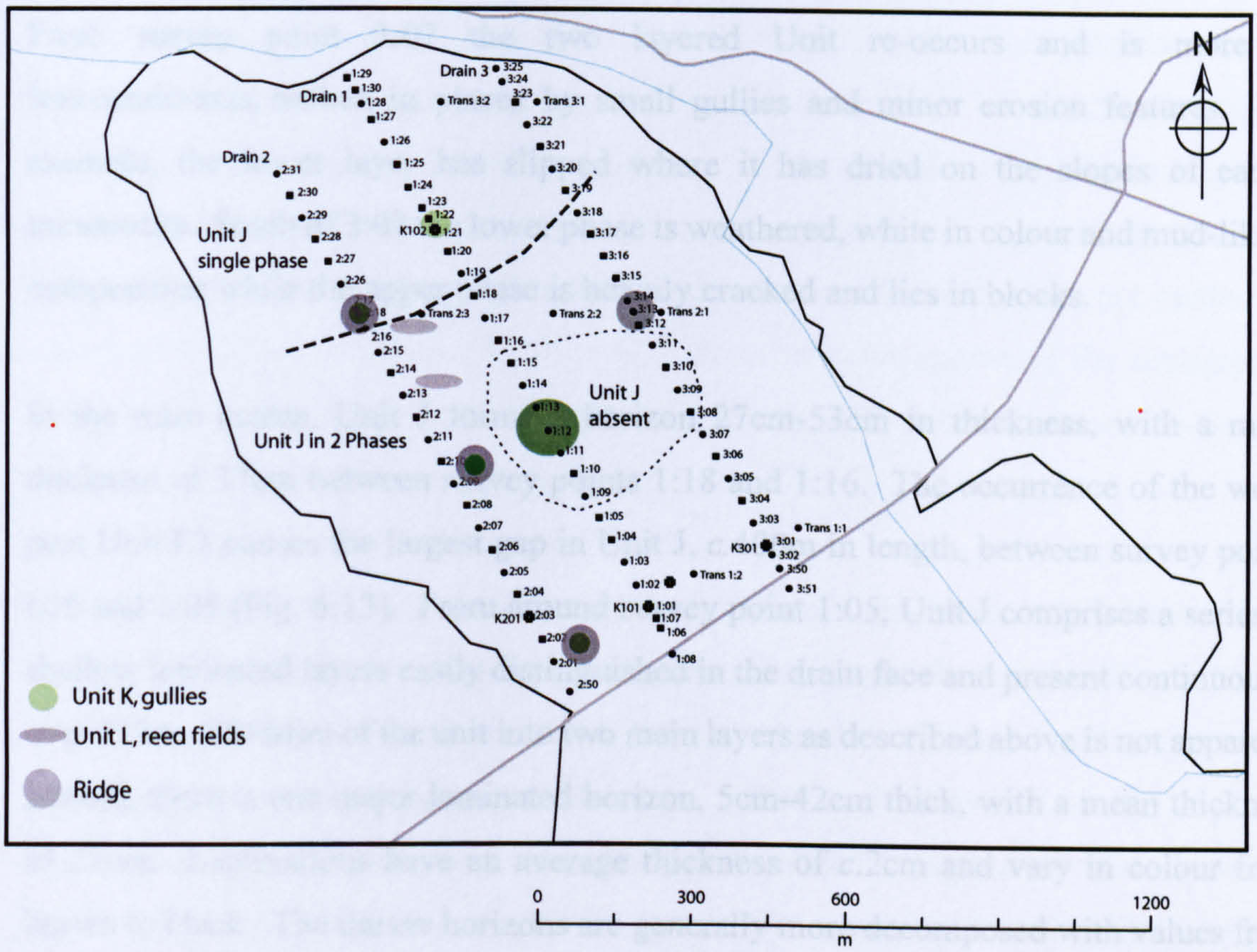

Fig. 6:15 Distribution of Units J, K & L in Kilnagarnagh Bog, Lemanaghan, Co. Offaly.

*c.*120m it could not be identified in the drain face because it was absent and in places the drain face was obscured due to flooding.

From survey point 3:07 the two layered Unit re-occurs and is more or less continuous, broken in places by small gullies and minor erosion features. For example, the lower layer has slipped where it has dried on the slopes of earlier hummocks. South of 3:03 the lower phase is weathered, white in colour and mud-like in composition while the upper phase is heavily cracked and lies in blocks.

In the mire centre, Unit J forms a horizon 27cm-53cm in thickness, with a mean thickness of 37cm between survey points 1:18 and 1:16. The occurrence of the wood peat Unit E3 causes the largest gap in Unit J, *c.*400m in length, between survey points 1:16 and 1:05 (Fig. 6:13). From around survey point 1:05, Unit J comprises a series of shallow laminated layers easily distinguished in the drain face and present continuously over 325m. Division of the unit into two main layers as described above is not apparent; instead, there is one major laminated horizon, 5cm-42cm thick, with a mean thickness of 23cm. Laminations have an average thickness of *c.*2cm and vary in colour from brown to black. The darker horizons are generally more decomposed with values from H7-H9 and are heavily desiccated in small blocks. In places, Unit J has a desiccated and eroded base. Between survey points 1:01-1:06 it appears to lie between hummocks and just over the hummock-hollow system (H2).

6:3:12 Unit L: Reed Fields

Fifteen metres northeast of survey point 2:15 there is a significant *Phragmites* presence in the top of the profile (Fig. 6:12). A band of *Phragmites*-rich peat extends for *c.*45m to the southeast. It tapers from 14m to less than 5m in width and is visible to a depth of 150cm. Individual reed beds are not apparent and the deposit is not laminated. There are lenses of poorly humified *Sphagnum* throughout which increase in frequency up the profile. The overall peat matrix is dark, crumbly and oxidised. Wood and reed form the base of the reed peat, marking the transition from Unit C to Unit J in this area. About 150m to the south is a second reed field, similar in character but smaller in extent.

6:4 CURSORY STRATIGRAPHIC SURVEY OF CURRAGHALASSA BOG

An access road runs around the perimeter of Curraghalassa Bog that facilitates the cutting of peat from the mire edges. Face banks, 2.5m-3m high, provide lengthy exposures of the stratigraphy though the base of these were usually flooded which hindered examination of the strata. The aim of the survey was to obtain a general picture of the mire's peat stratigraphy to compare with the stratigraphic record from Kilnagarnagh. The survey was limited to observation only, coring was not carried out and there was no follow-up GPS survey or detailed investigation of the stratigraphy. Hence, the description of the stratigraphy is limited and the results discussed in Section 10:2:3.

The lowermost peat deposit consists of a highly decomposed peat matrix with little reed. This equates to Unit C from Kilnagarnagh. The top of this horizon, equivalent to Unit D, is defined either by the presence of wood or by the remains of *Scheuchzeria palustris*. It is generally overlain by *Sphagnum* rich peat, either moderately (= Unit G) or poorly (= Unit H) humified. The presence of highly humified *Sphagnum* (= Unit F) at this junction was not observed. Higher in the profile poorly humified *Sphagnum* peat dominates with varying amounts of *Eriophorum* and, in the northwest, the presence of a poorly developed hummock-hollow system. Where pools were present, they were generally shallow with *Sphagnum cuspidatum*.

The upper metre of peat is distinguished by the presence of an extensive horizon of highly decomposed and cracked peat which lay between 40cm-60cm below the contemporary bog surface (Fig. 6:16). The band was up to *c*.40cm thick with sharp upper and lower boundaries. Traced for several hundred metres it forms a very distinct band. In places, two distinct horizons were present separated by a deposit of poorly humified *Sphagnum* peat. Based on its composition, structure and position in the profile this horizon may equate to Unit J (see Section 10:2:3).

Fig. 6:16 Face bank, Curraghalassa Bog showing the extensive desiccated peat horizon lying just below the uppermost poorly humified *Sphagnum* peat deposit.

CHAPTER 7

RESULTS OF LABORATORY ANALYSIS

7:1 INTRODUCTION

This chapter describes the results of the laboratory analysis of peat cores for chronology, testate amoebae analysis, plant microstratigraphy and humification determinations. The dating results and potential problems with these are described first. Next Core K101 is described followed by K202, K301 and finally K102. They are described in this order as K102 was retrieved from the northern end of the mire while the others lie on the same transect in the south.

7:1:1 Dating results & potential problems with chronology

Table 7:1 lists the nineteen AMS dates from this study. The dates extend from the early Holocene to the early historic period.

Core	Sample	Lab. code	Depth cm	Yrs BP	2 sigma	δ 13 ‰	Calibrated mid. point
	K101:5	Wk-14129	14	2030±40BP	170BC-70AD	-26.5±0.2	50BC±120
	K101:4	Wk-14128	53	2668±40BP	900BC-790BC	-27.7±0.2	845BC±55
K101	K101:3	Wk-14127	118	3712±40BP	2280BC-1970BC	-27.2±0.2	2125BC±155
	K101:2a	Wk-14126	164	4192±41BP	2890BC-2620BC	-27.9±0.2	2755BC±135
	K101 basal	Wk-14130	592	9966±73BP	10000BC-9200BC	-29.4±0.2	9600BC±400
	K102:6a	Wk-14135	60	1562±38BP	420AD-600AD	-27.5±0.2	AD510±90
	K102:5	Wk-14134	149	2757±40BP	1000BC-820BC	-25.6±0.2	910BC±90
K102	K102:4	Wk-14133	230	3643±40BP	2140BC-1880BC	-27.9±0.2	2010BC±130
	K102:3	Wk-14132	292	4185±41BP	2890BC-2620BC	-28.5±0.2	2755BC±135
	K102:2a	Wk-14131	358	4858±42BP	3730BC-3520BC	-27.9±0.2	3625BC±105
	K201:6	Wk-14136	28	1461±38BP	530AD-660AD	-27.4±0.2	AD595±130
	K201:4	Wk-14137	155	2730±41BP	980BC-800BC	-27.1±0.2	890BC±90
K201	K201:2	Wk-14138	245	3798±48BP	2460BC-2030BC	-27.3±0.2	2245BC±215
	K201:1	Wk-14139	299	4218±47BP	2910BC-2620BC	-27.6±0.2	2765BC±145
	K301:7	Wk-14140	30	1479±43BP	430AD-660AD	-27.0±0.2	AD545±115
	K301:6	Wk-14141	60	1892±43BP	20AD-240AD	-27.1±0.2	AD130±110
K301	K301:4	Wk-14142	132	2855±42BP	1190BC-900BC	-26.6±0.2	1045BC±145
	K301:3	Wk-14143	180	3781±43BP	2400BC-2380BC	-26.6±0.2	2215BC±185
	K301:2a	Wk-14144	283	5027±44BP	3950BC-3700BC	-27.0±0.2	3825BC±125

Table 7:1 AMS results from Kilnagarnagh; listed by core and by depth.

Age-depth models have been used to provide estimated dates for otherwise undated changes in the testate, plant macrofossil and humification sequences (see Section 5:3:5). The age-depth models from Kilnagarnagh must be utilised cautiously as producing age-depth models on compacted peat can add to the difficulties of using such models to provide age estimates (see Section 5:3:5). A clear indication of the problems caused by compaction is visible at the top of each age-depth model where each model suggests very fast rates of accumulation (Figs 7:1, 7:2, 7:3 & 7:4). These may be artificially high as extensive drainage has caused serious compaction of the uppermost peat deposit. All cores were taken from the contemporary bog surface and it was assumed the top of each core represented *c.*AD2000 as obviously truncated or damaged peat deposits were avoided.. However, extrapolating the ages of the top of each core from the individual dating models suggest the uppermost peat deposit may have been missing (Figs 7:1, 7:2, 7:3 & 7:4). An alternative explanation might be that the growth of the bog was impeded resulting in a slow down in growth. However, there is no evidence for this in the proxy data. A third explanation may be related to the extensive modern drainage which has been in place since the 1980s. This is likely to have caused extreme compaction of the uppermost peat deposit, and seems the most likely.

7:2 K101

7:2:1 Testate Amoebae K101 (Fig. 7:5)

Analysis of samples from K101 extended *c.*70cm into the underlying fen peat (from 242cm-312cm). Testates were present in low numbers in occasional samples. For this reason, deeper samples from K101 and fen levels from the other cores were not analysed.

K101:1a 312cm-235cm (*c.*5100BC-3875BC)

This sub-zone opens with trace values (1% or less) of four taxa - *Amphitrema flavum, Assulina muscorum, Assulina seminulum* and *Difflugia pulex*. *Assulina muscorum* and *Difflugia pulex* re-occur in trace amounts in the upper half of the sub-zone.

The impoverished testate fauna from this level prohibits the reconstruction of the water table.

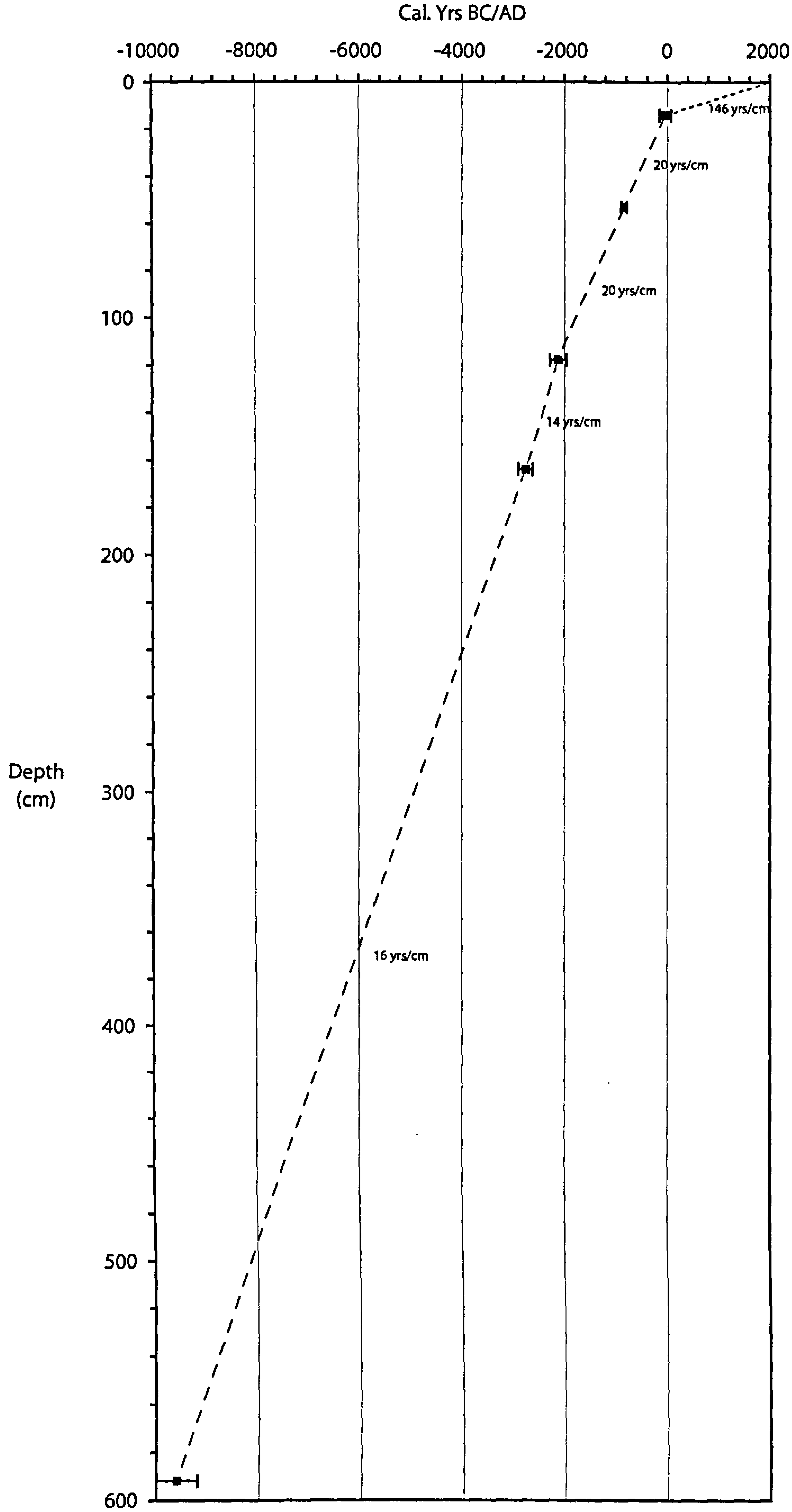

Fig. 7:1 Age-Depth model for Core K101. Estimated rates of accumulation are included. Accumulation rates in the upper metre of peat should be used cautiously due to compaction of the peat deposit because of ancient and modern drainage (see Sections 5:3:5 & 7:1:1).

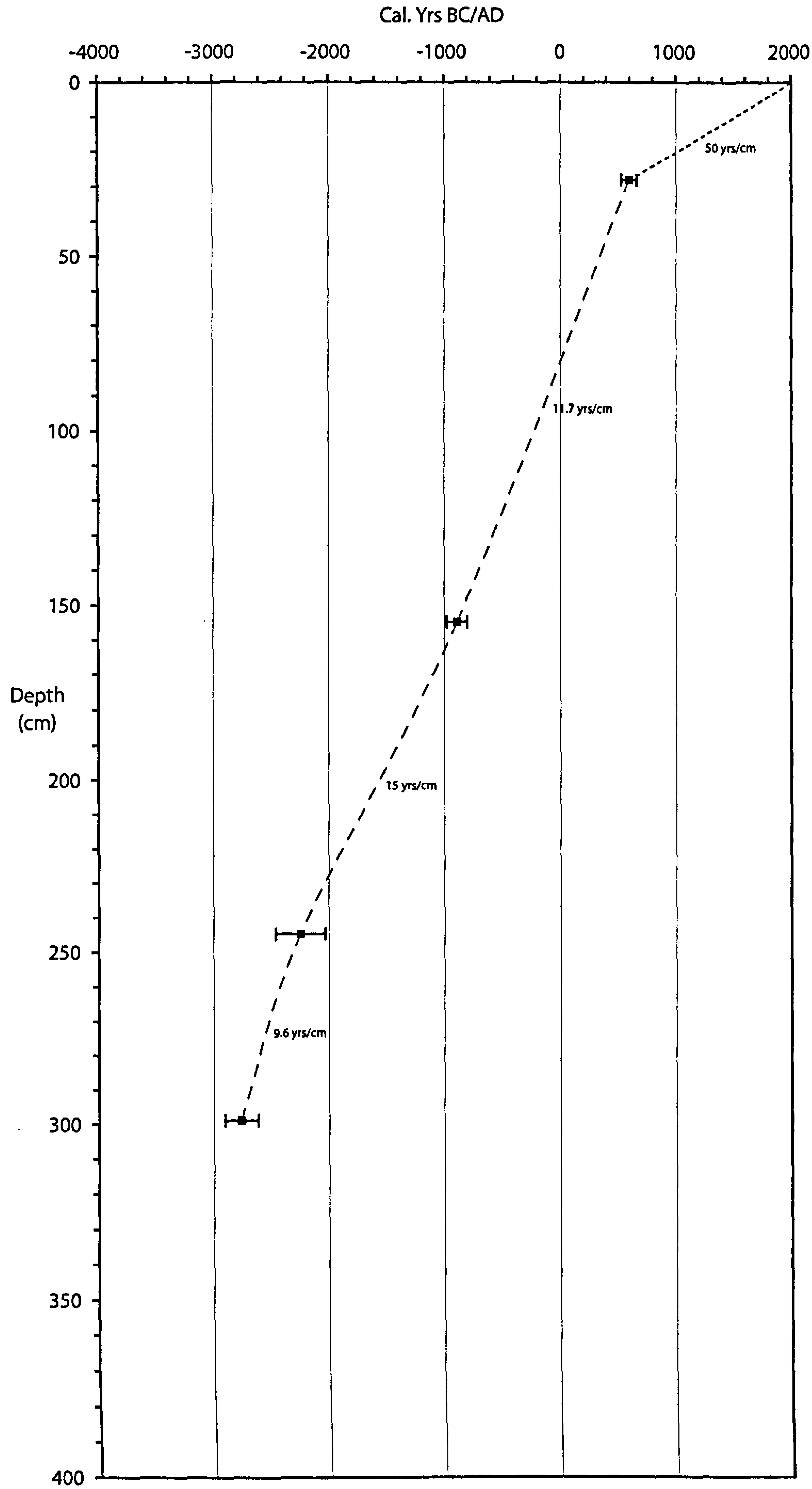

Fig. 7:2 Age-Depth model for Core K201. Estimated rates of accumulation are included. Accumulation rates in the upper metre of peat should be used cautiously due to compaction of the peat deposit because of ancient and modern drainage (see Sections 5:3:5 & 7:1:1).

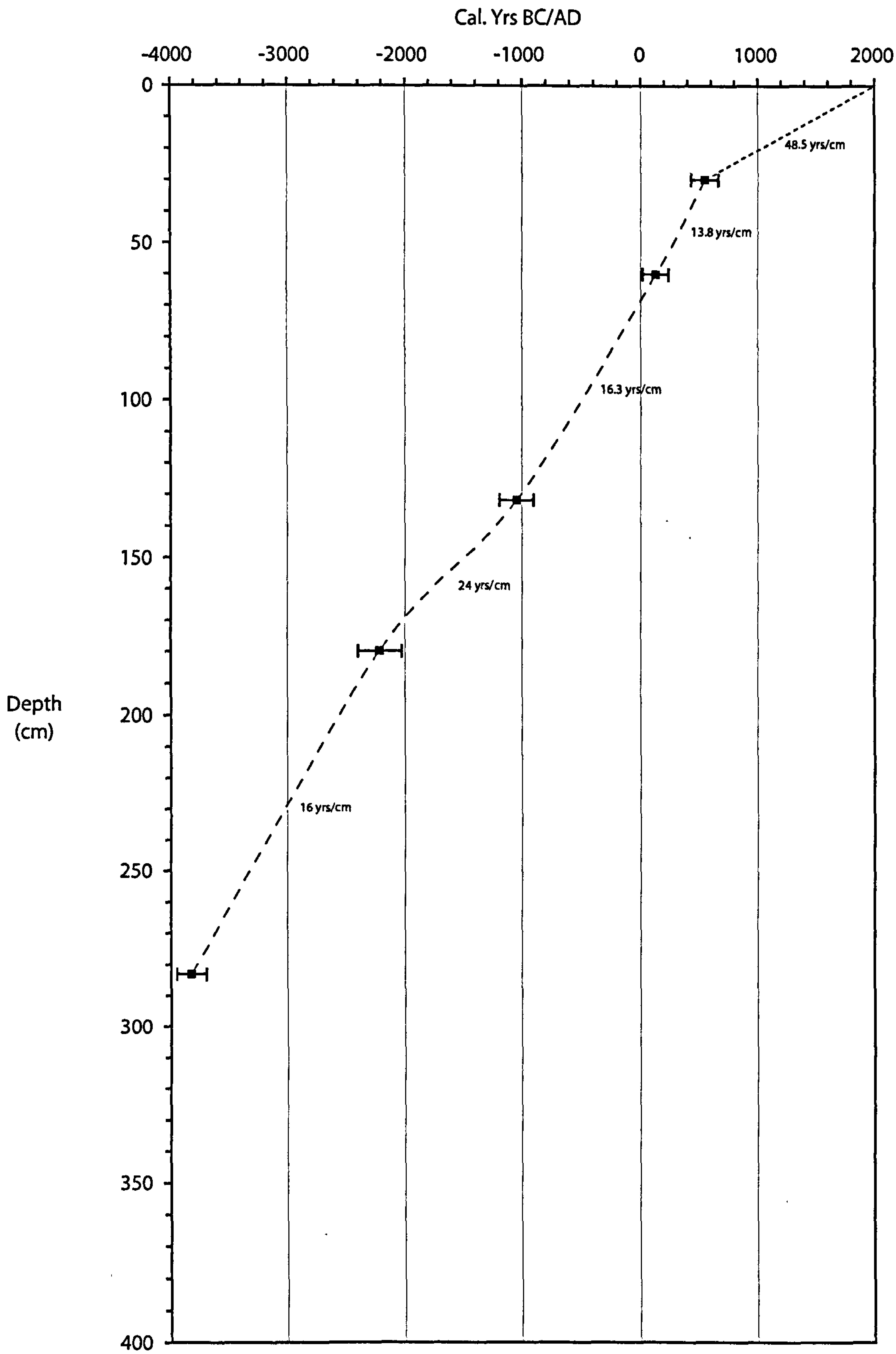

Fig. 7:3 Age-Depth model for Core K301. Estimated rates of accumulation are included. Accumulation rates in the upper metre of peat should be used cautiously due to compaction of the peat deposit because of ancient and modern drainage (see Sections 5:3:5 & 7:1:1).

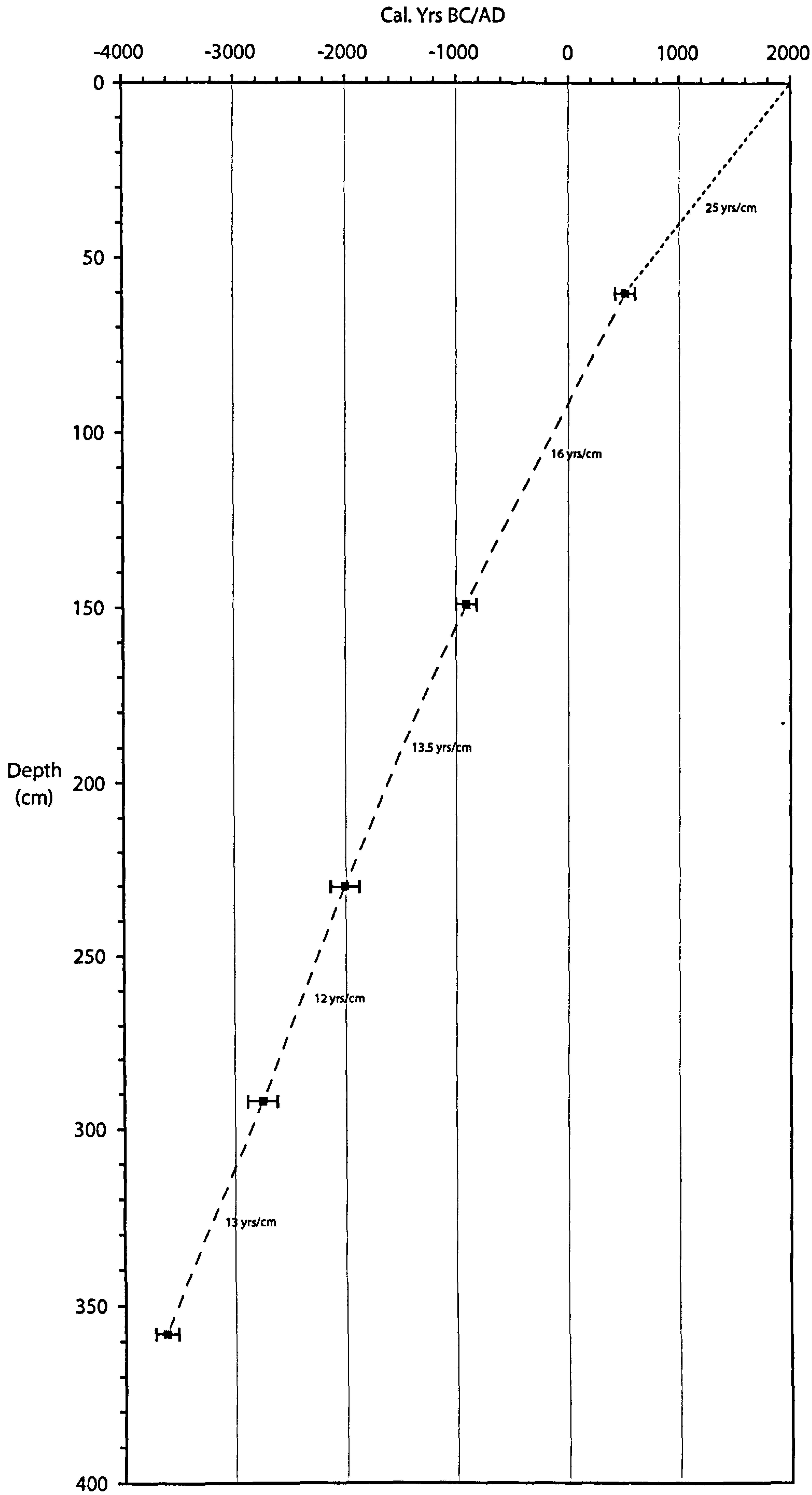

Fig. 7:4 Age-Depth model for Core K102. Estimated rates of accumulation are included. Accumulation rates in the upper metre of peat should be used cautiously due to compaction of the peat deposit because of ancient and modern drainage (see Sections 5:3:5 & 7:1:1).

K101:1b 235cm-220cm (*c.*3875BC-*c.*3635BC)

The first significant appearance of testate amoebae is in this sub-zone although the fauna is limited to three taxa. *Amphitrema flavum* and *Difflugia pulex* are more or less equally represented (*c.*45% each). *Assulina muscorum* is the only other taxon present at *c.*10%.

Testate numbers reached the minimum count of 150 individuals allowing the water table to be reconstructed. Here the water table lies at *c.*-5cm.

K101:1c 220cm-165cm (*c.*3635BC-2755±135calBC)

Trace amounts of testates are present but species diversity has improved with the addition of *Arcella discoides*-type and *Hyalosphenia subflava* to the assemblage. *Difflugia pulex* is the only taxon present consistently throughout the sub-zone.

Testate numbers were insufficient to allow reconstruction of the water table for this sub-zone.

K101:2a 165cm-148cm (2755±135calBC-*c.*2550BC)

The opening of this sub-zone has been dated to 2755±135calBC. Here the representation of testate amoebae improves with a return to good concentrations which persist through the rest of the record. This sub-zone is characterised by rising *Amphitrema flavum* values (which peak at 50%). *Difflugia pulex* reaches *c.*50% in the lower part of the sub-zone and falls to *c.*38% as the sub-zone closes. *Assulina muscorum* reaches *c.*15% but then drops to *c.*5%. *Assulina seminulum* and *Trigonopyxis arcula*-type appear in low numbers for the first time (*c.*5% or less); the latter only re-occurs towards the top of the profile. *Arcella discoides*-type appears at the top of the sub-zone, also in low numbers (*c.*5%).

The water table lies at *c.*-5cm but is rising to *c.*-3cm as the sub-zone closes.

K101:2b 148cm-118cm (*c.*2550-2125±155calBC)

This sub-zone is also dominated by *Amphitrema flavum* and *Difflugia pulex* but here *D. pulex* increases at the expense of *Amphitrema flavum*. *D. pulex* reaches up to *c.*65%, but drops to *c.*55% as the sub-zone closes. *Amphitrema flavum* decreases steadily falling to *c.*25% before it rises to *c.*35% at the expense of *Difflugia pulex*.

Arcella discoides-type and *Assulina muscorum* are more or less consistently present in low values (*c.*10% or less) through out the sub-zone. *Assulina seminulum* is present in small numbers in the upper half of the sub-zone.

The water table is stable at *c.*-3cm throughout the sub-zone.

K101:3 118cm-53cm (2125±155calBC-845±55calBC)

The boundary between zones K101:2b and K101:3 has been dated to 2125±155calBC. K101:3 is characterised by the relatively consistent presence of *Amphitrema wrightianum*. *A. wrightianum* is increasing from the opening of the zone though it never reaches more than 15%. *Amphitrema flavum* and *Difflugia pulex* continue to dominate. The latter is sub-dominant to *Amphitrema flavum* which reaches *c.*30%-70%. *Difflugia pulex* fluctuates between *c.*10% and 45%. The fourth best represented taxon is *Assulina muscorum* which is consistently present with a small peak (*c.*20%) near the middle of the zone. There is increased species diversity with the appearance of *Arcella catinus*, *Cyclopyxis arcelloides*-type, *cf. Assulina stenostoma*, and *Difflugia pristis* appearing for the first time in the upper half of the zone. Percentages range from 2%-5%. *Hyalosphenia subflava* makes its first appearance albeit in very low percentages until the close of the zone where it reaches *c.*10%.

In the lower half of the zone the water table is maintained at *c.*-3cm. Midway in the zone there is a slight drop to *c.*-5cm. This is followed by a gentle rise to around -3cm before another drop as the zone closes.

K101:4 53cm-12cm (845±55calBC-50±120calBC)

The dominance of *Hyalosphenia subflava* characterises this zone, fluctuating from 40-80%. *Difflugia pulex* is subdominant to *H. subflava*. *D. pulex* increases steadily from the bottom to the top of the zone peaking around 24cm at *c.*60% after which it decreases to *c.*40%. *Amphitrema wrightianum* is absent and *A. flavum* has fallen to between *c.*5%-10%. *Assulina seminulum* and *Arcella discoides*-type are occasionally present with values of less than *c.*2%. *Assulina muscorum* is present in percentages similar to the previous zone though it does not rise above *c.*10%.

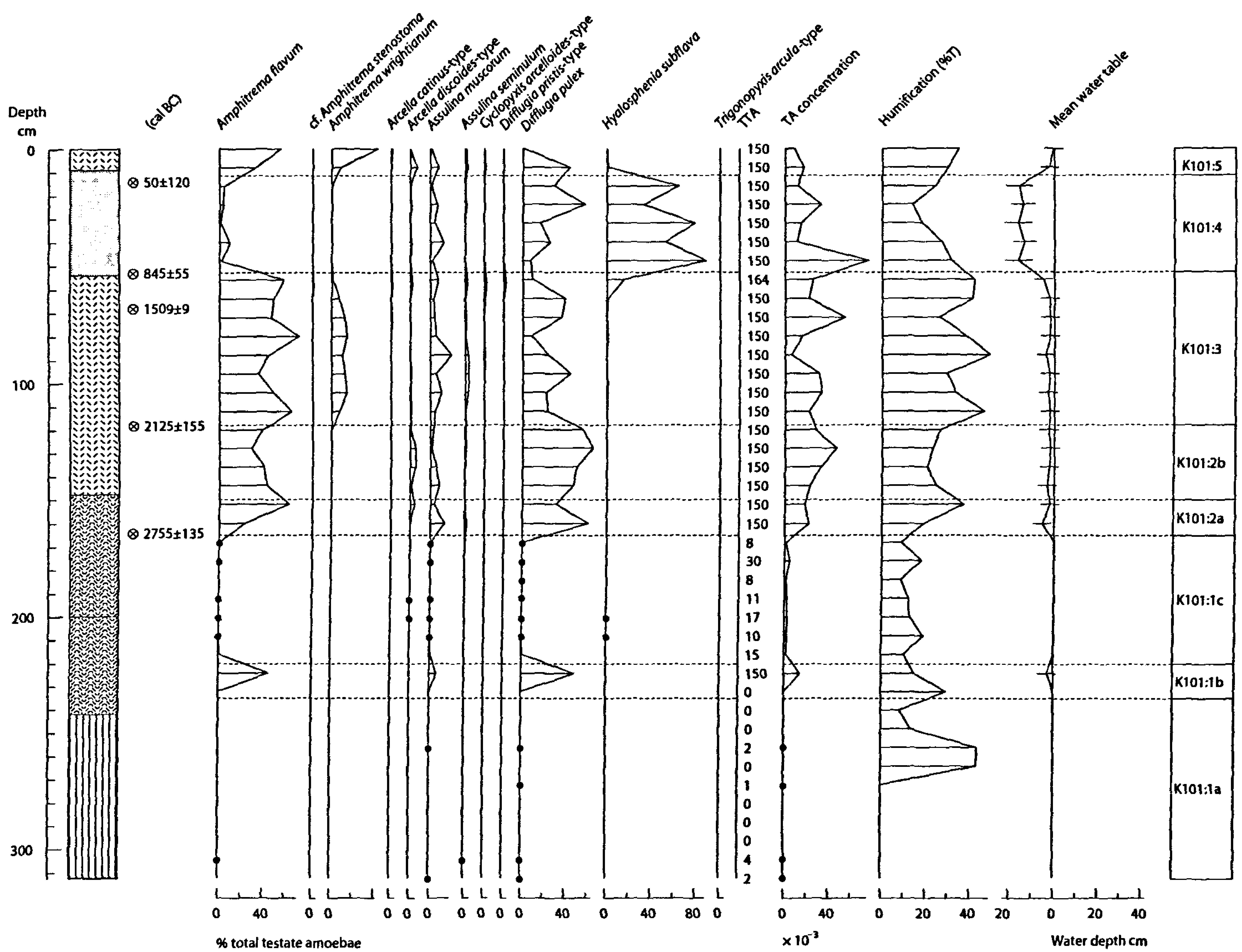

Fig. 7:5 Testate Amoebae Diagram from K101, Kilnagarnagh, Co. Offaly. For key to stratigraphy see Fig. 6:4.

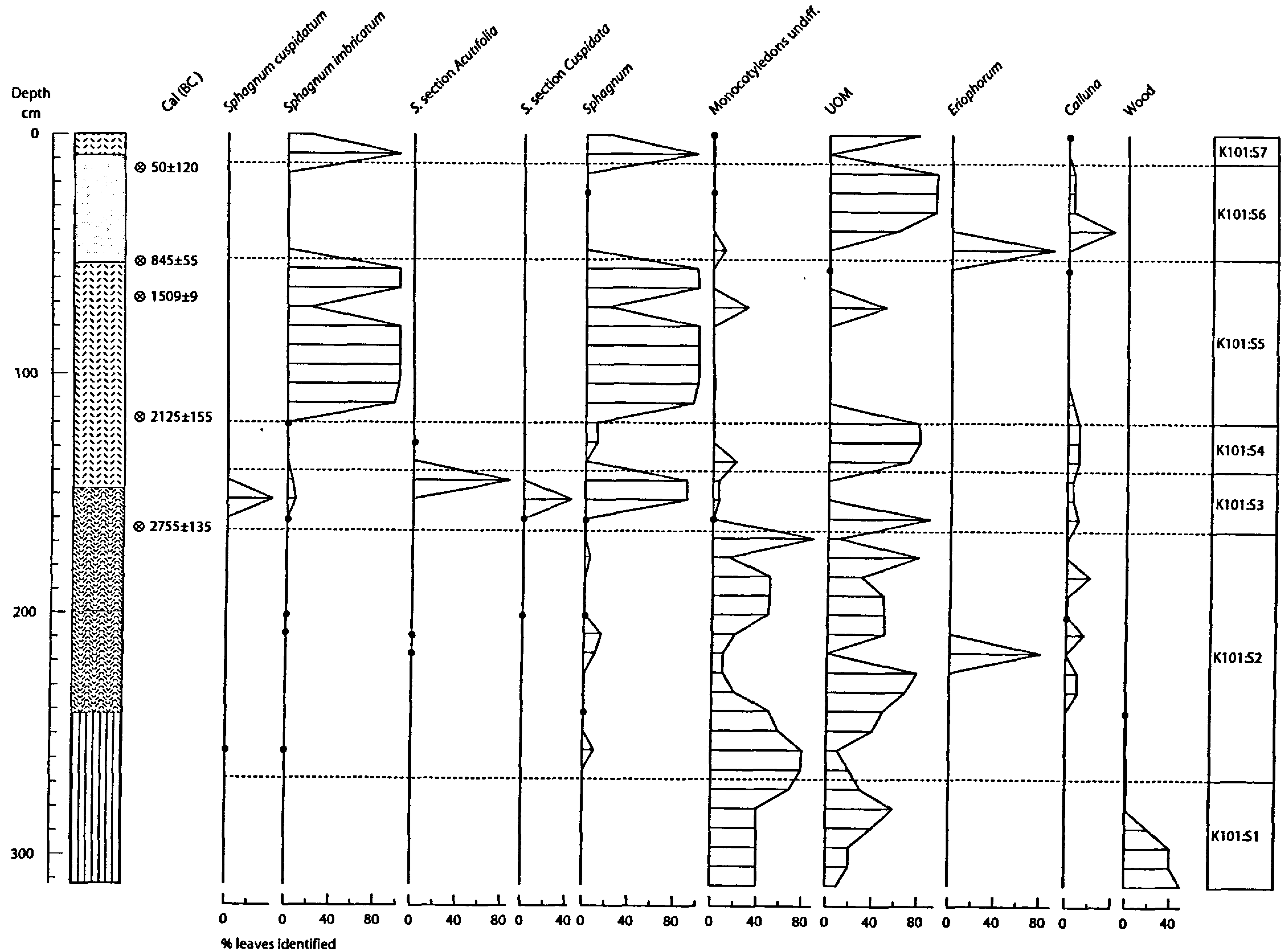

Fig. 7:6 Plant Microstratigraphy Diagram from K101, Kilnagarnagh, Co. Offaly. For key to stratigraphy see Fig. 6:4.

There is sharp reduction in the water table to *c.*-16cm between 16cm-48cm. This lowered water table is generally maintained throughout the zone.

K101:5 12cm-0cm (50±120calBC-*c.*AD2000)

K101:5 consists of only two levels, nonetheless it shows a clear change in species representation from the previous zone. *Hyalosphenia subflava* decreases to near trace levels while *Amphitrema flavum* and *A. wrightianum* rise to *c.*40% as the zone closes. There are also slight increases in other taxa - *Assulina muscorum* (*c.*10%), *Arcella discoides*-type (*c.*10%), *Arcella catinus* (*c.*2%), *Assulina seminulum* (*c.*2%) and *Cyclopyxis arcelloides*-type (less than 2%). The opening of this zone has been dated to 50±120calBC.

The sudden drop in water table which characterises the previous zone is mirrored by a sharp recovery in this zone. Here the water table reaches surface level as the sequence closes.

7:2:2 Plant microstratigraphy K101 (Fig. 7:6)

K101:S1 312cm-268cm (*c.*5107calBC-*c.*4400BC)

In this zone wood and undifferentiated monocots dominate in almost equal proportions, *c.*40% each until *c.*290cm when wood is in decline and UOM increases to near 60% at *c.*280cm. UOM values then drop as monocots increase to *c.*80% as the zone closes.

K101:S2 268cm-165cm (*c.*4400BC-2755±135calBC)

As this zone opens wood is by now a minor component and disappears from the record *c.*240cm. Undifferentiated monocots are initially dominant but then decline steadily to *c.*15% mid-way in the zone. As monocots decline, UOM values rise peaking at *c.*80% around 225cm. An *Eriophorum* spike to *c.*80% interrupts rising UOM and falling monocot values and is followed by a return to more or less shared dominance of UOM and monocots until *c.*180cm. UOM values then peak at *c.*80% and monocot values drop to *c.*20%. This situation is reversed as the zone closes. From *c.*240cm *Calluna* emerges comprising 10% and oscillates from 0% up to 20% over the course of the zone settling at *c.*10% at the top.

In K101:S2, *Sphagnum* makes its first appearance in low amounts. Here individual leaves were degraded and difficult to identify. For this reason the individual *Sphagnum* curves display trace values. Initial *Sphagnum* representation is confined to *Sphagnum imbricatum* and *Sphagnum cuspidatum* with *S.* section *Acutifolia* and *S.* section *Cuspidata* recorded from mid-way in the zone.

K101:S3 165cm-140cm (2755±135calBC-*c*.2200calBC)

This zone is characterised by the rise to dominance of *Sphagnum* to more than 90% of the record. UOM and monocots are much reduced lying below 5%. *Calluna* is consistently present at *c.*10%. *Sphagnum cuspidatum* and *S.* section *Cuspidata* initially comprise *c.*40% each of the *Sphagnum* record but *S.* section *Acutifolia* then replaces these as the primary moss constituent with *Sphagnum imbricatum* a minor component throughout the zone.

K101:S4 140cm-116cm (*c*.2200BC-2125±155calBC)

A reduction in the amount of *Sphagnum* characterises this zone. *Sphagnum* now lies at *c.*10%, as does *Calluna* while UOM is dominant comprising *c.*80% of the record and monocots at around 2% or less.

K101:S5 116cm-52cm (2125±155calBC-845±55calBC)

In this zone *Sphagnum*, in the form of *Sphagnum imbricatum*, is once again the primary peat constituent reaching values of nearly 100%. Monocots are represented sporadically and in low amounts until *c.*72cm where both UOM and monocots peak at 50% and 25% respectively. *Calluna* is represented at the opening and close of zone in low quantities but is otherwise absent.

K101:S6 52cm-12cm (845±55calBC-50±120calBC)

The zone opens with a peak to 80% in *Eriophorum* followed by an rise in UOM to *c.*60% and *Calluna* to *c.*40%. UOM then proceeds to dominate the zone, attaining its highest values (*c.*95%) over the entire sequence, with *Calluna* consistently represented at *c.*5%.

K101:S7 12cm-0cm (50±120calBC-*c*.AD2000)

This zone is represented by two levels which see an initial return to the dominance of *Sphagnum*, entirely *Sphagnum imbricatum*, reaching nearly 100% with a minor monocot component. The situation changes at the top of the sequence where UOM peaks at *c.*80% and *Sphagnum* falls to *c.*20%.

7:2:3 Humification K101 (Fig. 7:5)

The basal segment of the humification curve opens with transmission values of around 40%. It drops to *c.*10% and rises again to *c.*30% around 3900BC. Transmission values then oscillate between 10% and 20% until the close of testate sub-zone K101:2a where transmission values reach nearly 40%. Beginning around 2550BC, transmission values lie at around 25%. They then fluctuate between 25% and 50% between 2125±155BC and 845±55BC. At this point humification values are in decline and fall steadily to below 15% around 250BC. Around the middle of the first century BC transmission values have increased and reach *c.*35% at the top of the sequence.

7:2:4 Chronological control K101

Five AMS determinations were obtained for K101 (Table 7:1). The dates are sequential without any reversals present. The age-depth model (Fig. 7:3) shows continuous and relatively even sedimentation with the exception of the final phase of bog development from *c.*50BC to AD2000. This is probably a product of compaction of the upper peat deposit (see Section 5:3:5). After 2125±155calBC, the suggested rate of accumulation is 20yrs/cm though this does not account for the likely error caused by compaction of the upper metre of peat.

A dendrochronological date retrieved from an archaeological timber at this location, 1509±9BC (Q9291), falls within the sequence between 845BC±55calBC (Wk-14128) and 2125BC±155calBC (Wk-14127). Based on an accumulation rate of 20yr/cm, around 200 years should separate the younger AMS date and the dendrochronological date. This discrepancy may be related to the elevation or Ordnance Datum of the dendrochronological date and the core K101. The ODs are derived from two surveys, conducted six years apart using different approaches and equipment. Alternatively the compaction of the upper metre of the peat due to drainage may have caused the peat above the trackway to compact more thus reducing the interval between the timber and the dated peat horizon. Therefore the chronology of K101 is based on the AMS dates only; the dendrochronological date is not incorporated into the age-depth model.

7:3 K201

7:3:1 Testate Amoebae K201 (Fig. 7:7)

K201:1 300cm-245cm (2765±145calBC-2245±215calBC)

The zone opens with low concentrations of testates before an increase in concentrations that sees *Amphitrema flavum* reach values up to 90%. *Arcella discoides*-type is the second most significant taxon in the zone reaching around 15-18% and maintaining its presence until close to the top where *Amphitrema flavum* attains overall dominance. *Assulina muscorum* is consistently represented though never accounting for more than *c.*5%. *Difflugia pulex* is also present in small amounts between 2-5%. *Nebela militaris* is equal to *Arcella discoides*-type as the zone opens but then falls away completely. *cf. Hyalosphenia papilio* occurs low in the zone reaching *c.*10% after which it does not re-appear. *Trigonopyxis arcula*-type appears initially in trace amounts but increases to achieve its highest representation in the sequence at *c.*5% as the zone opens.

Initially the water table lies at *c.*-4m but it then rises and is maintained at *c.*-2cm throughout the rest of the zone.

K201:2 245cm-172cm (2245±215calBC-*c.*1100BC)

This zone marks the first appearance of *Amphitrema wrightianum* which reaches *c.*15% mid-zone. Though dominating the zone *Amphitrema flavum* demonstrates variation in abundance reaching a maximum of *c.*60% in the upper part of the zone and decreasing steadily after this peak to less than 20%. *Assulina muscorum* peaks at the lower and upper limits of the zone (reaching *c.*30%) and is consistently present, albeit with fluctuations, between these peaks. *Difflugia pulex* is the second most abundant taxa in the zone increasing sharply from low values at the opening of the zone to *c.*50% but then declining steadily to between10-15% until the close of the zone where it peaks again at 50%. Minor assemblage components include *Heleopera sylvatica*, *Nebela flabellum*, *Nebela militaris*, and *Trigonopyxis arcula*-type, present sporadically between 1% and 2%.

The zone opens with a drop in the water table after which it fluctuates between *c.*-2cm to *c.*-6cm midway into the zone. In the upper half of the zone the water table is relatively constant lying at *c.*-3cm before falling steadily to *c.*-7cm as the zone closes.

K201:3 172cm-155cm (*c.*1100BC-890±90calBC)

This zone is defined by a marked decrease in testate numbers, although the estimated testate concentration has changed little from the previous zone. Present in trace amounts are *Amphitrema flavum*, *Assulina muscorum*, *A. seminulum*, *Cyclopyxis arcelloides*-type, *Difflugia pristis*-type, *Difflugia pulex*, and *Trigonopyxis arcula*-type.

There is a lack of water table data from this zone due to low testate counts.

K201:4 155cm-53cm (890±90calBC-*c.*AD350)

This zone is similar to K201:2. *Amphitrema flavum*, *A. wrightianum*, *Difflugia pulex* and *Assulina muscorum* are the most important taxa. *Amphitrema flavum* steadily increases from 40-60% from the bottom of the zone to the upper third where its distribution is less consistent although it never drops below 40%. *Amphitrema wrightianum* is consistently present but displays variability in its abundance with peaks between *c.*30-40% at *c.*137cm and again at 88cm. The second most abundant taxon in this zone is *Difflugia pulex*. It is consistently present although its abundance fluctuates rising to *c.*35% in the lower half of the zone and near the upper zone boundary. *Assulina muscorum* is also a consistent presence at *c.*10%. *Arcella discoides*-type, *Cyclopyxis arcelloides*-type, *Difflugia pristis*-type and *Assulina seminulum* are consistently present throughout the zone but at percentages of less than 5%. *Amphitrema stenostoma*, *Arcella artrocrea*, *Centropyxis aculeate*-type, *Heleopera petricola*, *Heleopera sylvatica*, *Hyalosphenia subflava*, and *Trigonopyxis arcula*-type occur in low values of 2% or less throughout the zone. *Bullinularia indica* and *Nebela militaris* occur in the upper half of the zone only.

The reconstructed water table rises gently to *c.*-1cm towards the middle of the zone after which it gradually drops to *c.*-3cm.

K201:5 53cm-28cm (*c.*AD350-595±65calAD)

The increased presence of *Hyalosphenia subflava* and a peak in *Difflugia pulex* are the defining characteristics of this zone. *H. subflava* increases steadily towards the upper zone boundary achieving its highest representation of *c.*15-20%. *Difflugia pulex* dominates peaking at 50% mid-zone, whilst *Amphitrema flavum* declines in importance, falling to around 10% as the zone closes. *A. wrightianum* declines steadily from *c.*10% to *c.*20%. *Assulina muscorum*, *Cyclopyxis arcelloides*-type and *Difflugia pristis*-type are once again consistently present between 5-10%. The occurrence of *Arcella discoides*-type and *Assulina seminulum* is also consistent but at lower values of *c.*2%.

The relative stability of the water table implied near the top of the previous zone continues into K201:5. The curve then drops reaching its lowest value, *c.*-10cm, just below the upper zone boundary.

K201:6 28cm-0cm (595±65calAD-*c.*AD2000)

The zone opens with peaks in *Amphitrema flavum* (*c.*40%) and *A. wrightianum* (*c.*20%). *Difflugia pulex* and *Hyalosphenia subflava* have declined compared with zone K201:5. The latter is absent while *Difflugia pulex* has fallen to <5%. The representation of *Assulina muscorum* has not significantly altered but there are modest increases in *Assulina seminulum, Bullinularia indica* and *Centropyxis aculeata.* Testate numbers are then greatly reduced. Present in trace amounts are *Amphitrema flavum, A. stenostoma, A. wrightianum, Arcella catinus*-type, *Arcella discoides*-type, *Assulina muscorum, Centropyxis aculeata*-type, *Difflugia pulex, Heleopera sylvatica, Hyalosphenia subflava* and *Trigonopyxis arcula*-type. Testate numbers recover as the zone closes although species diversity is reduced. At the very top of the sequence *Amphitrema flavum* dominates at 40% followed by *Difflugia pulex* at *c.*20% and lower values of *Amphitrema wrightianum* and *Cyclopyxis arcelloides*-type at *c.*10%.

The reconstruction of the water table in this zone is limited because of insufficient testate counts. The available data suggests the water table had risen to *c.*-3cm in the bottom of the zone. The zone closes with a water table between *c.*-3cm and *c.*-2cm.

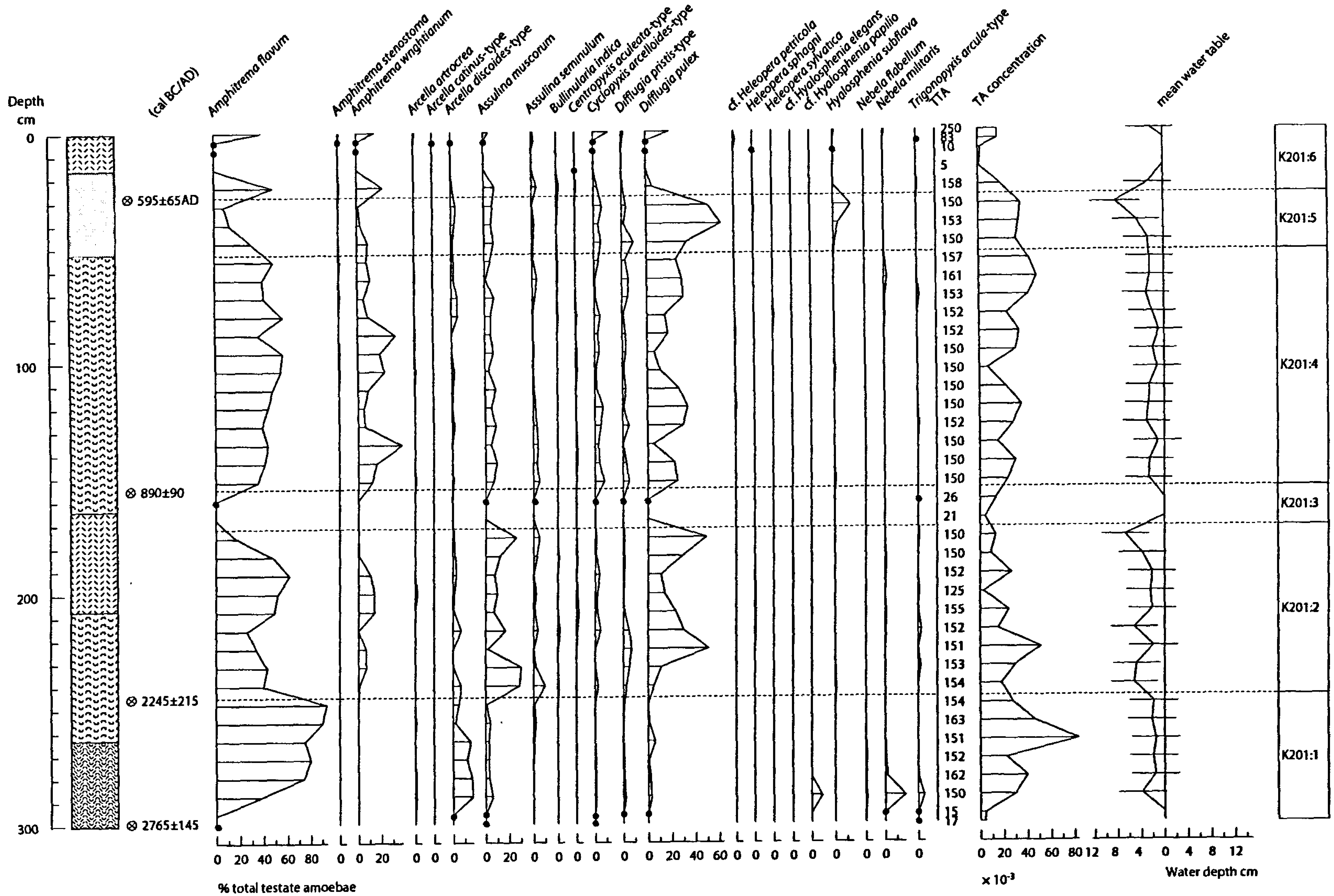

Fig. 7:7 Testate Amoebae Diagram from K201, Kilnagarnagh, Co. Offaly. For key to stratigraphy see Fig. 6:4.

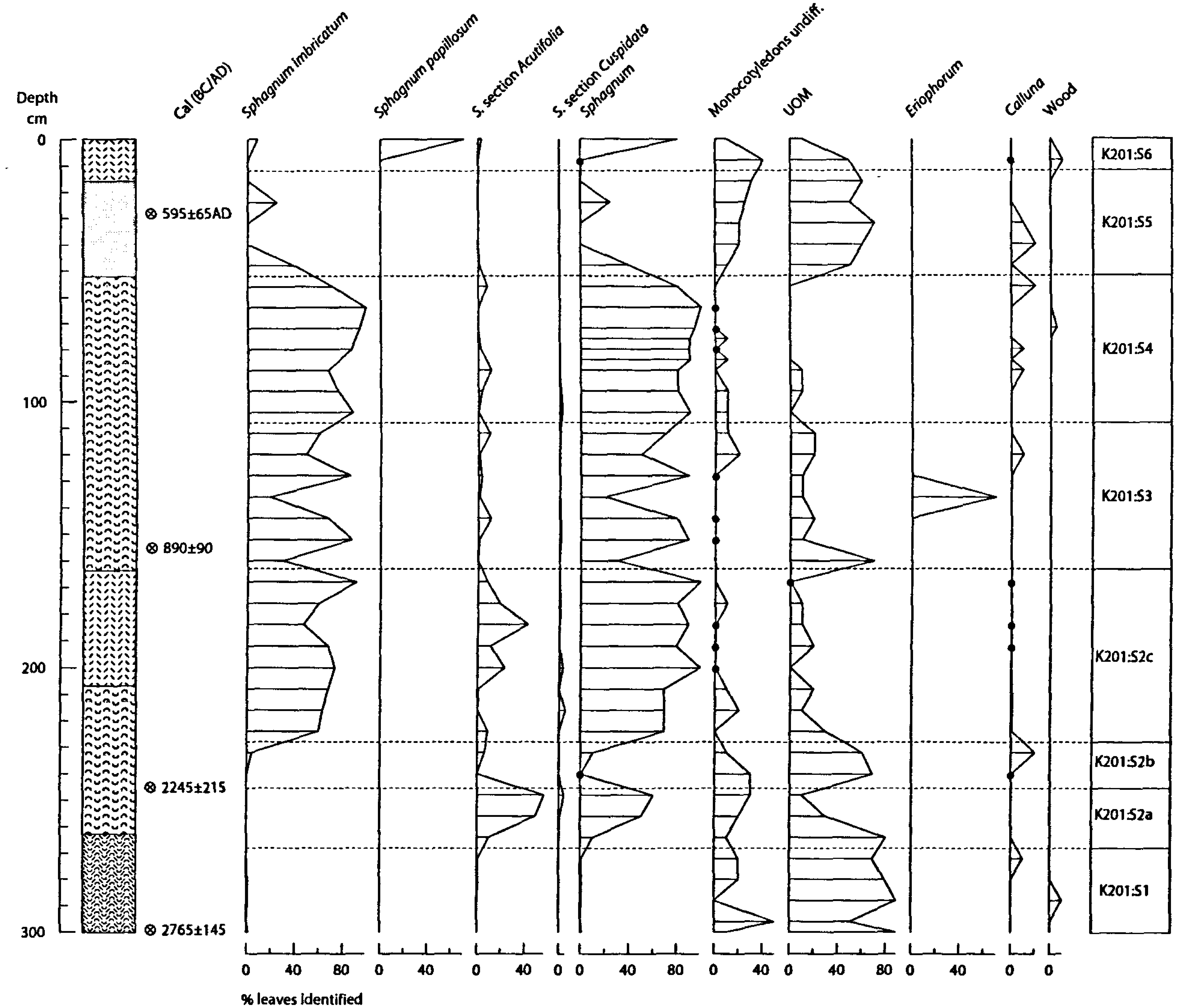

Fig. 7:8 Plant Microstratigraphy Diagram from K201, Kilnagarnagh, Co. Offaly. For key to stratigraphy see Fig. 6:4.

7:3:2 Plant microstratigraphy K201 (Fig. 7:8)

K201:S1 300cm-268cm (2765±145calBC-*c*.2500BC)

This sequence opens with low levels of *Sphagnum*. The peat is generally 80% UOM with monocots ranging from 20% to 40%. Wood and *Calluna* each occur once at *c.*10%. *Sphagnum* remains are represented by less than 2% each of *Sphagnum imbricatum* and *S.* section *Acutifolia*.

K201:S2a 268cm-242cm (*c*.2500BC-*c*.2150BC)

From *c.*270cm *Sphagnum* is registered in greater quantities rising to 50% at the top of the sub-zone. It is nearly entirely composed of *S.* section *Acutifolia* with *S.* section *Cuspidata* a minor component. UOM values decline over the sub-zone falling from an opening 80% to *c.*15%. Monocots rise to near 30% as the sub-zone closes.

K201:S2b 242cm-228cm (*c*.2150BC-*c*.2000BC)

Sphagnum values have declined to below 10% and UOM has risen to more than 70% in K201:S2b. There is a small peak in *Calluna* at *c.*20% and monocot values have declined to below 10%.

K201:S2c 228cm-163cm (*c*.2000BC-*c*.1100BC)

UOM and monocots are in decline over the course of this sub-zone in which *Sphagnum* representation dominates. *Sphagnum* accounts for between 70% and 90% of the peat in K201:S2c. UOM has fallen to between 10%-20% while monocots are present in trace amounts mid-way in the sub-zone. *Calluna* is consistently present though only as a minor component of less than 2%. Of the Sphagna represented, *S. imbricatum* has emerged to become the dominant taxa though an increase in *S.* section *Acutifolia* in the upper half of the sub-zone reduces its representation. *S.* section *Cuspidata* occurs in low amounts over the course of the sub-zone.

K201:S3 163cm-108cm (*c*.1100BC-*c*.350BC)

In this zone the general dominance of *Sphagnum* is interrupted by an opening spike in UOM values to *c.*70% and a mid-zone spike in *Eriophorum* to *c.*55%, the only occurrence of this plant in this profile. Following its initial dominance UOM values fall to between 10%-20% until the close of the zone. Near the top of the zone monocot values increase from trace amounts to around 20%. The *Sphagnum* record is again dominated by *Sphagnum imbricatum* which, with exception of the levels in which UOM and *Eriophorum* peak, lies consistently between 60%-80%. *S.* section *Acutifolia* is of lesser importance and *S.* section *Cuspidata* (≤2%) is present in the lower part of the zone.

K201:S4 108cm-52cm (*c.*350BC-*c.*400AD)

This zone is characterised by the dominance of *Sphagnum* remains which account for more then 80% until close to the top of the zone. In the lower half of the zone both UOM and monocots are present as minor components of 10% or less. Both *Calluna* and wood re-appear in the record (*c.*10% each) though the latter occurs only once. *Calluna*, UOM and monocot values are poorly represented mid-zone but increase as the zone closes where UOM is re-established as a significant component reaching *c.*50% and the *Sphagnum* curve is in decline. *Sphagnum imbricatum* is the most important moss represented followed by *S.* section *Acutifolia* whose abundance oscillates up to 10%. *S.* section *Cuspidata* occurs in the lower part of the zone, reaching ≤2% and then disappears from the record.

K201:S5 52cm-10cm (*c.*400calAD-c.AD1500)

Falling *Sphagnum* values and increases in UOM and monocots characterise this zone. *Sphagnum* continues to drop with the exception of a small peak to 30% mid-zone. UOM accounts for more than 50% and monocots rise steadily from 10% to 40%. *Calluna* rises to *c.*20% and then falls to 10% and below. *Sphagnum imbricatum* is the most significant moss.

K201:S6 10cm-0cm (*c.*AD1500-*c.*AD2000)

Sphagnum rises to *c.*80% replacing UOM and monocots, each at *c.*10%. *Sphagnum papillosum* has replaced *S. imbricatum*; the latter is below 10% while the former accounts for nearly 70% of the bryophyte content. *S.* section *Acutifolia* re-appears but at low values (≤2%).

7:4:3 Chronological control K201 (Fig. 7:2)

Four AMS dates were obtained from this sequence (Table 7:1). The age-depth model (Fig. 7:2) which is probably based on compacted peat suggests sedimentation was relatively even and continous with the exception of the uppermost peat deposit. The rate of peat accumulation slowed from *c.*AD600 to the present day. Where previously it was *c.*12yrs/cm, the rate of accumulation slowed to 50yrs/cm suggesting impeded bog growth from the middle of the first millennium AD or compaction.

7:4 K301

7:4:1 Testate Amoebae K301 (Fig. 7:9)

K301:1 344cm-283cm (*c.*4800BC-3825±125calBC)

No testates were found in these samples. The upper zone boundary demarcates where the testates increase to countable levels.

K301:2a 283cm-252cm (3825±125calBC-*c.*3500BC)

A peak in *Amphitrema flavum* to *c.*75% marks the opening of this sub-zone followed by a steady decline in the taxon to the close of the zone. *Arcella discoides*-type, *Cyclopyxis arcelloides*-type, *Difflugia pulex* and, in the upper part of the sub-zone, *Trigonopyxis arcula*-type are almost equally represented and each attains maximum representation at *c.*20%.

As the sub-zone opens the water table lies *c.*-2cm below the surface. From here it drops steadily to *c.*-7cm.

K301:2b 252cm-242cm (*c.*3500BC-*c.*3100BC)

This sub-zone is characterised by low representation of *Amphitrema flavum* and the shared dominance at *c.*20% each of *Assulina muscorum*, *Cyclopyxis arcelloides*-type and *Trigonopyxis arcula*-type. This is followed by a fall to either absence or trace values in all taxa. As the sub-zone closes test values are beginning to recover.

Water table reconstruction is hindered by insufficient testate numbers in the upper sample from this sub-zone. Data from the bottom of the sub-zone suggests the water table was maintained at the same level found in K301:2a, *c.*-7cm below the surface.

K301:2c 242cm-180cm (*c.*3100BC-2215±185calBC)

Amphitrema flavum steadily increases and reaches over 60% in the upper half of the sub-zone. *Difflugia pulex* is subdominant to *Amphitrema flavum.* It increases steadily to nearly 40% in the top of the sub-zone. The lower half of the zone sees an initial increase then a steady decline in *Assulina muscorum* (from *c.*30% to *c.*10%), with falls in *Cyclopyxis arcelloides*-type (from *c.*20% to >2%) and *Difflugia pulex* (from *c.*20% to trace values) also recorded. Other taxa such as *Nebela militaris* and *Trigonopyxis arcula*-type tend to be concentrated in the bottom half of the sub-zone but in low amounts (*c.*10% and *c.*15% respectively).

At the base of the sub-zone the water table reconstruction suggests a situation similar to that at the close of K301:2a. The water table lies at *c.*7cm below the bog surface. This is followed by a steady increase in the level of the water table to *c.*-2cm as the zone closes.

K301:3 180cm-132cm (2215±185calBC-1045±145calBC)

Once again *Amphitrema flavum* dominates although it decreases from *c.*65% to *c.*50% from zone bottom to top. *Amphitrema wrightianum* is subdominant to *A. flavum*, increasing to *c.*40% near the middle of the zone after which it decreases to *c.*30%. *Assulina muscorum* is consistently present though it is reduced mid-zone to <3%. *Difflugia pulex* follows a similar pattern. Close to the top of the zone, *Hyalosphenia subflava* (<5%) makes its first appearance. *Arcella artrocrea*, *A. discoides*-type, *Assulina seminulum*, *Centropyxis aculeata*-type, *Cyclopyxis arcelloides*-type, *Difflugia pristis*-type and *Nebela militaris* are all present in low amounts, <2% or as trace values. Of these taxa, *Arcella artrocrea* and *Assulina seminulum* are consistently present while the others occur occasionally.

The water table rises from *c.*-2cm to the bog surface in the middle of the zone. After this the water table gradually drops by one or two centimetres.

K301:4 132cm-83cm (1045±145calBC-*c.*250BC)

This zone is characterised by the increased importance of *Hyalosphenia subflava* which peaks at 50% at the top. *Amphitrema flavum* though declining is still abundant, reaching *c.*30%-50% apart from at the top of the zone where it drops below *c.*15%. *A. wrightianum* falls steadily from *c.*20% to trace values in the upper part of the zone. *Arcella discoides*-type, *Assulina seminulum* and *Assulina muscorum* are consistently present in relatively stable but low amounts (between *c.*5%-10%). *Difflugia pulex* is the fourth most abundant taxon although it drops from *c.*15% to trace values mid-zone. It then rises to near 20% above this point. Trace components in the lower half of the zone include *Amphitrema stenostoma, Arcella artrocrea, Bullinularia indica,* and *Cyclopyxis arcelloides*-type. *Heleopera sphagni* and cf. *Nebela vitraea* occur in trace amounts near the top of the zone.

The water table continues to lower gradually over this zone falling from *c.*-2cm to a previously unattained low of *c.*-10cm.

K301:5 83cm-60cm (*c.*250BC-130±110calAD)

This zone is defined by the decline in *Hyalosphenia subflava* which persists throughout the zone but has dropped below 10%. The zone brackets two peaks in *Amphitrema flavum* which dominates with values between 40-60%. *Difflugia pulex,* the second most abundant taxon, accounts for *c.*20%-30%. *Arcella discoides*-type, *Amphitrema wrightianum, Assulina muscorum, A. seminulum, Cyclopyxis arcelloides*-type and *Difflugia pristis*-type are consistently present in low numbers within the zone. The remaining taxa include *Bullinularia indica, Centropyxis aculeata*-type, and *Heleopera petricola* are present in trace amounts as are *Nebela militaris* and *Trigonopyxis arcula*-type. A modest increase in the latter to *c.*2% occurs in the upper part of the zone.

The water table has recovered from its low point of *c.*-10cm to *c.*-3cm.

K301:6 83cm-60cm (130±110calAD-545±115calAD)

The zone is characterised by the predominance of *Hyalosphenia subflava* and the reduced incidence of *Amphitrema flavum* and *A. wrightianum. Hyalosphenia subflava* has increased to almost 95% in the lower part of the zone. It then falls to *c.*50% only to rise again to *c.*90%. Other taxa, *Arcella discoides*-type, *Assulina muscorum, Cyclopyxis arcelloides*-type, *Difflugia pristis*-type, *Difflugia pulex* and *Trigonopyxis arcula*-type are generally persistent throughout the zone and, with the exception of *Arcella discoides*-type, each maintain percentages of 10% or less.

In this zone the greatest drop in the water table recorded for the sequence is implied. Having fallen from *c.*-4cm at the beginning of the zone the water table sinks to *c.*-15cm after which it recovers slightly to *c.*-10cm before falling again to *c.*-15cm.

K301:7 30cm-0cm (545±115calAD-*c.*AD2000)

The zone opens with *c.*70% *Amphitrema flavum* and the reappearance of *A. wrightianum* which rises to *c.*30% at the close of the sequence. *Hyalosphenia subflava* falls to values of <10% but then disappears from the record. There is small peak (<20%) in *Assulina muscorum* as the zone closes. *Arcella discoides*-type, *Assulina muscorum*, *Cyclopyxis arcelloides*-type and *Difflugia pulex* persist throughout the zone but in low values between <5%-*c.*10%. The trace components *Amphitrema stenostoma* and *Difflugia pristis*-type provide the assemblage with species diversity albeit reduced in comparison with previous zones.

The water table rises from a low of *c.*-15cm at the close of K301:7 to *c.*-2cm.

7:4:2 Plant microstratigraphy K301 (Fig. 7:10)

K301:S1 342cm-228cm (*c.*4800BC-*c.*3000BC)

The sequence opens with monocots and wood each at *c.*30% and sub-dominant to UOM which lies at *c.*40%, until wood rises to *c.*50% and then *c.*60% after which it disappears from the record. Monocots drop to trace amounts mid-zone after which they increase and stabilise at *c.*15%. *Calluna* appears in the upper half of the zone to attain its highest values of *c.*15%.

In the bottom half of the zone *Sphagnum* is poorly represented although a *Sphagnum* spike occurs at *c.*280cm (just after *c.*3825calBC) followed by a decline. The *Sphagnum* spike is represented by cf. *Sphagnum palustre* at *c.*50% with the remainder composed of *S.* section *Acutifolia*, cf. *Sphagnum magellanicum* and *S. imbricatum*.

K301:S2 228cm-52cm (*c.*3000BC-*c.*AD250)

This zone is characterised by consistent and high *Sphagnum* representation at the expense of UOM and monocots with the latter represented in low values of <10% at most. Their representation increases in the upper part of the zone where they rise to between 30%-40%. In the bottom of this zone UOM is temporarily dominant rising to *c.*80% at 200cm before declining to *c.*10% at 170cm. Above 170cm UOM gradually increases, hitting a small peak of *c.*45% at *c.*105cm. Its representation then oscillates before rising to *c.*40% at the close of the zone.

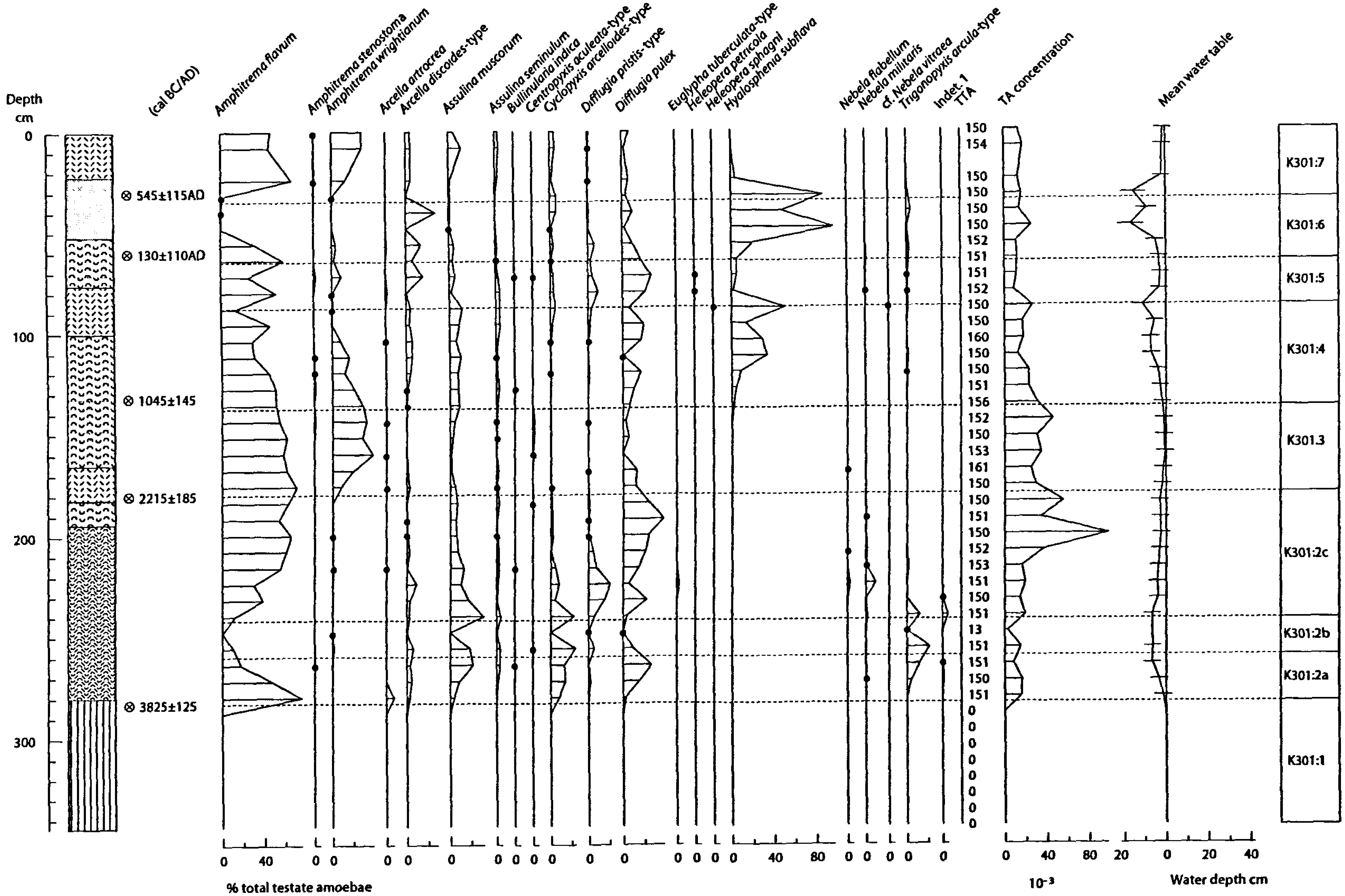

Fig. 7:9 Testate Amoebae Diagram from K301, Kilnagarnagh, Co. Offaly. For key to stratigraphy see Fig. 6:4.

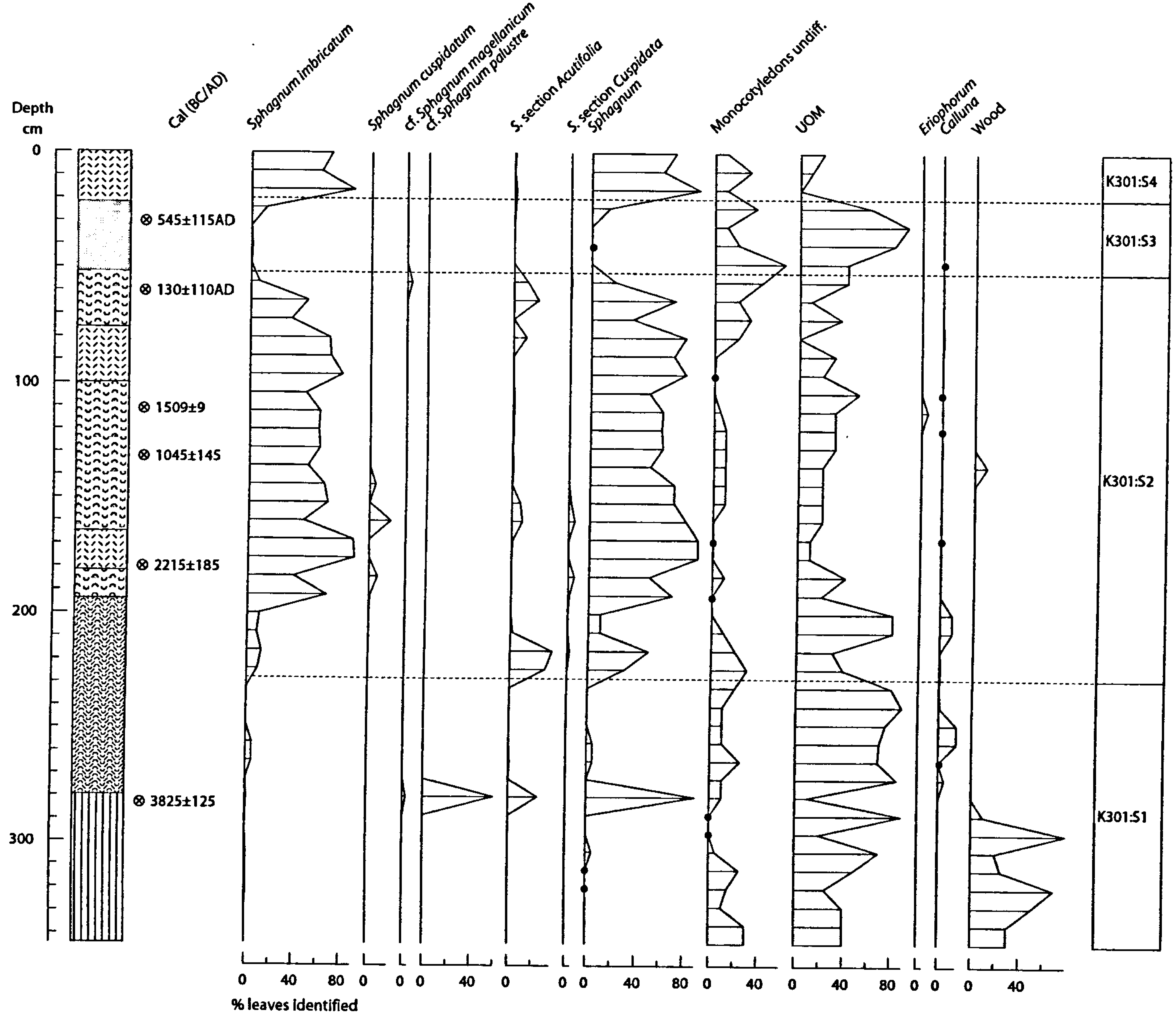

Fig. 7:10 Plant Microstratigraphy Diagram from K301, Kilnagarnagh, Co. Offaly. For key to stratigraphy see Fig. 6:4.

From 230cm to 55cm *Sphagnum* begins to dominate the record with reductions in monocot and UOM. At 230cm *Sphagnum* rises to 45% before falling to *c.*10% but rising to dominate the sequence to the close of the zone. At *c.*35% *S.* section *Acutifolia* is the primary bryophyte from *c.*230cm-210cm. It is then replaced by *Sphagnum imbricatum* which dominates the *Sphagnum* record accounting for 60%-80% of the identified Sphagna although close to the top of the zone its value drops below 10%. Here *S.* section *Acutifolia* has risen in value to over 20%. *Sphagnum cuspidatum* and *S.* section *Cuspidata* are minor components in the *Sphagnum* assemblage in the lower half of the zone. The former achieves its highest representation of *c.*20% around 160cm after which it declines and does not re-appear in the record. *S.* section *Cuspidata* re-emerges at the close of this zone as a very minor constituent.

K301:S3 52cm-20cm (*c.*AD250-*c.*AD1000)

An almost complete absence of *Sphagnum* and a return to dominance of UOM characterises this zone. UOM peaks at *c.*90% while *Sphagnum* is no longer significant other than as a trace component and is represented either by *Sphagnum imbricatum* or *S.* section *Acutifolia.*

K301:S4 20cm-0cm (*c.*AD1000-*c.*AD2000)

In this zone *Sphagnum,* almost entirely *Sphagnum imbricatum,* is once again dominant comprising between 70% and 80% of the peat constituents. UOM has fallen to between 15%-20% and monocots oscillate between 10% and 20%. *S.* section *Acutifolia* is registered in trace amounts.

7:4:3 Chronological control K301 (7:3)

Five levels were subject to AMS dating with the chronology extending from early fourth millennium BC to the middle of the first millennium AD (Table 7:1). As with the other AMS sequences from Kilnagarnagh this model (Fig. 7:3) suggests continous sedimentation. The estimated rate of accumulation slowed from 16yrs/cm to 24yrs/cm after *c.*2200BC. From *c.*1000BC it appears to have increased to 16yrs/cm and to *c.*14yrs/cm from around AD150, though as these peat deposits are compacted these estimates may be artificial.

The trackway, dated by dendrochronology to 1509±9BC (Q9291), is found at the site of K301. As with K101 this date lies closer to the AMS date of 1045±145BC (Wk-14142) than might be expected given the estimated peat accumulation rate of 24yrs/cm. It is possible a discrepancy exists between the OD of the core and that of the trackway either related to the survey or to compaction of the peat because of drainage (see Section 7:2:4).

7:5 K102

7:5:1 Testate amoebae (Fig. 7:11)

K102:1 400cm-359cm (*c*.4000BC-3625±105calBC)

Testates are present only in trace amounts. There are nine taxa represented - *Amphitrema flavum*, *A. wrightianum*, *Arcella discoides*-type, *Assulina muscorum*, *A. seminulum*, *Centropyxis aculeata*-type, *Cyclopyxis arcelloides*-type, *Difflugia pulex* and *Trigonopyxis arcula*-type. *Amphitrema flavum* and *Difflugia pulex* are consistently present with the exception of one sample in the middle of the zone where *Difflugia pulex* was absent.

Insufficient testate numbers have prevented water table reconstruction in this zone.

K102:2a 359cm-330cm (3625±105calBC-*c*.3250BC)

Difflugia pulex is dominant reaching values of *c*.60%. Mid-way in the sub-zone *Amphitrema flavum* rises to *c*.40% and this is followed by a sharp decline to almost trace values. Other taxa are represented in small amounts with *Assulina muscorum* and *Cyclopyxis arcelloides*-type comprising the greater part of the minor assemblage components.

Here, over three levels, the water table falls steadily from *c*.-3cm to *c*.-6cm.

K102:2b 330cm-292cm (3250BC-2755±235calBC)

Testate concentrations in this sub-zone are variable. It opens with *Difflugia pulex* prevalent at *c*.60%. This initial dominance is reduced to an almost equal share, *c*.40%, with *Amphitrema flavum* in the top half of the sub-zone. The remaining assemblage components, *Arcella discoides*, *Cyclopyxis arcelloides*-type, *Difflugia pristis*-type and *Assulina muscorum* have values below 5-10% or are present in trace amounts.

Testate numbers were insufficient to allow inclusion of all levels in the water table reconstruction. The water-table has risen to *c.*-1cm but drops as the sub-zone closes to *c.*-3cm.

K102:3 292cm-230cm (2755±235calBC-2010±130calBC)

This zone opens with increased representation of *Amphitrema flavum* which rises to *c.*70% in the bottom section of the zone. There is an initial small peak in *Assulina muscorum* at *c.*20% followed by fluctuating values from 5%-15%. *Arcella discoides*-type and *Difflugia pristis*-type increase to *c.*10% towards the top of the zone and *Cyclopyxis arcelloides*-type decreases to low values. *Difflugia pulex* generally increases throughout the zone achieving c.60%. Species diversity is maintained in this zone by the presence of trace amounts or very low percentages of *Arcella catinus* type, *Assulina seminulum*, *Centropyxis aculeata*-type, *Nebela militaris*, *Nebela flabellum* and *Trigonopyxis arcula*-type, particularly in the lower half of the zone.

In K102:3 an initial fall in the estimated water table to *c.*-4cm is followed by a steady rise to *c.*-2cm. The water table then drops again to *c.*-4cm before returning to *c.*-2cm in the top of the zone.

K102:4 230cm-149cm (2010±130calBC-910±90calBC)

The emergence of *Amphitrema wrightianum* characterises the zone, reaching values of 10%-30%. *A. flavum* is present in trace amounts as the zone opens but reaches *c.*50-60% within the zone. *Difflugia pulex* shares dominance with *Amphitrema flavum*, the former increasing as the latter declines. *Assulina muscorum* is consistently present reaching *c.*15% in the upper part of the zone. *Arcella discoides*-type is present in very low percentages (>2%) at the start but is not recorded in the upper sections of this zone The reconstructed water table oscillates between *c.*-1cm to *c.*-5cm.

K102:5 149cm-60cm (910±90calBC-510±90calAD)

The main feature of this zone is the increase in *Hyalosphenia subflava*, reaching *c.*30%. Trace levels of *Trigonopyxis arcula*-type and *Nebela militaris* occur sporadically. *Amphitrema wrightianum*, which was consistently present in the previous zone, is absent from the bottom half of K102:6 but recovers to *c.*10% in the upper half. *A. flavum* continues to be an important component fluctuating between *c.*10%-50%. *Assulina muscorum* and *Arcella discoides*-type are consistently present and the latter achieves its highest representation of *c.*20% mid-zone. *Difflugia pulex* is again dominant peaking between 50%-60%.

The water table curve falls to *c.*-4cm in the bottom part of the zone, then more or less continues to rise to just below the mire surface at *c.*88cm. Above this point, it dips to *c.*-4cm as the zone closes.

K102:6a 60cm-12cm (510±90calAD-*c.*AD1600)

This sub-zone is dominated by *Amphitrema flavum* (*c.*50%-65%) and *A. wrightianum* (*c.*20%-30%). The representation of *Difflugia pulex* has dropped to less than *c.*20% and is absent from some samples. *Assulina muscorum* is present at *c.*10% and *Amphitrema stenostoma*, *Arcella discoides*-type, *Centropyxis aculeata*-type, *Cyclopyxis arcelloides*-type, and *Heleopera sphagni*, occur in percentages of less than 5%. Other taxa present in trace amounts of 1% or less include *Arcella artrocrea*, *Arcella catinus*, and *Bullinularia indica*. The latter is confined to the bottom half of this sub-zone while *Arcella artrocrea* and *Arcella catinus* appear in the bottom and top thirds.

Oscillations in the reconstructed water table are less pronounced than previously with a more or less stable water table of *c.*-2cm recorded.

K102:6b 12cm-0cm (*c.*AD1600-*c.*AD2000)

This sub-zone is characterised by increased *Difflugia pulex* values, peaking at *c.*40% at the close of the profile. *Amphitrema flavum* is still important, although it has dropped to *c.*45%. *Amphitrema wrightianum* has also fallen to *c.*10% and *Assulina muscorum* has dropped to trace amounts as the sub-zone closes. There are increases in *Arcella discoides*-type to *c.*15% and *Cyclopyxis arcelloides*-type to *c.*10%. *Heleopera sphagni*, *Nebela flabellum*, *N. militaris* and *Trigonopyxis arcula*-type are present in low quantities.

The reconstructed water table is maintained at *c.*-2cm.

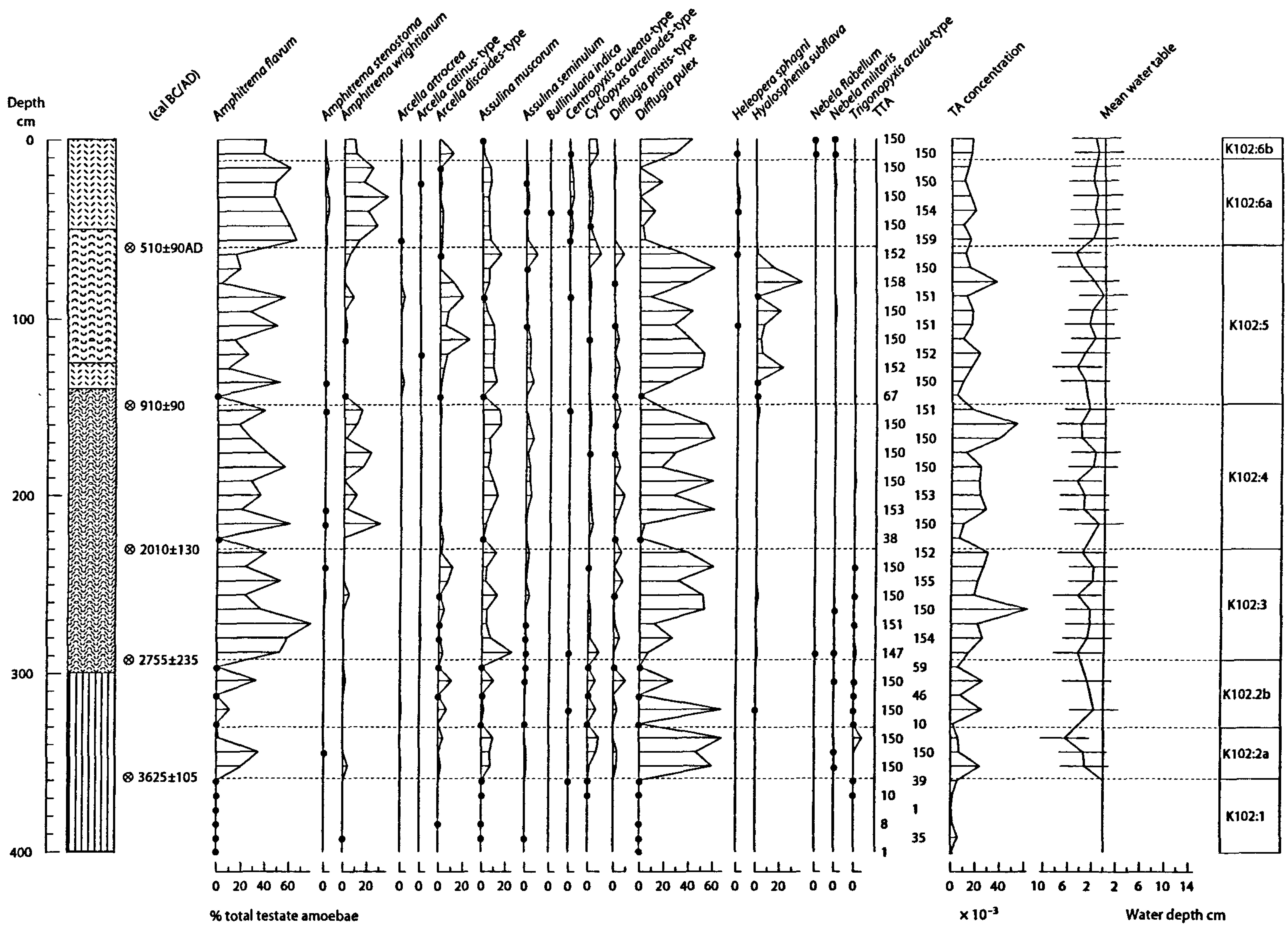

Fig. 7:11 Testate Amoebae Diagram from K102, Kilnagarnagh, Co. Offaly. For key to stratigraphy see Fig. 6:4.

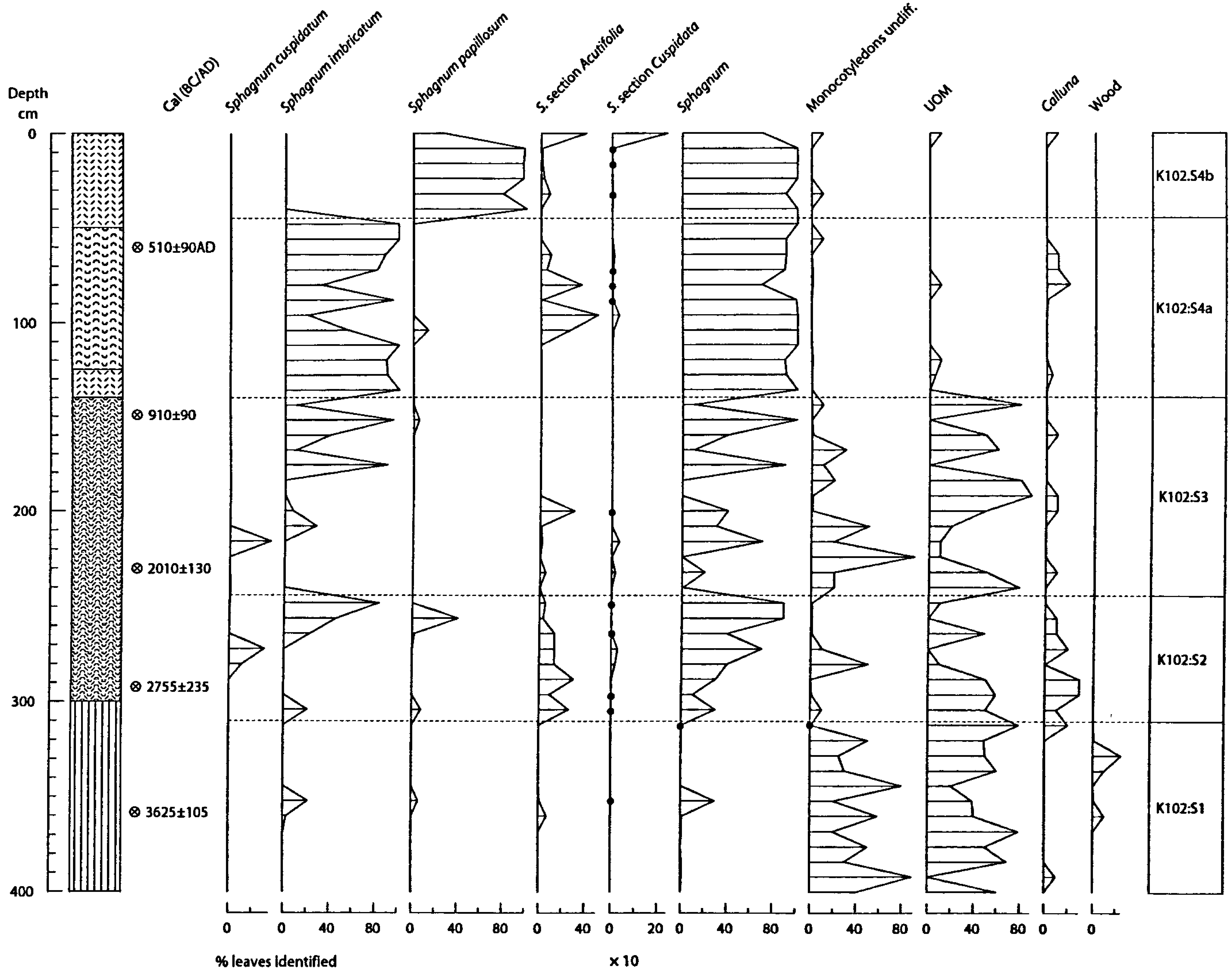

Fig. 7:12 Plant Microstratigraphy Diagram from K102, Kilnagarnagh, Co. Offaly. For key to stratigraphy see Fig. 6:4.

7:5:2 Plant microstratigraphy K102 (Fig. 7:12)

K102:S1 400cm-310cm (*c.*4000BC-*c.*2900BC)

This zone is characterised by fluctuating amounts of UOM and undifferentiated monocots which attain values from 20%-80%. In the top half of the zone wood accounts for 10%-20%. Sphagna, *S. imbricatum* with lesser amounts of *S. papillosum* and *S.* section *Acutifolia,* are represented by low values peaking at *c.*20% around 355cm.

K102:S2 310cm-244cm (*c.*2900BC-*c.*2200BC)

Sphagnum is now consistently present and rises steadily to dominate the zone reaching almost 90% at the top of the zone. Monocots are generally poorly represented though peak at *c.*40% mid-zone. UOM declines from around 80% to low values though there is a spike at *c.*50% around 265cm. *Calluna* rises to *c.*30% in the bottom half of the zone but is reduced and disappears from the record. The *Sphagnum* record is characterised by the consistent presence of *S.* section *Acutifolia* which maintains values of between *c.*10%-35% until the close of the zone where it has fallen to below 5%. *Sphagnum imbricatum* and *S. papillosum* occur in the lower and upper parts of the zone with *Sphagnum imbricatum* always dominant, peaking at *c.*80% at the close of the zone. *Sphagnum cuspidatum* and *S.* section *Cuspidata* are best represented mid-zone where the former peaks at *c.*35% though the latter does not rise above *c.*2%.

K102:S3 244cm-140cm (*c.*2200BC-*c.*800BC)

UOM and monocots alternate dominance at the base of this zone. UOM opens the zone at *c.*70% but declines to *c.*10% as monocot values rise to over 80% from *c.*20%. UOM then rises steadily reaching over 80% mid-zone. Its values then fluctuate up to 50% before rising to nearly 80% in the top of the zone. Monocots generally decline but oscillate between 2% and 25%. *Calluna* occurs sporadically at values of *c.*10%.

Initial *Sphagnum* values of *c.*20% rise to *c.*70% after which *Sphagnum* declines and is absent mid-zone. In the bottom half of the zone Sphagna comprises *S.* section *Cuspidata* (≤2%), *S.* section *Acutifolia* (≤5%) with successive small peaks in *Sphagnum cuspidatum* (*c.*40%), *S. imbricatum* (*c.*30%) and *S.* section *Acutifolia* (*c.*40%). Mid-way in the zone *Sphagnum* is no longer represented. In the upper half of the zone two *Sphagnum* spikes, largely *S. imbricatum,* rise to 80% and 90% and are separated by drops to *c.*10%. The upper spike includes the first appearance of *S. papillosum* at *c.*5%.

K102:S4a 140cm-45cm (*c*.800BC-*c*.AD800)

Zone K102:S4 (a & b) is characterised by the predominance of *Sphagnum* remains. It has been sub-divided into two zones based on taxonomic changes in the *Sphagnum* content. Other peat components such as monocots, UOM and *Calluna* represent minor elements of the macrofossil record.

Sphagnum imbricatum is the only taxa represented until *c*.115cm after which *S.* section *Acutifolia* increases, achieving its highest representation of *c*.45%. *Sphagnum papillosum* and *S.* section *Cuspidata* re-appear in the record as minor components but *Sphagnum imbricatum* is the sole bryophyte present by the top of the sub-zone.

K102:S4b 45cm-0cm (*c*.AD800-*c*.AD2000)

This sub-zone is dominated by *Sphagnum* remains. Unlike sub-zone K102:S4a, *Sphagnum papillosum* has replaced *S. imbricatum* as the primary bryophyte with the latter no longer represented in the record. *S.* section *Acutifolia* and *S.* section *Cuspidata* are minor elements though their value increases at the top of the zone where the former dominates (40%) followed by *Sphagnum papillosum* (30%) and *S.* section *Cuspidata* (20%). The remaining 10% comprises monocots, UOM and *Calluna*.

7:5:3 Chronological control K102 (Fig. 7:4)

Five levels were subject to AMS dating in this core (Table 7:1). The earliest lies in the middle of the fourth millennium BC and the latest in the middle of the first millennium AD. The dates are sequential and there are no reversals. The age-depth model (Fig. 7:4) suggests sedimentation in the deeper peats at a rate of 12yrs/cm to 13.5yrs/cm. Accumulation rates above 910±90calBC have been affected by significant compaction of the upper peat deposits. The model suggests the rate of accumulation slowed to *c*.16yrs/cm and then *c*.25yrs/cm.

CHAPTER 8

INTERPRETATION OF PEAT STRATIGRAPHIC & ARCHAEOLOGICAL RESULTS

8:1 INTRODUCTION

This chapter opens with interpretation of gross peat stratigraphic survey results. The evolution of the mire is then modelled using DEMs based on the gross stratigraphic record. This is followed by interpretation of the archaeological sequences present in Kilnagarnagh Bog and discussion of the relationship between the plank walkway and its local palaeoenvironmental record. Its wider archaeological and palaeoenvironmental context is considered later (see Section 10:2).

8:2 INTERPRETATION OF THE PEAT STRATIGRAPHIC RECORD

8:2:1 The deposit sequence

The twelve stratigraphic units or depositional environments can be assigned to three broader categories of deposit (Table 8:1).

	Categories	Stratigraphic Unit
1.	Mineral substrate	A. Lacustrine clay
		B1 & B2. Intermediate horizon
2.	Minerotrophic or fen peat deposits	C. Basal peat deposit
		D1-D4. Top of the basal peats
		E1-E3. Wood peat
3.	Ombrotrophic or raised bog horizons	F. Highly humified *Sphagnum* (HHS)
		G. Moderately humified *Sphagnum* (MHS)
		H. Poorly humified *Sphagnum* (PHS)
		I. Loose unconsolidated peat
		J. Arrested development
		K. Gullies
		L. Reed fields

Table 8:1 List of depositional environments distinguished in Kilnagarnagh Bog.

8:2:2 Unit A: Lacustrine clay

The basin floor consists largely of sticky blue clay. This clay represents lacustrine deposits that accumulated in shallow water bodies forming the post-glacial network of the Shannon basin (Hammond *et al.* 1987). Following the retreat of the ice sheet this area was covered in a network of lakes and the Shannon itself had swollen to become one huge lake (Mitchell 1986). In the early post-glacial, sediment was washed and blown into the lakes (Delaney 1997). This sediment formed lacustrine deposits of blue or grey clays that were usually fine grained, heavy, sticky and sometimes laminated with fine sand, silt and clay (Feehan & O'Donovan 1996). These lacustrine clays are known to underlie many raised bogs in counties Longford and Offaly (Hammond 1981) and many early Bord na Móna surveys identified them as the substrate over which bogs developed including the raised mire complex in Lemanaghan (Dubsky 1945). The effect of the accumulation of lake clays had been to fill in depressions in the till surface. The depth of the blue clay lacustrine deposits at Kilnagarnagh was not ascertained but at nearby Clara up to 6m of clay was identified in the central parts of the basin (Warren *et al.* 2002). Their formation was halted following a sudden drop in the regional water table that drained the Shannon basin in the early post-glacial period leaving numerous shallow lake basins in which mires later developed.

High points in the mineral substrate over which the lake clays did not form are known as ridges. At Kilnagarnagh these ridges form a distinctive zone of high ground across the middle of the basin. This serves to separate the higher surface in the north from the lower-lying basin floor in the south. This central area is interpreted below as a water shed and played an important role in the wider development of the mire.

8:2:3 Unit B: Intermediate horizon (Fig. 6:7)

At Kilnagarnagh the lacustrine clay deposits (Unit A) were overlain by Units B and C. Unit B comprises of two sub-units: Unit B1 is organic silt and B2 is a calcareous deposit. Sub-unit B1 represents sediment formed directly over the blue clays, generally situated on high or rising ground and may represent a palaeosol occupying drier locations. The calcareous sediment, Unit B2, represents deposits of lake marl. Marl is formed from the precipitation in clear lake waters of calcium carbonate from plants such as stoneworts and other organisms including ostracods and molluscs (Wetzel 1983). Deposits can range from centimetres to a few metres in thickness (Feehan & O'Donovan 1996). In the area of the Shannon basin, lake marl is not as widespread as blue clay although it has been found to directly overlie the lacustrine clays (Warren *et al.* 2002). Dubsky (1945) identified patches of marl in the Lemanaghan complex. At Clara, marl 40cm-50cm in thickness was laid down in the central and deepest parts of the basin (Warren *et al.* 2002) though at nearby Raheenmore no deposits of marl were present.

At Kilnagarnagh the survey points where lake marl was located represent some of the lowest points in the basin. They may indicate the location of the earliest water bodies within the basin in which the fen developed. At survey point 1:13 and Trans 1:2, fen peat lay directly over the marl. A similar situation is recorded at Clara Bog where the fen peat lies directly on lake marl, which Connolly (1999) suggests indicates that the lake rapidly became a fen. This may also be the case at Kilnagarnagh at these particular locations.

8:2:4 Unit C: Fen Peat (Figs 6:4-6:6, 6:8)

Unit C represents the lowermost peat deposit in the mire forming the substrate on top of which the raised bog later developed. Its composition and position within the mire sequence imply that Unit C derived from a fen peat-producing system. In general, it lies on top of sticky blue clay forming a clear, sharp boundary with the underlying mineral deposit. This suggests the rapid accumulation of organic material from 9600BC±400calBC (Table 7:1). The primary elements in Unit C are sedge-dominated deposits followed by reed peat and various combinations of sedge and reed peat. The reed is *Phragmites australis* and the sedges were undifferentiated. Within Unit C, homogenous deposits of sedge and/or reed peat indicate a continuously rising water table allowing for the accumulation of plant debris and increasing terrestrialisation over time. Fluctuating groundwater conditions are suggested by stratigraphic variation in fen peat deposits such as shallow, dark layers (>10mm) lying within the reed peat. These layers represent drops in the groundwater table that led to shrinkage of the reed peat causing its aeration and oxidisation. The seeds of *Menyanthes trifoliata* represent former areas of standing water within the fen. Close to the base of the fen, in the low part of the basin, *Menyanthes* seeds suggest the presence of shallow open water conditions during the earliest stages of fen development. There is, however, a general absence of aquatics higher in the profile pointing to a loss of standing water perhaps because of increasing terrestrialisation of the system.

Frequent and dispersed horizons of wood-rich peat or fen carr occur within Unit C representing variation in the fen. The wood is generally either *Alnus glutinosa* or *Betula* sp., common fen taxa (O'Connell 1981; Tallis 1983; O'Connell *et al.* 1984). In general, species identifications were made in the field with a limited number of microscopic identifications completed (see Table 8:2). The wooded areas represent drier episodes or situations, which may relate to fluctuations in the groundwater table or the topography of the fen. The presence of wood can imply a degree of relief at peat surface level with higher points subject to better drainage and therefore suitable for colonization by trees (Streefkerk & Casparie 1989). The longevity of individual fen carr horizons is unknown as dating was confined to ombrotrophic horizons with the exception of a single date from the base of the system. Elsewhere, pollen evidence from Walland Marsh in Southeast England (Waller *et al.* 1999) suggests fen carr was present over *c.*2000 years at Horsemarsh Sewer and The Dowels. Although these sites are coastal peatlands the pollen evidence does show that long-lived examples of fen carr do occur. At Kilnagarnagh the fen carr horizons represent temporary episodes of tree growth eventually succeeded and replaced by other fen peat types (Figs 6:4-6:6).

Sample location	Wood Species
Survey point 2:17, Sample 7	*Alnus glutinosa*
Survey point 2:17, Sample 8	*Betula* sp.
Survey point 2:5, Sample 13	*Betula* sp.
Survey point 3:7, Sample 22	Unknown. Too immature.

Table 8:2 Microscopic wood species identifications from Kilnagarnagh. Identification completed by Gavin Thomas.

8:2:5 Unit D (Figs 6:4-6:6, 6:9)

Unit D is a major transitional boundary within the mire's overall hydroseral development. It represents the fen bog junction or FBT (fen/bog transition: Hughes & Barber 2003) typically located at the interface between the lower, minerotrophic fen peats, in this case Unit C, and upper, oligotrophic raised bog deposits. The degree of variability within Unit D shows that this transition was not uniform in character, differing spatially and perhaps temporally.

The four sub-units fall in two groups:

(a) D1 and D2 represent combinations of sedge, reed and pool peat that formed a wet or very wet substrate on top of which ombrotrophic peats accumulated. This suggests that over the course of the transition from fen to raised bog a near-surface water table was maintained in these areas. D2 is best represented in the east where the occurrence of *Sphagnum cuspidatum* implies the presence of pools. The growth of *Sphagnum cuspidatum* reflects the acidic nature of the water that probably reflects the negligible influence of mineral-rich groundwater and thus the switch to ombrotrophic conditions.

(b) D3 and D4 are characterised by the presence of wood implying the existence of a drier fen surface on which trees could establish. The combination of reed and wood in D3 suggest more varied hydrological conditions than in D4. Sub-unit D3 is best represented in the northeast corner of the mire where it defines the northeastern edge of the fen system prior to the expansion of ombrotrophic peats. Its character is probably a product of its location at the edge of the system and in close proximity to the upland. It also occurs on the ridge at survey point 3:13; this ridge is not as prominent as those to the west which may explain why here a mixed wet-dry regime is represented.

The formation of D4, one of the best-defined wood horizons identified in the mire, may be a product of the elevation of the fen surface above the groundwater table due to the accumulation of peat. This produces a drier fen surface on which trees can establish. Fig. 6:9 shows that D4's distribution is closely associated with ridges in the mineral substrate, particularly in the west, implying better drainage in these areas. It is possible tree cover encroached from the ridges onto the fen surface as the latter became drier. The influence of the ridges is apparent in the extension of a wooded fen/bog transition into the middle of the mire (Fig. 6:9) (see Unit E3 below).

Unit D is overlain by Unit F, the lowermost ombrogenous deposit, with exception of those areas where the sequence was interrupted by the presence of loose peat (Unit I). The nature of the transition between Units C, D and F is discussed later in Section 10:3:2.

8:2:6 Unit E: wood peat/wood rich peat (Figs 6:4-6:6, 6:9)

E1

Close to the northern limit of the mire (survey points 1:29 and 3:25) wood peat (Unit E1) occupies the lower reaches of the basin slope. This is interpreted here as bog marginal woodland. Initially this woodland was composed of *Quercus* sp. and *Fraxinus excelsior*. The mire system expanded laterally and the area became increasingly waterlogged and acidic causing the composition of the woodland to change. Though the species of the trees present were not formally established, field identification suggest the presence of

Alnus glutinosa or *Betula* sp., species more suited to the wetter fringes of a fen or bog. Eventually, as the raised bog expanded laterally these areas were overgrown by *Sphagnum* mosses.

An undated silt horizon, lying within E1 at survey point 3:25 at 55.47m OD, represents an episode of minerogenic inwash into the margins of the mire from the nearby upland. It is represented by a single shallow horizon suggesting that it occurred once only. It appears to be limited in extent as it was not identified in cores from any other locations. This horizon may have resulted from erosion of the nearby dryland soils possibly associated with woodland clearance. Similar occurrences from other mires in Ireland include Derries bog, Co. Offaly (IAWU unpublished data) and Derryville bog, Co. Tipperary where a series of silt layers dated between *c.*240BC and *c.*0BC were identified in the fen marginal peats (IAWU 1995; Caseldine *et al.* 2005).

E2

Tree-covered ridges in the basin floor were identified in the centre, the east, the west and in the southwest corner of the mire (Fig. 6:9). Over the course of the development of the fen and the growth of the raised bog the drier situation on the ridges sustained successive stands of trees resulting in the accumulation of 80-120cm of wood peat and the preservation of tree trunks and root systems. Eventually, ombrotrophic peat inundated the ridges indicating the final loss of tree cover from the raised bog surface except in the southwest. Differences in elevation between the ridges and in the depth of overlying ombrotrophic deposits suggest this process was time-transgressive.

E3

The area of wood peat situated close to the centre of the mire demonstrates the presence of successive stands of trees almost continuously at one location during the mire's development. The gross stratigraphy suggests this was an area of hydrological flux with minerotrophic and ombrotrophic influences exchanging dominance (see below). Only the densest wood horizons are shown in Fig. 6:4, though wood was present throughout the sequence.

Above 53m OD lies the first well-defined wood horizon bordered to the south by a sedge-rich fen. Its northern limit is defined by the presence of loose peat, Unit I; given the ambiguity surrounding the formation of Unit I (see below) this may be an artificial boundary. This wood horizon developed on top of wood-rich fen peat. Sometime later, the fringing fen expanded over the northern margin of the wooded zone probably because of a rise in the groundwater table that caused partial inundation of the area. This was a temporary situation reflected in the expansion of *Sphagnum* over the area and suggesting a reduction in the influence of groundwater. The change towards ombrotrophy had already taken place above 54m OD about 100m to the south and *Sphagnum* may have expanded from here.

Renewed tree growth suggests a fall in the water table and that the influence of the groundwater was re-established in this area. The accumulation of wood peat resulted in a perched surface and removal of the peat surface from its water supply, thus leaving the area open to colonisation and the acidifying effects of *Sphagna* (Lindsay 1995) marked by the accumulation of highly humified *Sphagnum* (Unit H) in which small wood remains survive. The ombrotrophic mire was sufficiently dry to allow limited tree growth on the developing raised bog. Above 56m OD a pronounced wood peat horizon, inclusive of *Sphagnum*, sedge and reed remains, is present. It reaches about 130cm in thickness and appears to have been a consistent feature of the upper ombrotrophic landscape. This horizon marks a nutrient-rich and dry zone within the mire sequence from at least mid-way in the development of the fen to relatively recently.

The development of the wooded zone, E3, within the fen and the later ombrotrophic mire may relate to basin morphology despite its situation in the deepest part of the basin. A series of ridges extend across the middle of the basin towards the centre, i.e., the ridges identified near survey points 2:10 and 3:16. Although the ridges do not reach the centre their influence appears to extend beyond their physical limits. The ridges were generally tree covered and fringed by fen communities of sedge and reed followed later by mixed *Sphagnum*- and *Phragmites*-dominated vegetation once ombrotrophy had been attained. The ridges formed a network of treed areas and fringing wet zones extending across the middle of the basin. The wooded zone, E3, developed on the southern side of this complex drawing its nutrients from a mixed water supply - a combination of groundwater, ridge and mire (be that fen or raised bog) surface run-off and precipitation. It represents the southern limit of a major internal boundary, or watershed, within the mire where there was a mixing of water supplies, with the area sensitive to fluctuations in supply.

It is not uncommon to find stands of trees, particularly of *Betula* sp., on cut-away or dried out bogs (Cross 1987b). They are also found in association with flushes or soaks, nutrient rich areas capable of supporting mixed species *Sphagna* carpets, shrubs and small trees, e.g., at Clara Bog, Co. Offaly (Kelly & Schouten 2002). In general, such wooded areas cover small areas, >5ha though a woodland comprising *c.*20ha, fringed by an open flushed area comprising *Sphagnum* lawns and hummocks, is known from All Saint's Bog, Co. Offaly (Cross 1987b). The evolution of this woodland has not been mapped though it does lie across the centre of the bog in an area clearly subject to flushing. It may be that the underlying topography holds the key to its development at Kilnagarnagh.

8:2:7 Ombrotrophic peat units

There are three major ombrotrophic peat units in Kilnagarnagh which represent typical raised bog *Sphagnum* peat formation. Before discussing these units individually some brief comments regarding the general formation of the main peat types represented are made.

Typically the development of highly humified *Sphagnum* follows that of the fen and reflects changes in the trophic status of the mire water supply, i.e., from minerotrophic to oligotrophic, and falling pH; changes which allow a *Sphagnum* peat-forming environment to establish and maintain itself. Highly humified *Sphagnum* peat is accumulated during periods of relatively low local water tables which exposes plants to greater decay. In contrast, moderately humified *Sphagnum* peat indicates a higher water table resulting in reduced decomposition and greater peat accumulation.

Poorly humified *Sphagnum* formation reflects oligotrophic conditions and a high water table, and forms in environments where peat has been accumulating for a long time, generally on a substrate of moderately or highly humified *Sphagnum*. This can occur because more water is entering or being stored in the system and the level of discharge is reduced.

The presence of differently humified levels within the major peat units reflects variability in the water content of the peat forming surface. Moisture level variability in the acrotelm is a typical feature of a raised bog, related to factors such as vegetation, surface relief and the level of rainfall. It may occur in response to a change in climate, for example, because of a few dry summers or because the drainage system of the mire changes and discharges water at a faster rate allowing the surface to dry out more. Differently decomposed horizons may also be related to spatial features or patterning within the mire, for example, hummock-hollow systems

8:2:8 Unit F (Figs 6:4-6:6)

Unit F equates to highly humified *Sphagnum* peat and represents the earliest ombrotrophic deposit in Kilnagarnagh. Once *Sphagnum* had become established at Kilnagarnagh the change to ombrotrophy was permanent with one exception, the wooded zone, Unit E3 (see above).

The accumulation of up to 270cm of highly humified *Sphagnum* peat reflects a long-term relatively low water table. The occurrence of less well humified horizons within Unit F indicates that the accumulation of peat was not uniform because of oscillations in the water table. For example, at survey point 1:26, between 55m-56m OD layers of moderately and poorly humified *Sphagnum* lying within a broader highly humified matrix imply that the water table rose temporarily allowing the accumulation of less decomposed peat. The presence of less well humified levels may also reflect local variability in the relief of the bog surface. The occurrence of companion species such as *Eriophorum*, ericales and *Sphagnum cuspidatum* within this unit suggests the presence locally of higher, drier situations as well as lower, wetter milieu, e.g., typical of a raised bog in which hummock and hollows exist.

Identification of the peat forming systems responsible for the accumulation of *Sphagnum* within Unit F is hindered by the degree of decomposition which can obscure structural evidence, and by the limitations of coring as a means of investigation. For instance, both hummock-hollow systems and lawns are capable of producing highly humified *Sphagnum* peat but limited stratigraphic exposures make it difficult to identify such structural features within this Unit.

The thickest deposits of highly humified *Sphagnum* peat accumulated in the north and centre between *c.*3000BC-900BC. The shallower southern deposit accrued between *c.*4000BC-2400BC (Figs 6:4-6:6). This suggests that there may have been two centres of raised bog development separated by the zone of higher ground stretching across the mire and the wooded zone, E3. From each centre the raised bog expanded over the fen and onto the slopes of the tree covered ridges and the fringing slopes of the basin.

8:2:9 Unit G (Figs 6:4-6:6, 6:11)

Unit G represents moderately humified *Sphagnum* peat. Its position, between Unit F (HHS) and Unit H (PHS), shows that the transition from highly humified to poorly humified peat took place via moderately humified peat although the latter is not mire wide. As with Unit F, Unit G displays sensitivity to changes in the availability of water. Shallow horizons of poorly and highly humified peat occur, indicating hydrological fluctuation within the wider moderately humified accumulation.

Unit G is best represented in the southern half of the bog with its deepest accumulations south of the ridge in Drain 3 and the central wooded area, Unit E3. The production of moderately humified peat at these locations may be a result of greater water accumulation in the lee of these features, i.e., these features acted as a watershed within the mire with surplus water pooling to the south. In the east the occurrence of sizeable *Sphagnum cuspidatum* horizons within Unit G indicates the presence of this moss in depressions on the bog surface which lay below the water table and formed shallow open pools.

8:2:10 Unit H (Figs 6:4-6:6, 6:12)

This unit, which is composed of poorly humified *Sphagnum*, represents the upper ombrotrophic deposit found across Kilnagarnagh. The timing of the onset of poorly humified peat accumulation is variable across the mire. In the south and southeast, Unit H is established by 2500BC, in the southwest by 2000BC, and in the north by at least 1000BC. The deepest and earliest poorly humified *Sphagnum* accumulations display the thickest horizons of homogenous poorly humified *Sphagnum*. This deposit type suggests a persistent high water table consistently wet enough to allow poorly humified *Sphagnum* to accumulate more or less uninterrupted. This could have occurred in a system of *Sphagnum* lawns. These appear to have been a permanent feature at least in the centre and north, particularly in the area of Unit H3 (Fig. 6:12). Lawns appear to have been in place at Kilnagarnagh from the beginning of poorly humified *Sphagnum* peat accumulation, from at least 2000BC in the south and 1000BC in the north. Based on its position within the overall bog profile, (in terms of height OD and bounding units), it is likely that the lawn complex was, at least in part, contemporary with the hummock-hollow system (H2) in the southwest (see below).

Within H3, thin layers of *Sphagnum cuspidatum* are frequent demonstrating the presence of shallow temporary pools on the lawn surface. In the east somewhat longer lived collections of water are reflected by the presence of laminated *Sphagnum cuspidatum* peat often accompanied by layers of pool algae. This suggests that a wet lawn situation prevailed in the east, wetter than the lawns to the west. This is probably related to the overall discharge system of the mire. The basin in which the mire formed dips from northwest to southeast and this seems the most likely direction for the mire to have discharged. The ridges in the west and the central wooded area may also have impeded drainage forcing the discharge flow eastwards. Hence the bog is likely to have been wetter in the east leading to the difference in the lawn-type seen.

In the southwest the formation of the hummock-hollow complex H2 (see Section 6:3:9) is difficult to date as identification of this complex was largely confined to drain face stratigraphy. Extrapolating dates from the laboratory sequences to the gross stratigraphic records suggests that this system may have been in place by *c*.2000BC although it is not until after 1500BC (post-trackway) that distinct hummock-hollow forms are observed. They remain a distinctive feature of the mire surface until the development of Unit J. In the centuries preceding the change in conditions marked by the appearance of the Unit J, the overall impression is that *Sphagnum* lawns covered the mire in the centre and north, fringed by hummock-hollows in the south and southwest.

8:2:11 Unit I (Figs 6:4-6:6, 6:10)

This unit represents areas of water in which unconsolidated peat remains appear to be suspended. Two possible explanations for the presence of deposits of this nature are:

(a) Water that is not stored in the mire or dispersed by means of evapotranspiration or deep seepage must be discharged in another manner, for example via open channel systems such as rills or gullies on the surface of the raised bog (Ingram 1983). The areas occupied by Unit I may represent former channels or gullies through which surplus water was discharged. The peat held within the channels may be allochthonous material, eroded from the sides of the channel, or autogenous peat accumulating within the channel body as its discharge function diminished.

(b) These water-filled zones may represent voids in the peat deposit derived from drainage activities related to peat extraction by Bord na Móna. Piped sub-surface drainage networks are sunk to encourage long-term drainage of a bog. The locations of these drains are not always readily identifiable from the field surface.

8:2:12 Units J & K (Figs 6:4-6:6, 6:13)

This unit represents a distinctive mire-wide, though not continous, 'event' horizon and represents a significant interruption in the development of the raised bog at Kilnagarnagh. Its position in the bog profile is consistent across the mire; it seals Unit H and is itself sealed by later accumulations of poorly humified *Sphagnum*.

The base of Unit J is distinguished by a band of dark, highly decomposed *Sphagnum*. This implies desiccation, most likely the result of a significant drop in the water table. Peat accumulation would have been greatly restricted because of a dry bog surface. The bog appears to have been drier to the south of the arc extending between survey points 2:18 and 3:19 (Fig. 6:13). Here, the basal layer is frequently thicker and heavily cracked and represents the first phase of mire-wide desiccation. Unit J lies at a higher altitude on the edges of the mire than in the centre; giving it a concave east-west cross-section. This may reflect compression of the peat deposit because of contemporary changes in the overall system drainage or may be related to compaction of the upper peat deposit as a result of recent drainage.

South of the arc, shallow layers of poorly and moderately humified *Sphagnum* separate this lower desiccation band (Phase 1) from a second distinct and highly humified horizon. The intervening deposit suggests a renewed, albeit oscillating, bog water table which saw a return to "normal" bog conditions allowing the deposition of less humified peat. The upper highly humified deposit (Phase 2) indicates another significant fall in the water table. In general, north of the arc between 2:18 and 3:19, Unit J is distinguished by the presence of one distinct desiccation horizon overlain by successive shallow layers of less decomposed *Sphagnum*. It is possible the northern end of the system was affected by only one serious drop in the water table and second episode may not have registered in this area.

In places across the mire, both Phase 1 and 2 displayed heavy polygonal cracking which suggests the peat had previously dried out, i.e., originally it accumulated under wetter conditions but once exposed it shrank and cracked. Where such cracking is present it may represent the dried out bases of former pools. In the east, at survey points 3:15 and 3:13, the lower desiccation horizon is distinguished by its gyttja-like appearance. Here, the peat is nearly amorphous and has weathered white-grey, which suggests these deposits originally accumulated within water; possibly long lived pools that occupied the wet bog surface prior to the drop in the water table represented by the Phase 1 desiccation horizon. Also in the east, around survey points 3:18-3:15, *Sphagnum cuspidatum* underlies Unit J indicating a shift from a very wet bog surface to very dry conditions.

The stratigraphy of Unit J is complicated between survey points 1:23 and 1:19. From 1:23, Unit J is present in two phases, although its distribution is interrupted by the presence of a series of gullies lying between survey points 1:22 and 1:21 (Fig. 6:13). Gullies represent erosion phenomenon related to the discharge of water from the bog surface. These gullies represent later erosion of the dry bog surface, creating low points in which poorly decomposed peats could accumulate as the water table recovered.

The distribution of Unit J is further complicated in the mire centre by the presence of the wooded zone, E3. Here, the drop in the water table implied by Unit J is not manifest. Peat accumulation in and around this zone appears to have continued more or less uninterrupted with the peat (apart from the zone of woodland) displaying less pronounced changes in decomposition. Indeed the stratigraphy reflects optimal conditions for ombrotrophic peat growth with, for example, a well developed sequence of intercalating layers of poorly and moderately humified peat immediately north of the wooded zone E3 (Survey point 1:13, Appendix 2). Occasionally small gullies can be seen interrupting the development but these represent localised erosion rather than a wider erosion network. Bordering this system are horizons of laminated *Sphagnum cuspidatum* and poorly humified *Sphagnum* peat. The gross stratigraphy suggests this area may have been somewhat 'buffered' from the effects of a major drop in the water table owing to the influence of the nearby ridges, and their external water input, which formed a water shed across the middle of the mire (see Section 8:3:3).

Across the mire Unit J is overlain by a *Sphagnum* deposit which reflects a return to "normal" ombrotrophic conditions in which both poorly and moderately humified *Sphagnum* could accumulate. In places former shallow pools are represented by the presence of *Sphagnum cuspidatum*. The bog surface may have largely comprised of wet *Sphagnum* lawn. Recent industrial scale drainage, however, has once again seriously altered the mire's hydrology. At the time of survey, the contemporary surface was generally devoid of mosses with the surface dominated by *Calluna vulgaris*, *Myrica gale* and tree saplings of *Salix* sp. and *Picea* sp.

8:2:13 Unit L (Figs 6:12-6:13)

Unit L represents two reed fields which developed in tandem with the ombrotrophic peat deposits. The reed fields were present on the raised bog until relatively recently when mire-wide drainage and localized burning of the bog vegetation curtailed their growth. They developed in the lee of the ridge at survey point 2:16 (Fig. 6:12). The overall peat matrix was dark and crumbled easily, reflecting its oxidation in the past rather than because of recent drainage. It was not an anaerobic environment, possibly because of oxygen fed into *Phragmites* root systems. The reed fields imply a mesotrophic regime with the availability of nutrient rich water allowing reed growth within an otherwise acidic, nutrient poor environment. This may reflect the influence of the ridge and the nearby upland in this area, each serving as an additional source of nutrients and water. Unit L may be regarded as part of the watershed or contact zone formed across the middle of mire as a result of the presence of the tree covered ridges and central wooded zone, E3. The reed fields appear to have formed a hydrological buffer to the development of the ombrotrophic peat to the west and south, as recorded in Drain 2.

8:3 MODELLING MIRE DEVELOPMENT (Figs 8:1-8:8)

Further interpretation of the gross stratigraphic record has been carried out using DEMs created for each of the major phases in the mire's development are presented (Figs 8:1-8:8). The lighter hues represent higher elevations. The DEMs have been annotated graphically to indicate the vegetational composition of the mire at each stage of development. The DEMs on which these are based are included in Appendix 3. The timing of the phases of mire development is suggested using dates extrapolated from AMS determinations returned for cores subject to laboratory analysis (Table 7:1).

8:3:1 Fen development

The stratigraphic record implies that this mire developed in a clay-lined lake basin which dips from northwest to southeast (Fig. 8:1). The basin floor is punctuated by high points in the underlying glacial till and the influence of basin morphology on mire evolution is apparent from the earliest phase of development. As discussed above, ridges appear to have acted as a watershed, forming an area of high ground across the middle of the basin influencing the overall drainage and development of the mire system. The lowest points in the basin floor were occupied by two early water bodies (Unit B) out of which the fen developed. These areas were defined by the ridge system in the basin which served as high dry points facilitating the growth of woody vegetation communities (Figs 8:1-8:2). The earliest fen vegetation comprised sedge and reed communities co-existing with patches of fen carr and wetter areas inhabited by the aquatic *Menyanthes trifoliata*. By about 8000BC the fen is well established throughout the basin. In contrast to the wet sedge and reed fen, higher areas are tree covered (Units E1 & E2) (Fig. 8:2). In the centre of the fen from around 7000BC trees are consistently present in the stratigraphy (Unit E3). This can be viewed as an extension of the influence of the nearby mineral ridges on the fen and the succeeding raised bog. The ridges provided for increased drainage as well as greater nutrient availability in this area thus enabling stands of trees to establish. To the north and south of this watershed the fen consisted of wetter communities dominated by sedge and/or reed. This is broadly representative of the development of the fen from around 7000BC to the period of transition from fen to raised bog (Fig. 8:3).

8:3:2 Fen-bog transition

The fen-bog transition is marked by a variety of peat deposits (Unit D1-4). Fig. 8:3 shows some of the possible forming environments. Spatial and hydrological variability in the character the later fen is evident. A wetter transition is implied on the eastern side of the mire where there more evidence of reeds and pools. In the middle, near ridges and the basin slopes a dry pathway to ombrotrophy is suggested by the expansion of trees from these areas on to the fen surface. The model (Fig. 8:3) might imply that a synchronous change to ombrotrophy took place across the mire. However, dates (Figs 6:4-6:6) suggest ombrotrophy was attained time-transgressively, in the south (excluding

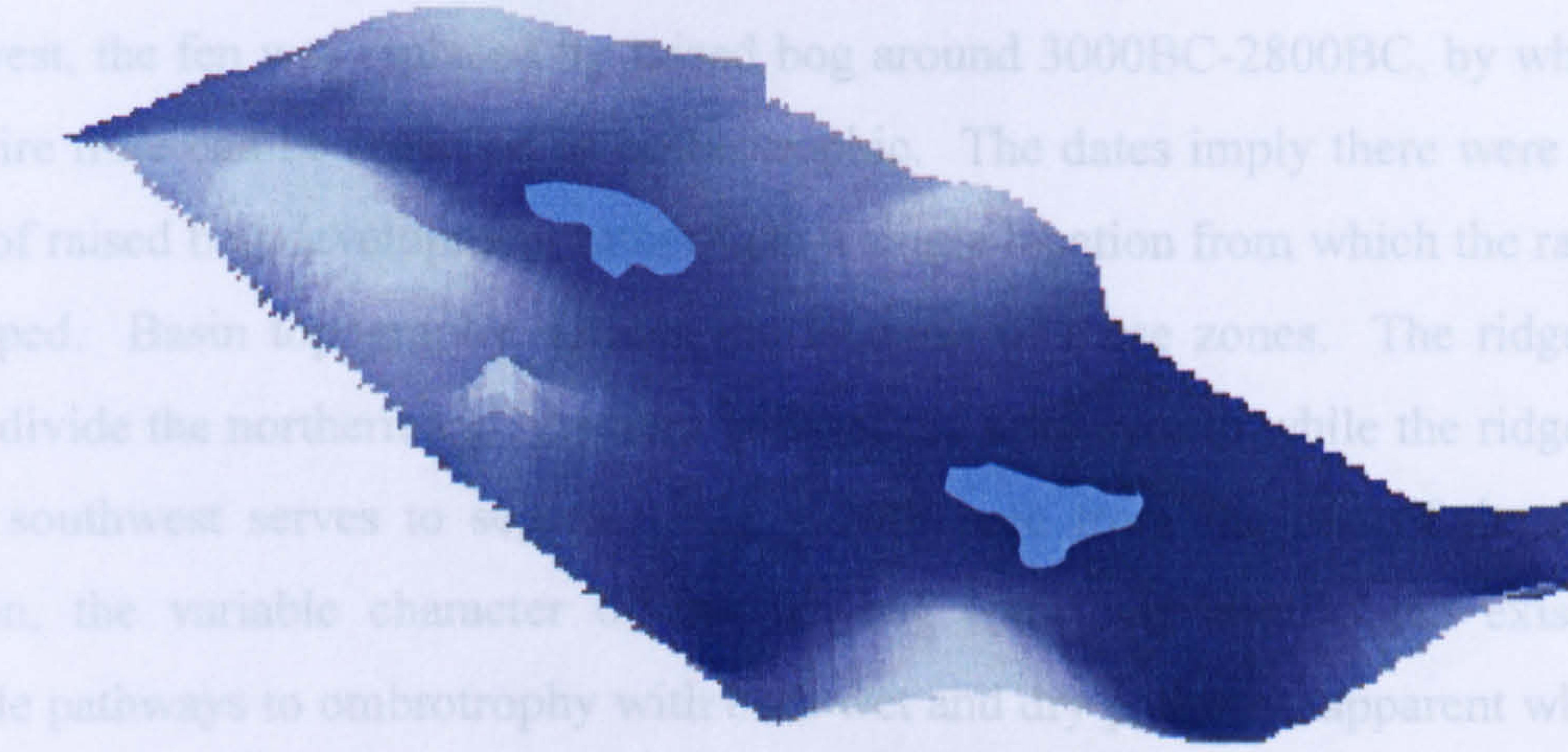

Fig. 8:1 Basin floor (Unit B1 & 2) *c*.10,000BC

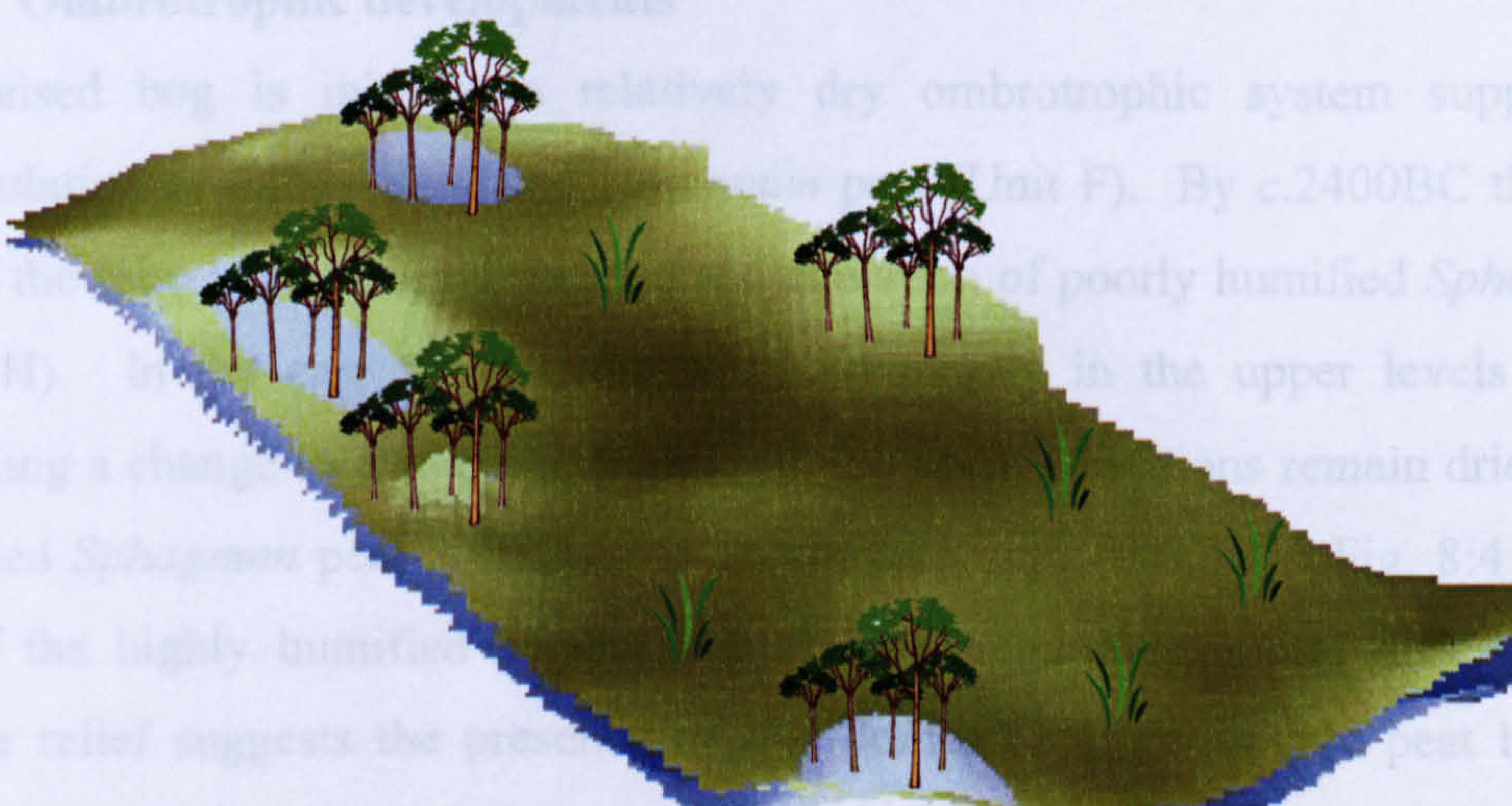

Fig. 8:2 Early fen (Unit C) development *c*.8000BC

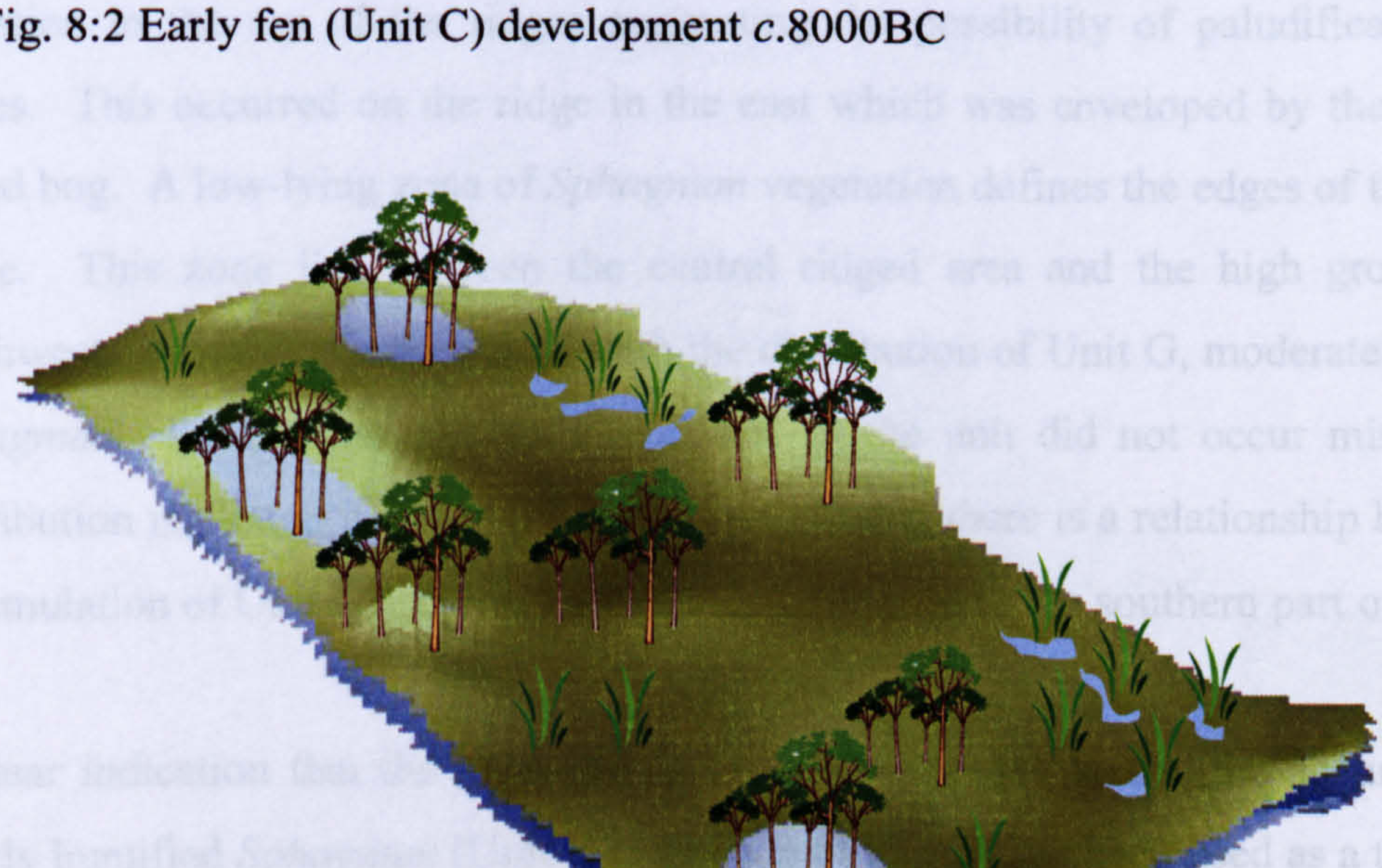

Fig. 8:3 Top of fen (Units C & D). In the north *c*.3000BC, in the south *c*.4000BC

the southwest) around 4000BC-3800BC and in the north around 3000BC. In the southwest, the fen was replaced by raised bog around 3000BC-2800BC, by which time the entire mire can be regarded as ombrotrophic. The dates imply there were multiple zones of raised bog development rather than a single location from which the raised bog developed. Basin topography defines the location of these zones. The ridges in the centre divide the northern and southern parts of the mire system while the ridge located in the southwest serves to separate bog growth here from the rest of the mire. In addition, the variable character of the fen-bog transition implies the existence of multiple pathways to ombrotrophy with both wet and dry pathways apparent which may have been determined by overall system drainage and topography. This is discussed further in Section 10:3:2.

8:3:3 Ombrotrophic developments

The raised bog is initially a relatively dry ombrotrophic system supporting the accumulation of highly humified *Sphagnum* peat (Unit F). By *c*.2400BC the southern end of the mire is wetter enabling the accumulation of poorly humified *Sphagnum* peat (Unit H). In the east pools occur more frequently in the upper levels of Unit F signalling a change to wetter conditions. In the north conditions remain drier as highly humified *Sphagnum* peat continues to accumulate until *c*.900BC. Fig. 8:4 depicts the top of the highly humified deposit but again disregards temporal differences. The surface relief suggests the presence of two domes of ombrotrophic peat lying to the north and south of the central group of ridges. In the north the dome lies at a similar elevation to the top of the ridges suggesting the possibility of paludification of the ridges. This occurred on the ridge in the east which was enveloped by the expanding raised bog. A low-lying zone of *Sphagnum* vegetation defines the edges of the southern dome. This zone lies between the central ridged area and the high ground in the southwest. It more or less equates with the distribution of Unit G, moderately humified *Sphagnum*. Unit G has not been modelled as the unit did not occur mire-wide; its distribution is plotted in Fig. 6:11. It is possible that there is a relationship between the accumulation of Unit G and surface relief and drainage in the southern part of the mire.

A clear indication that the mire had become increasingly wet is the accumulation of poorly humified *Sphagnum* (Unit H). The top of Unit H has been used as a template for the growth of this peat unit (Figs 8:5-8:6). The accumulation of poorly humified *Sphagnum* peat occurs across the mire but does not appear to be a synchronous development.

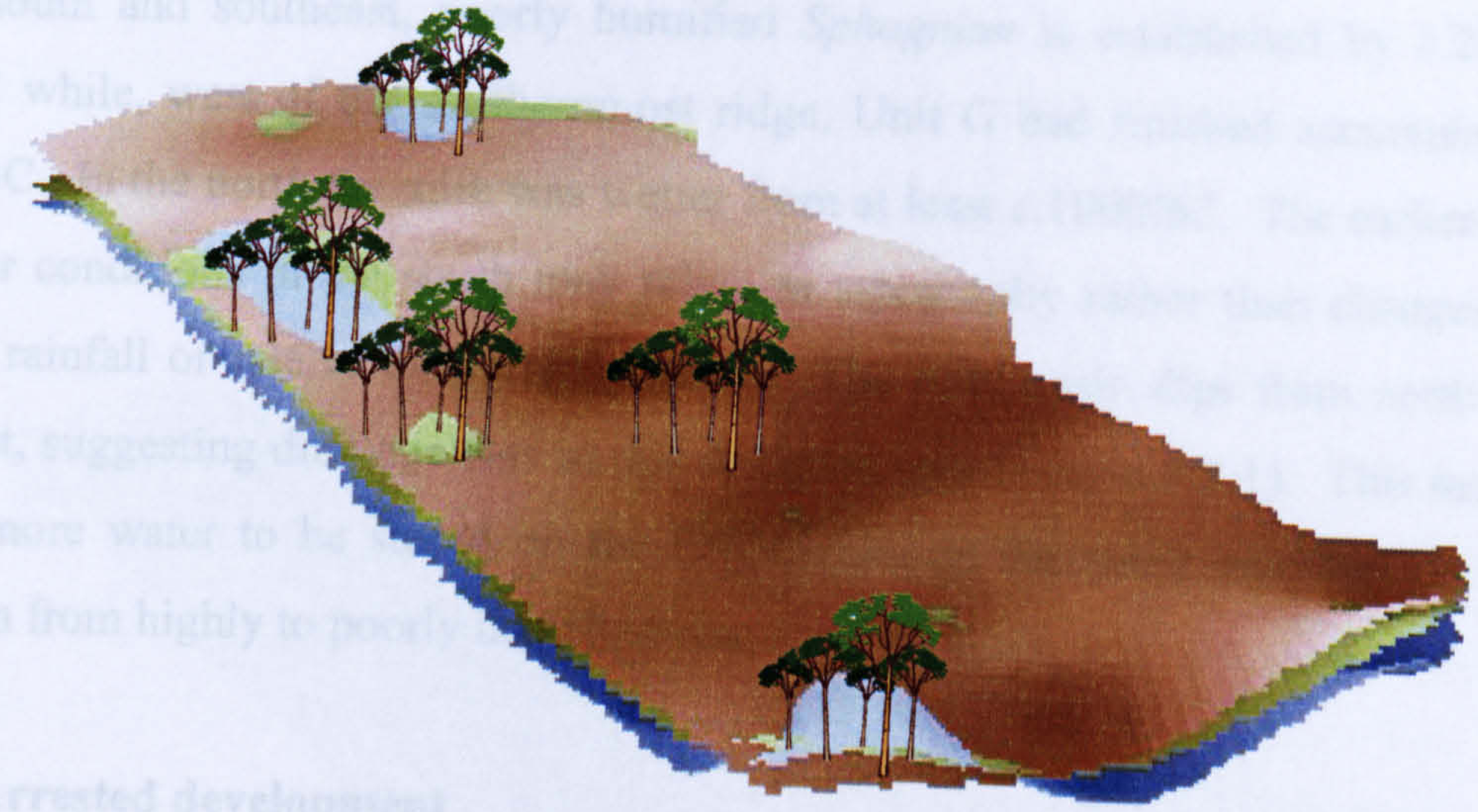

Fig. 8:4 Highly humified *Sphagnum* (Unit F)

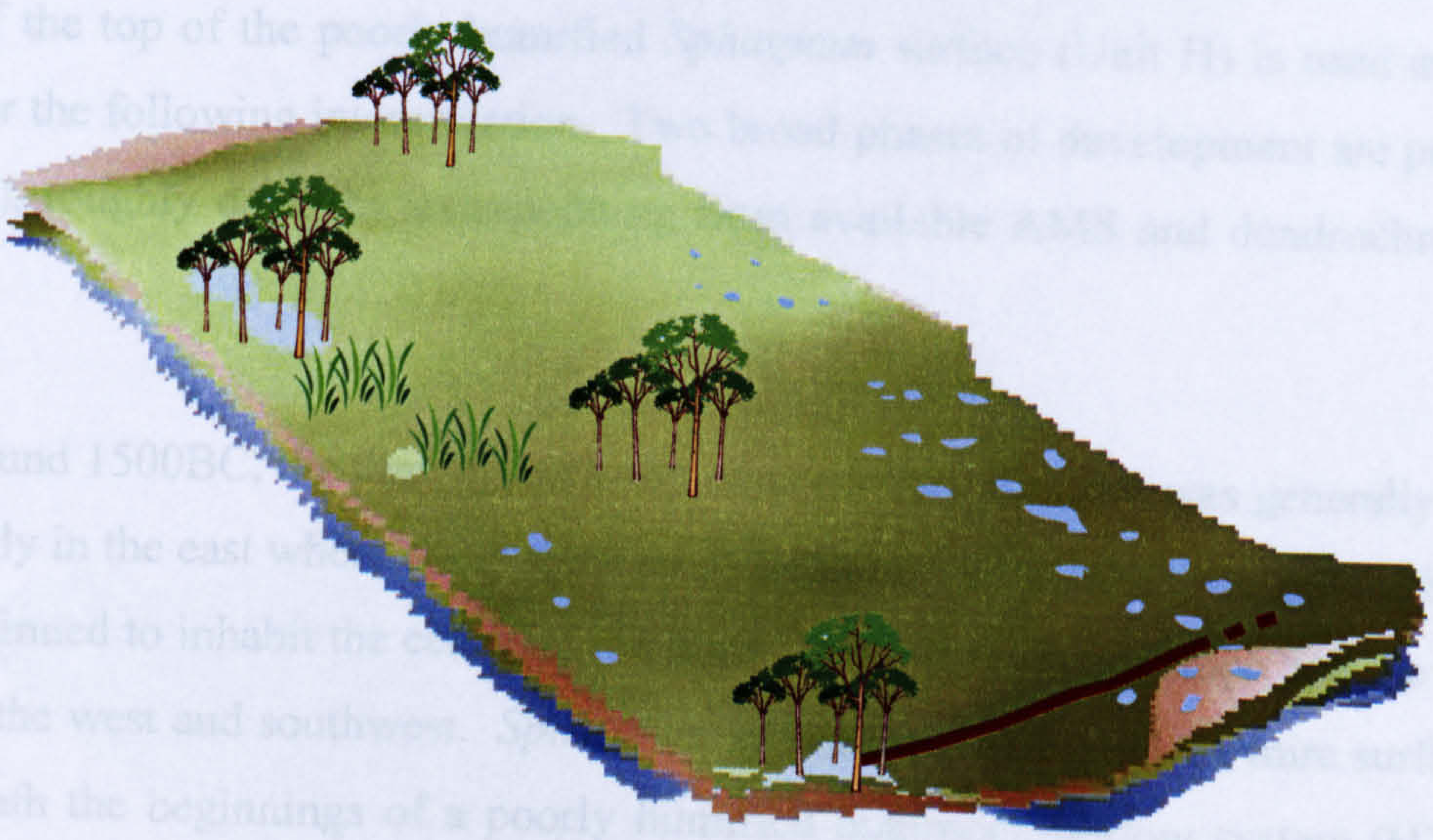

Fig. 8:5 Poorly humified *Sphagnum* (Unit H) *c.*1500BC

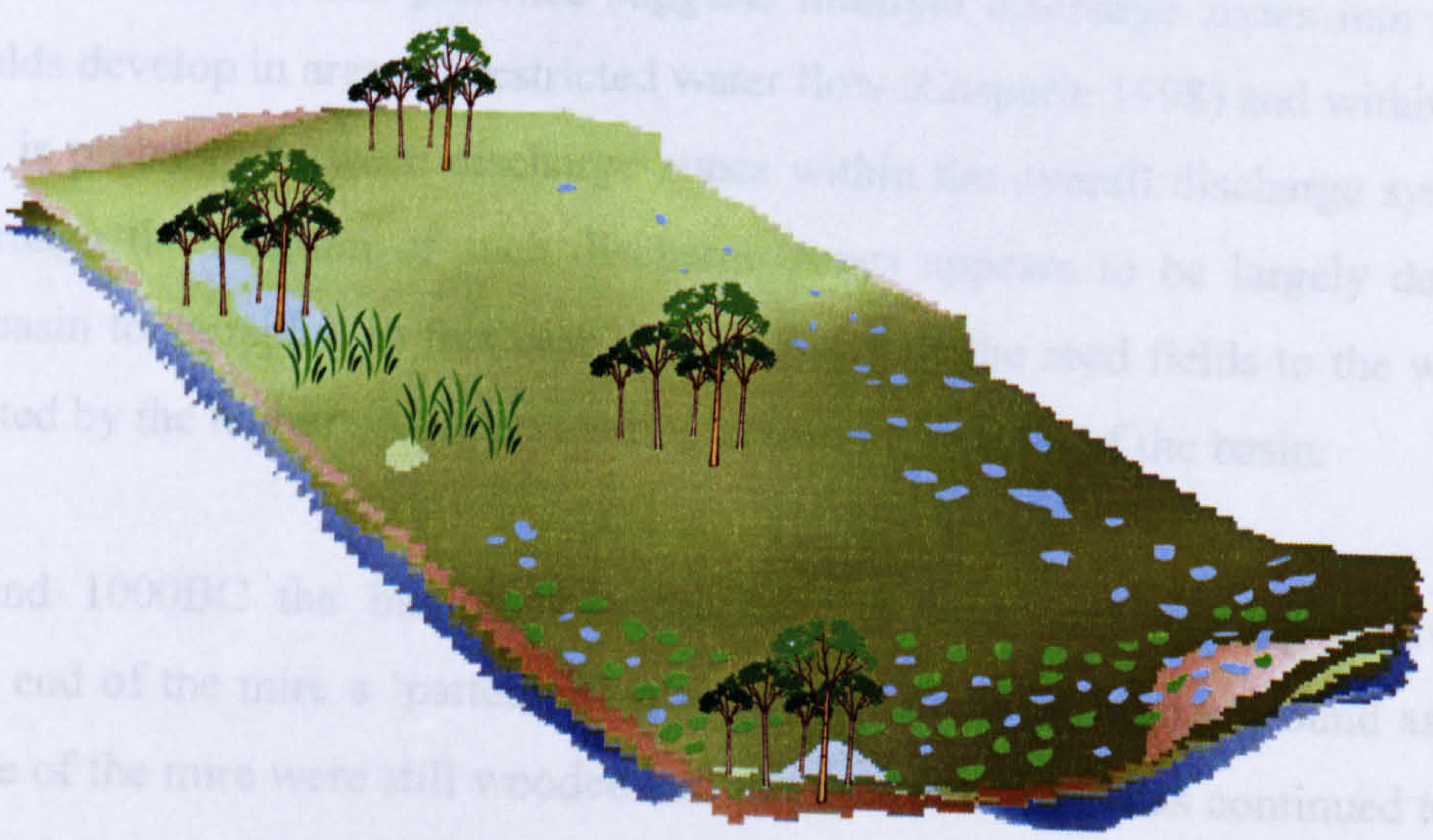

Fig. 8:6 Top of poorly humified *Sphagnum* (Unit H) *c.*1000BC

In the south and southeast, poorly humified *Sphagnum* is established by *c*.2500BC-2400BC while, west of the southernmost ridge, Unit G had finished accumulating by *c*.2000BC. In the north the mire was wetter from at least *c*.1000BC. The earlier change to wetter conditions in the south may relate to topography rather than changes in the level of rainfall or rate of evapotranspiration. The mire basin dips from northwest to southeast, suggesting drainage was in this direction (see Section 8:3:1). This may have caused more water to be stored on the bog surface in the south enabling the earlier transition from highly to poorly humified peat accumulation.

8:3:4 Arrested development

The drain face investigation of the upper peat deposits, Units H, J and K have allowed a more detailed picture of the evolution of the later phases of the mire to be developed. A model of the top of the poorly humified *Sphagnum* surface (Unit H) is used as a base model for the following interpretation. Two broad phases of development are presented (Fig. 8:7), roughly dated by extrapolating from available AMS and dendrochronology dates.

From around 1500BC, the time of trackway construction, the mire was generally wetter, particularly in the east where pools were more frequent. Tree cover was reduced though trees continued to inhabit the centre of the mire, the northern basin slope and the highest ridges in the west and southwest. *Sphagnum* vegetation dominated the mire surface and in the south the beginnings of a poorly humified hummock-hollow system (H2) were established. Two major reed fields lay on the western side of the mire in the lee of the ridges on this side. Their presence suggests multiple discharge zones into the mire. Reed fields develop in areas of restricted water flow (Casparie 1998) and within a raised bog this is probably between discharge zones within the overall discharge system. At Kilnagarnagh the location of such discharge zones appears to be largely defined by overall basin topography, in this case the proximity of the reed fields to the watershed represented by the higher ground extending across the middle of the basin.

By around 1000BC the hummock-hollow system was well developed giving the southern end of the mire a 'patterned' appearance. Areas of higher ground as well as the centre of the mire were still wooded and the western reed fields continued to thrive. In the north, wet acidic conditions allowed for the continued accumulation of poorly humified *Sphagnum* where a wet-lawn environment prevailed. In the east, where

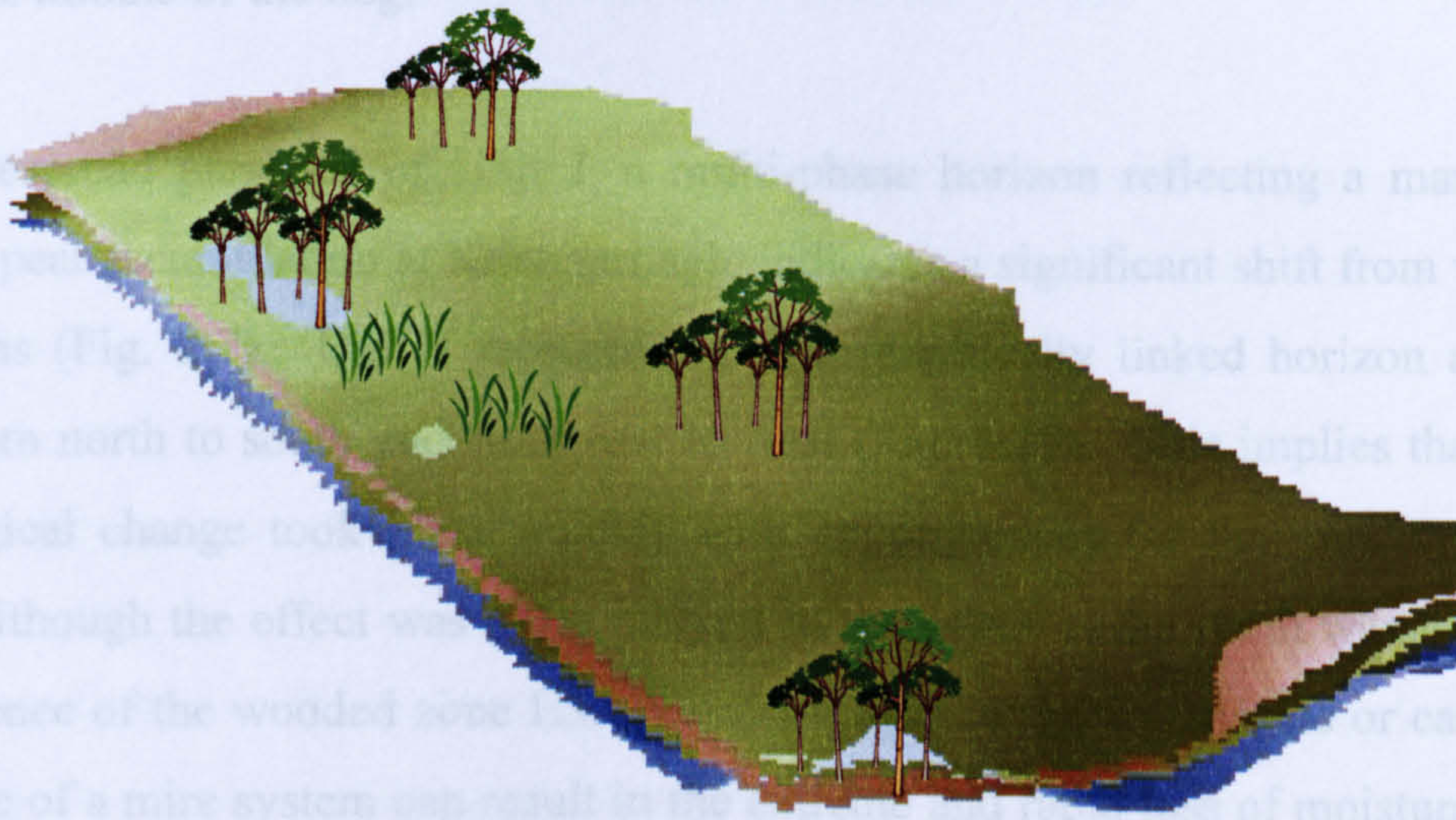

Fig. 8:7 Unit J - period of retarded bog growth

Fig. 8:8 Modern mire surface AD2001

elevations were the lowest, pools dominated the mire surface. By *c.*1000BC the accumulation of poorly humified *Sphagnum* peat was mire-wide and the mire can be viewed as a two areas of raised bog linked by the continued influence of the watershed across the middle of the bog.

The widespread presence of Unit J, a multi-phase horizon reflecting a marked slow down in peat accumulation at Kilnagarnagh, indicates a significant shift from wet to dry conditions (Fig. 8:7). Unit J represents a stratigraphically linked horizon across the mire, from north to south and from east to west (Fig. 6:15). This implies that a major hydrological change took place quickly with consequences for the mire system as a whole, although the effect was more marked in the south as the north was buffered by the presence of the wooded zone E3. A sudden drop in the water table or catastrophic discharge of a mire system can result in the extreme and rapid loss of moisture required for such a stratigraphic signature. At Kilnagarnagh there is no stratigraphic evidence for major discharge such as a bog burst occurring within the mire itself, which would normally take the form of extensive redeposited and/or eroded peat surfaces (Casparie 2001). The base of Unit J, follows the pre-existing surface topography, undulating in those areas where hummocks were present and relatively regular where *Sphagnum* lawns prevailed. This suggests that the mechanism responsible for the drop in the water table that interrupted the growth of the mire may have been located elsewhere in the hydrological dynamics of the wider Lemanaghan system (see Section 10:2:2).

The gross stratigraphy of Unit J suggests that the water table in the mire was adversely affected on more than one occasion. A single major phase of desiccation is suggested in the north but south of the central watershed two phases are implied. The interval between each phase is unknown though the depth of intervening peat is generally shallow (often less than 5cm-10cm).

Dating for Unit J has been extrapolated from AMS determinations derived from the laboratory cores in which significant dry shifts that may equate to Unit J are implied (see Sections 9:2-9:5). Dating brackets both major phases of retardation visible in the gross stratigraphy and does not provide an indication of the duration of each phase. There is broad agreement between three sets of dates; those from K201, K301 and K102. In the west and east Unit J appears to have been deposited between *c.*AD200 and *c.*AD600. In the north at K102, the biostratigraphic evidence for this event, though slighter, is dated to from *c*.AD100 to *c*.AD500. In the southern end of the mire, in the centre (Drain 1, K101), a significantly earlier date is proposed for the slow down in peat growth. Here the relevant stratigraphy appears to date to between *c*.850BC, the beginning of the first phase and *c*.50BC, the end of the second.

The difference in time suggested by the core-derived dates is difficult to explain as Unit J clearly represents a stratigraphically linked, two-phase mire-wide horizon. A number of hypotheses were considered in an effort to explain this.

(a) Were the cores sampled correctly?

All cores were re-checked in terms of the depth from which peat samples subject to dating were taken. No errors were identified and it can be concluded that the sampling was in order.

(b) Are the dates correct?

Three sets of dates, those from the west (K201), the east (K301) and the north (K102), share synchroneity and can be considered as accurate reflections of a period of retardation and recovery in the development of the mire (Fig. 8:9). In addition, the dates from K101 represent a stratigraphically logical sequence supported by the position of the trackway, dated to 1509±9BC, within the chronological sequence. The peat between the trackway and Unit J is intact, albeit compacted, representing *in situ* accumulation of poorly humified *Sphagnum*.

(c) The dates from the south represent the first phase of desiccation in the mire while the other dates refer to Phase 2.

This is unlikely as the depth of peat between the relevant dates at K101 more or less equates to the full depth of Unit J at this location. They also share similar Ordnance Datums.

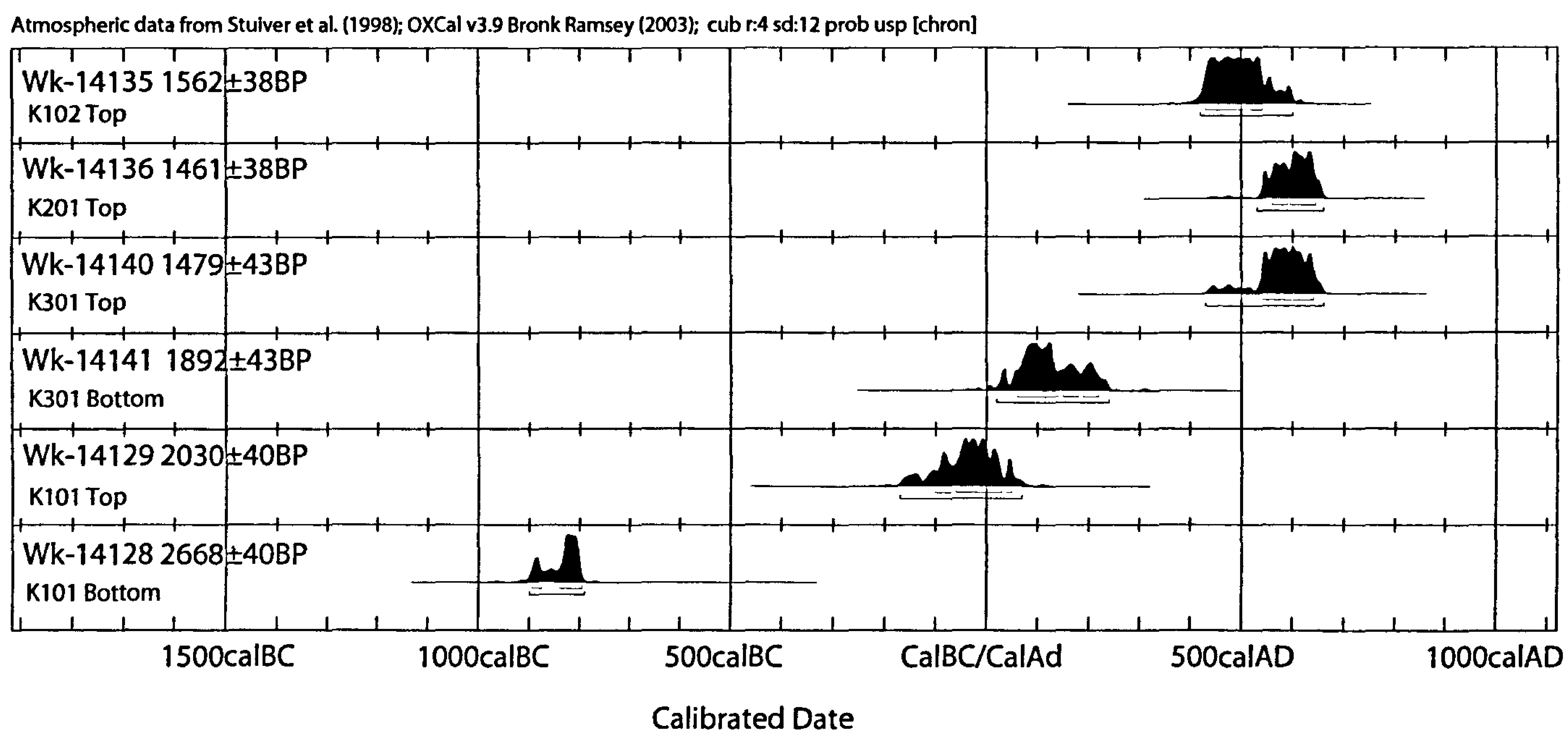

Fig. 8:9 Distribution of calibrated dates bracketing the major dry shifts and period of retarded bog growth in Kilnagarnagh.

(d) There is a problem using age-depth models and derived rates of accumulation in order to explain mire development where the peat deposit has been subject to compaction.

Two sources of compaction have acted on the upper peat deposit in Kilnagarnagh: the first is represented by the drainage, which resulted in the retarded growth of the mire (Unit J), and the second relates to recent intensive drainage. It has been shown that, despite compaction, the dates reflect the time at which the relevant sediment was deposited (see Section 5:4:4). This suggests the different timing of the desiccation of the mire in the south and elsewhere is not a product of compaction.

(e) The south central part of the mire was subject to significant hydrological change centuries before the rest of the mire (Fig. 8:9).

This may reflect significant differences in water storage mechanisms or controls between the centre and the sides and the northern part of the mire. The presence of the watershed may have shielded the northern end of the mire from the agency or force which caused the south central part of the system to desiccate earlier. It then took several hundred years for the hydrological balance of the mire to be altered as a whole. The mire struggled to maintain hydrological equilibrium once the water balance in the south was significantly altered and the loss of water from the centre was eventually followed by desiccation of the surrounding area. With desiccation of the flanks and the north, the growth of the south central part was impeded and its recovery is linked to the wider mire recovery from *c.*AD600 (see below).

In summary, it is difficult to explain the difference in timing between the shift to drier conditions in the south and in the rest of the mire. The stratigraphic record suggests they should be viewed as a synchronous occurrence whilst the dating suggests a time-lag between desiccation in the south and elsewhere. The discrepancy may suggest a difficulty in extrapolating from cores to a broader macro-scale record. Nonetheless, the available evidence suggests the mire was subject to long-term hydrological change from *c.*850BC to *c.*AD600.

From *c.*AD600 the mire system appears to have recovered as poorly humified *Sphagnum* peat was deposited and pools reappeared on the bog surface. A series of gullies (Unit K) in the north (Fig. 6:15) reflect a new drainage network in the northern part of the bog. The gullies truncate Unit J indicating that they belong to the phase of the mire's recovery rather than its retardation. The gullies reflect large scale erosion of peat deposits in the north possibly related to the continued drainage of the mire from the northwest. The gullies eventually lost their discharge function as they became infilled with deposits of poorly humified *Sphagnum*.

8:3:5 The modern mire surface

The gross morphology of the mire surface in AD2001 (Fig. 8:8) reflects the shape that the mire has taken because of compaction related to recent drainage. Overall basin morphology is better represented than it might be in an intact raised bog and the ridges are easily identified. Initial raised bog growth occurred in two locations (see Section 8:3:2) represented by possible domes in Fig. 8:4. Though not as pronounced in the later record, these domes are still visible in the modern bog surface.

8:3:6 Summary

Ridges in the mineral substrate formed a watershed across the middle of the basin which exerted a long-term influence on mire evolution from the initial fen, *c*.9600BC, to the later ombrotrophic system which developed from *c*.3800BC. Woodland extended from the ridges into the fen and the raised bog, enabling the constant presence of trees on the mire. The mire became increasingly wet overtime and developed a southern hummock-hollow system and a wider system of wet *Sphagnum* lawns, from at least *c*.2000BC. A significant drop in the water table resulted in the loss of these environments from the mire surface, firstly from the south central part of the mire from *c*.850BC, and later from the rest, *c*.AD100. Peat growth was seriously curtailed with at least two phases of low-level peat accumulation recorded. From *c*.AD600 the mire recovered with *Sphagnum* dominating until recent drainage resulted in the dry, moss-free surface currently prevalent at the site.

8:4 ARCHAEOLOGICAL INTERPRETATION

8:4:1 Field surface sites

These six sites, dating from the post-medieval period or later, represent the most recent archaeological material on the bog. Two have been classified as 'toghers', i.e., brushwood tracks up to 30m in length. This site type, easyily assembled and of simple construction, is generally interpreted as a site laid down to aid access to or across a particular part of the bog (see Section 2:5:4). Their presence demonstrates human activity on the bog in relatively recent times. The other four sites near the field surface are small deposits of brushwood. These may be deliberate deposits or may represent stray pieces of wood lying on the bog surface due to natural agency. In common with most of the known archaeological sites from Kilnagarnagh, all these near-surface sites lie in the south, within 150m of the modern road (Fig. 5:1). This suggests activity on the bog was restricted to close to the road. Their likely recent origin excludes further consideration of these structures and their relationship to the development of the mire.

8:4:2 The Bronze Age walkway

The wooden walkway which spans the southern end of the mire (see Section 6:2:2) represents the most substantial structure in the mire and dates to 1509±9BC or later (Q9291). A second timber from the site's western landfall returned a date of 1492±9BC or later (Q9290) thus placing the site securely within the Irish Middle Bronze Age. The site comprises longitudinal planks laid end to end secured in the peat with pegs. Sites of this nature have been referred to as 'plank paths' and 'single plank walkways' and are known from Ireland and raised bogs in northwest Europe (see Section 2:4). The plank walkway at Kilnagarnagh has a maximum recorded width of *c.*0.68m, probably sufficiently wide to have provided for single file pedestrian traffic although in places site width is as low as 0.12m. This may be a product of limited exposure or the site may have been less substantial in these places and as such more precarious to negotiate on foot.

This walkway is situated in the south, at the narrowest point across the bog, just north of where it widens to join with the greater Lemanaghan complex (Fig. 5:1). It was probably positioned to allow journeys across the bog rather than taking a significantly longer route around the bog via the esker in the north (Fig. 3:2). This south-westerly routeway is mirrored in the modern road network; a minor public road runs parallel to the Bronze Age route. This alignment was also favoured in the later Bronze Age when, in Killaghintober bog, a series of plank pathways were constructed in the tenth century BC (Figs 3:2 & 3:4).

The Kilnagarnagh walkway has a known length of 445m. Its eastern landfall has not been identified and it is possible the site was once originally longer. About 320m east of the last sighting is a 60m contour to which the bog had once extended. Given how bogs expand laterally, the distance from the end of the track to its contemporary dryland was probably less than this. Using the available OD data and the distance from the last trackway sighting to the 60m contour (320m) it is possible to estimate how much longer the site might have been (Fig. 8:10). Ordnance Survey maps show this contour equates to the eastern edge of the bog in the mid-nineteenth century. Assuming the trackway was built to span the bog (identification of the site's western landfall and the fact that similar sites have been constructed to join dryland to dryland allow for this assumption) the site's eastern landfall can be taken as an indication of the edge of the bog around 1500BC.

Other assumptions include:

1. The level OD of the trackway remains constant between the last known sighting and the slope.
2. This estimation disregards the degree to which drainage has compressed the peat and hence may altered the original OD of the trackway.
3. The slope from the base of the bog to the contour is a straight line. The morphology of the sub-peat topography is unknown. The slope may be either concave or convex (though more than likely concave) thus the estimate may either under- or overestimate distance.

The final sighting on the trackway lies at 55.6m OD; the mineral substrate is 3.4m below this at 52.20m OD. This means the base of the bog is 7.8m lower than the dryland 60m contour. The gradient of the slope between the mineral substrate at 52.20m and the 60m contour is 0.025 (tanθ). The trackway would hit this point, i.e. dryland, at 136m thus giving a possible site length of 581m (445m + 136m). This figure should be viewed as an approximation based on the idealisation presented in Fig. 8:10.

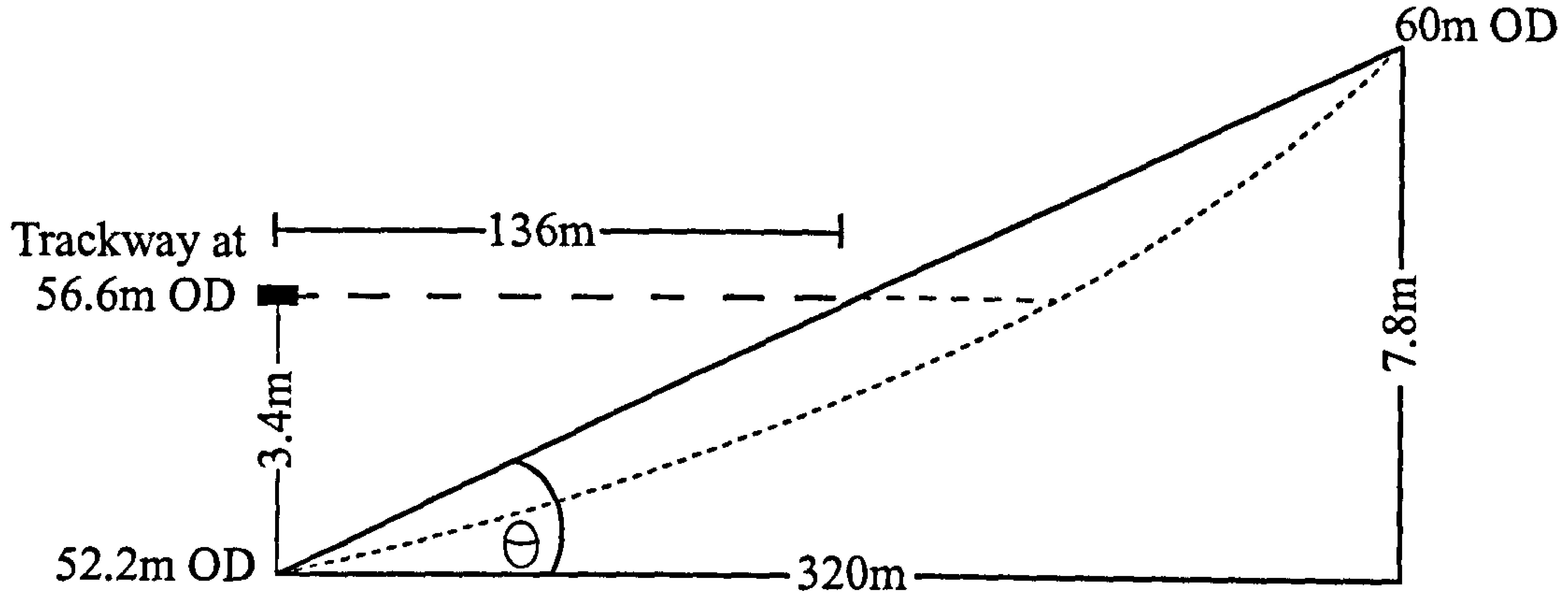

Fig. 8:10 Estimation of trackway length, Kilnagarnagh Bog.

Gaps identified in the eastern end of the site (see Section 6:2:2) may reflect real changes in the character of the structure. There are a number of possible explanations for these gaps including:

(a) the site was incomplete in parts

(b) the route was not planked over its entire length

(c) the structure was altered, damaged or dismantled through natural or human agency.

Evidence for any of the above is difficult to establish in the absence of comprehensive excavation and associated palaeoenvironmental investigations. The depth (OD) at which the site lay in the east means the peat stratigraphic record is restricted to core based records thus limiting the identification of spatial features which may have influenced site construction. In broad terms the site was constructed across a hummock-hollow complex, largely represented by deposits of homogenous poorly humified *Sphagnum*. Gaps in the site may have occurred because the local topography, particularly hummocks, negated the need for a planked surface. This seems unlikely as the presence of hummocks in the west did not prevent the use of timber. The wider peat stratigraphic record has shown (see Section 8:2) that the eastern side of Kilnagarnagh was generally wetter than the centre or the western side of the raised bog. Construction here may have been more difficult but also more necessary. Gaps in the walkway may reflect wetter zones along the route from which timbers were either inadvertently displaced or deliberately re-positioned rather than being originally absent. Two plank deposits which lie within *c.*5m of the track (see Section 6:2:3) may represent such adjustments. There is no evidence in the peat stratigraphic record to suggest the breaks in site construction resulted from catastrophic changes in bog hydrology of the kind identified by Casparie (2001) at Derryville Bog, Co. Tipperary where a bog burst destroyed one end of a substantial corduroy road dated to *c.*600BC (Cross *et al.* 2001).

8:4:3 'Flanking' deposits

The OD range for the deposits 'flanking' the plank walkway is 56.41m-56.92m. This falls within the OD range of the walkway with the majority of its sightings (29 out of 36) lying between 56m and 56.9m (Fig. 6:2). The proximity and the shared ODs between the walkway and the 'flanking' deposits suggest that the latter can be associated with the construction or use of the longer site. This is a phenomenon known from other long sites in Irish bogs (Raftery 1996; Moloney *et al.* 1995) and scattered 'flanking' deposits are known from other trackways in the Lemanaghan system such as early medieval walkways in Killaghintober and Castletown bogs (IAWU 2001; Bermingham 1997).

Two of the plank deposits from Kilnagarnagh, which lie within 5m of the walkway, may represent timbers displaced from the original line of the site either deliberately or inadvertently.

8:4:4 The local palaeoenvironmental context of the Bronze Age walkway

Two cores subject to laboratory analysis were retrieved from immediately adjacent to the walkway, K101 and K301. These are discussed in detail below (see Sections 9:2 & 9:4). The plant microstratigraphic record from each location shows that *Sphagnum imbricatum* dominated the mire at the time of site construction. In K101:S5 (Fig. 7:6) there are small peaks in UOM and monocots just below the level of the track. This suggests that a somewhat drier situation existed at this location in advance of site construction. At survey point 1:01m, which lay *c.*1m to the east of K101 (Fig. 5:1), the trackway lay in poorly humified *Sphagnum* peat with small *Eriophorum* tussocks lying at more or less at the same elevation. The gross stratigraphy suggests that this location was also relatively dry. The palaeohydrological record derived from testate amoebae from K101 (Fig. 7:5) implies the bog water table had stabilised at *c.*-2cm at the time of trackway construction. Shortly afterwards, possibly within a couple of decades, the water table began to fall to *c.*-5cm.

In K301:S2 (Fig. 7:10) the range of Sphagna present indicated a relatively wet bog surface, prior to the construction of the trackway, with pools occupied by *Sphagnum cuspidatum* and *S.* Section *Cuspidata.* This situation changed by the time the trackway is constructed. The hydrophilous mosses are no longer present implying the absence of pools on the bog surface at this location. The gross stratigraphic record shows that the trackway lay within poorly humified *Sphagnum* peat with *Eriophorum*; the presence of the latter might suggest a somewhat drier situation prevailed. However, a roundwood from the trackway was also found to lie in a small pool occupied by *Sphagnum cuspidatum* implying local variability in mire surface wetness. *Sphagnum imbricatum*, monocots and higher UOM values characterise the vegetation record of the peat overlying the trackway. At this location the plant microstratigraphic record implies the bog was less wet at the time of and following trackway construction. A similar situation is implied in the testate and water table record from K301 (Fig. 7:9). Mid-way through zone K301:3 the water table lies at the bog surface, it then begins to fall. At the time the trackway was laid down the water table had fallen to *c.*-2cm and declined steadily from this time on.

The plant microstratigraphic and gross stratigraphic records from K101 (survey point 1:01, Fig. 5:1) suggest the trackway lay on top of a hummock. The mean water table record implies relative stability in the bog water table at this location only, suggesting a change in conditions some time after the site was built. At K301, the plant microstratigraphy and the water table record imply that the trackway was constructed on a drying bog surface. The gross stratigraphic record supports this suggestion, though the presence of a small pool reflects spatial variability on the bog surface.

8:4:5 A trackway in the north

The trackway identified in Cooldorragh townland on the northern edge of the bog is undated (see Section 6:2:4). It is located at the interface of two major peat horizons: highly humified *Sphagnum* and poorly humified *Sphagnum*. In the southern end of the mire this boundary dates from *c.*2500BC but in the north at K102 it is considerably later at *c.*1000BC (see Section 8:2). Thus the trackway may date from the Late Bronze Age (1250BC-650BC after O'Sullivan 2001) and represent a new prehistoric presence in the area. Its position at the interface of drier, more decomposed peat and poorly humified peat suggests that its construction took place at a time when the mire was changing from dry to wetter conditions. This is discussed further in Chapter 10.

The site appears to be a relatively substantial oak plank trackway (Fig. 6:3). Sites of this kind were built both to access and to bridge bogs (see Section 2:5). Its location in the north, close to the edge of the bog, suggests that it ran from the base of the esker which lies immediately to the north (Fig. 5:1). Moore and Stanley (2003) suggest that the trackway served to access rather than traverse the bog. If built to cross the bog, its NW-SE axis would have provided a long route through the bog which, given the proximity of the esker in the north and the dryland in the east, would appear unnecessary. Further archaeological investigation of this structure is required in order to better understand its purpose.

8:4:6 Summary

The archaeological record from Kilnagarnagh bog can be grouped into three chronological periods: the Early Bronze Age, the Middle Bronze Age, and the post-medieval period. The latter is represented by six lightly constructed sites lying close to the field surface. Their position in the bog profile implies that they are clearly historic, and most likely of relatively recent origin. The function of these sites is not known;

short, lightweight and frequently poorly defined structures are known from other Irish bogs though few have been dated (Raftery 1996; Moloney *et al.* 1993b; 1995). The trackway situated close to the northern margins of the bog discussed above may extend the archaeological record of Kilnagarnagh into the Early Bronze Age. The site's limited exposure and recent discovery mean that it does not form part of the detailed archaeoenvironmental record from Kilnagarnagh. It, along with other archaeological sites from Kilnagarnagh and Lemanaghan, provide a wider land use history of the bog which allow examination of broader patterns of human activity and how this may have been influenced by the bog environment (see Section 10:4).

CHAPTER 9

INTERPRETATION OF BIOSTRATIGRAPHIC SEQUENCES

9:1 INTRODUCTION

In this chapter the high resolution proxy data sets are interpreted independently in relation to each of the four cores. This is followed by an integrated discussion of the proxies relevant to each core.

9:1:1 Interpretation of testate amoebae: associated trends & potential problems

The testate profiles from Kilnagarnagh display fluctuations between two distinct sub-fossil assemblages (Table 9:1). The environmental significance of these groupings have been arrived at with reference to patterns identified in other subfossil assemblages from mires in the UK and Ireland (Blundell 2002; Caseldine *et al.* 1998; Charman *et al.* 1999; Chiverrell 2001; Hendon *et al.* 2001; Mauquoy & Barber 2002). In these comparative assemblages, DCA revealed the association between taxa and the hydrological gradient. A similar relationship is apparently present in the data set from Kilnagarnagh. The associations listed in Table 9:1 aid the interpretation of the fossil communities from each core. While the range of species represented can differ between cores each assemblage profile falls within the groupings listed below.

Group 1 (Wet conditions)	Group 2 (Dry conditions)	Problematic taxa
Amphitrema flavum, A. wrightianum, A. stenostoma, Arcella artocrea, A. catinus-type, *A. discoides*-type, *Assulina muscorum, A. seminulum, Centropyxis aculeata*-type, *Cyclopyxis arcelloides*-type, *Difflugia pristis*-type, *Heleopera sphagni, Hyalosphenia elegans, H. papilio*	*Bullinularia indica, Heleopera sylvatica, Hyalosphenia subflava, Nebela flabellum, Nebela militaris, Trigonopyxis arcula*-type	*Difflugia pulex, Heleopera petricola*

Table 9:1 Sub-fossil groups from Kilnagarnagh. Taxa are listed in alphabetical order.

The absence of modern ecological data for *Difflugia pulex* presents a problem when interpreting its presence in fossil assemblages. Based on associations with other taxa, *Difflugia pulex* appears to be a more cosmopolitan species than previously suggested (see Section 4:4:3). Rather than being a relatively dry indicator (Hendon 1998 in Charman *et al.* 2000), *Difflugia pulex* occurs in wet and dry situations but is less well represented in very wet or very dry conditions. Hence in this study it is regarded as cosmopolitan rather than as an indicator of dry conditions. The transfer function was performed with *D. pulex* having a dry weighting and as such the reconstructed mean water table may indicate lower water tables than actually prevailed. This may be countered by excluding *D. pulex* from the transfer function though the implications this may have for the quality of the transfer function is not known. Exclusion of *D. pulex* would necessitate counting 150 tests in excess of any *D. pulex* represented in cases where the taxon dominates. Stuijts (pers. comm.) found that *D. pulex* dominated samples from Lough Kinale, Ireland and excluded it from minimum testate counts and percentage based diagrams, thus basing water table reconstructions on all other taxa represented. In Kilnagarnagh *D. pulex* dominates each sequence, thus, it is possible the that frequency with which it occurs masks trends in the data. Here *D. pulex* has been counted as normal as exclusion may introduce another unquantifiable bias in the data.

Difflugia pulex does not appear to dominate testate stratigraphies from British sites in the same way it does from Irish sites (Caseldine *et al.* 1998; Blundell 2002). Its ecological affinities may differ between the islands. Developing a modern calibration data set from Ireland may clarify this problem (see Section 2:3:3).

9:2 K101

9:2:1 Testate Amoebae K101 (Fig. 7:5)

K101:1a-c 312cm-165cm (*c.*5100BC-2755±135calBC)

The impoverished testate fauna as this sequence opens is a result of the nature of the peat deposit, in this case fen peat in which testates are typically poorly represented (see Table 4:1). A single sample makes up sub-zone K101:1b. This sample may represent an anomaly or it may reflect incipient raised bog growth (Caseldine *et al.* 1998). Testates are better represented in ombrotrophic peats (Tolonen 1986) and embryonic raised bog growth may account for their occurrence here. Of the three taxa represented, *Amphitrema flavum* favours wet situations while *Assulina muscorum* is considered either as cosmopolitan (Warner 1990) or as a dry indicator (Tolonen 1986). *Difflugia pulex* is considered a relatively dry indicator though, as stated above, its ecological affinities are poorly understood. The combination of taxa present, hygrophilous and cosmopolitan, suggests a generally wet situation.

In K101:1c testate concentrations remain low but are higher than K101:1a. Species diversity has improved with the addition of *Arcella discoides*-type and *Hyalosphenia subflava*. The range of taxa present is repeated up the profile and may be considered typical of this site. The low number of tests suggests that conditions were unsuitable to allow testate communities to thrive and/or to be preserved. The impression however is of an increasingly wet and acidic environment.

K101:2a-b 165cm-118cm (2755±135calBC-2125±155calBC)

Here, a generally wet regime is implied by the testate-derived reconstructed water table data, which suggests a relatively high and stable water table just below the bog surface at *c.*-2cm.

The opening of this zone reflects well-established testate communities. Rising *Amphitrema flavum* values suggest a generally wet situation, supported by the presence of other hydrophilous taxa such as *Assulina seminulum* and *Arcella discoides*-type. The latter can occupy standing water. *Assulina seminulum* can inhabit floating or partly submerged vegetation (Charman *et al.* 2000). The presence of *Difflugia pulex* and the appearance of *Trigonopyxis arcula*-type, a xerophilous taxon, suggest drier milieu within an otherwise wet situation.

K101:3 118cm-53cm (2125±155calBC-845±55calBC)

The combined dominance of *Amphitrema flavum* and *A. wrightianum* suggest that conditions remained wet in this zone. The latter favours bog pools and hollows and its appearance may reflect the presence of surface water (Charman *et al.* 2000). Other taxa present, including *Arcella catinus*-type, *Arcella discoides*-type, *Assulina seminulum*, *Cyclopyxis arcelloides*-type and *Difflugia pristis*-type, generally favour wet situations. The continued presence of *Assulina muscorum*, regarded as cosmopolitan with a preference for acidic situations, is also consistent with this impression. In this zone *Hyalosphenia subflava*, regarded as a reliable dry indicator (Tolonen 1986; Charman *et al.* 2000), makes its first appearance and serves as signal to the change in conditions identified in the overlying zone, K101:4.

The reconstructed water table suggests a generally wet and stable situation. As the zone closes the water table is beginning to fall suggesting a change in moisture conditions on the bog surface.

K101:4 53cm-12cm (845±55calBC-50±120calBC)

Increased representation of *Hyalosphenia subflava* shows that this taxon became dominant at a location where taxa inhabiting wetter situations had previously prevailed. *Hyalosphenia subflava* frequently occurs in drained peats (Tolonen 1986; Charman *et al.* 2000). In this zone, it replaces *Amphitrema flavum* as the dominant taxon indicating a shift to drier conditions. The mire surface could still however sustain hygrophilous taxa; the representation of *Assulina seminulum, Arcella discoides*-type and *Assulina muscorum* has changed little from the previous zone and *Amphitrema flavum,* though diminished in importance, is consistently present. The overall picture is of a shift to drier conditions which favoured taxa inhabiting dry or drained peats.

A fall in the reconstructed mean water table to *c.*-16cm suggests a major change in surface moisture conditions with a significantly drier situation maintained until the water table recovers by the top of the profile in K101:5.

K101:5 12cm-0cm (50±120calBC-*c.*AD2000)

The decreased importance of *Hyalosphenia subflava* and increases in *Amphitrema flavum* and *A. wrightianum* reflect the restoration of wetter surface conditions. Minor hydrophilous components continue to be represented with slight increases in *Arcella discoides*-type and *Assulina seminulum.* A generally wet situation prevails as the sequence closes. The reconstructed water table data shows the water table had recovered, lying at the surface at the top of the profile.

9:2:2 Plant Microstratigraphy K101 (Fig. 7:6)

K101:S1 312cm-270cm (*c.*5100BC-*c.*4400BC)

The peat here is wood and monocotyledonous rich, relatively well decomposed and is devoid of *Sphagnum* remains. This is interpreted as wood-rich fen peat, the wood indicating the minerotrophic nature of the deposit and a relatively dry fen situation.

K101:S2 270cm-165cm (*c.*4400calBC-2755±135calBC)

The almost complete absence of wood, the rise in monocots and the emergence of *Sphagnum* remains signals a change towards ombrotrophy which, given the emergence of *Calluna* and *Eriophorum*, appears to have been established by 230cm. Above 230cm UOM and monocot dominated peat with *Calluna* and low *Sphagnum* values suggest a relatively dry situation prevailed.

K101:S3 165cm-140cm (2755±135calBC-*c*.2200BC)

A shift to wetter conditions is implied in the switch from UOM and monocot peat to *Sphagnum* dominated peat. The presence of *Sphagnum* section *Cuspidata* and *S. cuspidatum* suggest the surface was inundated allowing pools to form. The break in UOM representation suggests decomposition was inhibited. The rise to dominance of *S.* section *Acutifolia* and increasing UOM values suggests a drier situation was developing as the zone closes.

K101:S4 140cm-120cm (*c*.2200calBC-2125±155calBC)

The change towards a drier situation implied at the close of the previous zone is evident where UOM values rise to 80% and *Sphagnum* preservation is restricted. *Calluna* remains a consistent minor component supporting the picture of a dry bog situation.

K101:S5 120cm-48cm (2125±155calBC-845±55calBC)

The water table appears to have recovered, facilitating the accumulation of poorly humified *Sphagnum imbricatum* peat. This situation continues to the close of the zone with the exception of spikes in UOM and monocots just below the level of the trackway. This suggests a drier episode within an otherwise generally wet situation where *Sphagnum imbricatum* is the primary peat former. The site appears to have been too wet for *S.* section *Acutifolia* but not wet enough for hydrophilous taxa such as *S.* section *Cuspidata* or *S. cuspidatum*. *Sphagnum* values decline at the top of the zone signalling a change in surface wetness.

K101:S6 48cm-16cm (845±55calBC-50±120calBC)

This zone opens with increases in *Eriophorum*, *Calluna*, a clear rise in UOM and the disappearance of *Sphagnum*. Conditions on the bog have become significantly drier resulting in limited peat accumulation over a period of *c*.800 years.

K101:S7 16cm-0cm (50±120calBC-*c*.AD2000)

In this zone a return to wetter conditions is implied by the increased representation of *Sphagnum* and declines in UOM and *Calluna*. The profile closes however with a switch to increased decomposition and a renewed drier situation.

9:2:3 Humification K101 (Fig. 7:5)

The bottom of the humification curve, where transmission values reach nearly 40% suggests relatively wet conditions with low decomposition rates. This is followed by a shift to generally drier conditions beginning around 4000BC and ending around 2755±135calBC. Succeeding humification values imply a change to greater wetness until around 2550BC by which time transmission values are beginning to fall. This may represent a dry shift occurring between 2550BC and 2125±155calBC. Humification values then rise and fall between 2125±155calBC and 845±55calBC suggesting two shifts to drier conditions. The steady decline in transmission values post-845±55calBC suggests the bog surface became increasingly less wet followed by a return to wetter conditions *c.*50BC.

9:2:4 Combined interpretation of biostratigraphic data sets K101 (Fig. 9:1)

In this core the testate and plant microstratigraphic zones generally coincide (Fig. 9:1). In the lower half of the sequence the testate zone K101:1a-c corresponds with the macrofossil zones K101:S1 and K101:S2 dating from *c.*5000BC to *c.*2750BC (Figs 7:5-7:6). The testate zone K101:1a-c does not support mean water table reconstruction as too few testates were present. The macrofossil record shows that the bottom of the sequence consists of fen peat (K101:S1) which explains the absence of testates. The fen-bog transition is marked by the boundary between K101:S1 and K101:S2. The macrofossil stratigraphy suggests that there was a shift towards ombrotrophy from *c.*4400BC with a move towards generally dry conditions enabling the accumulation of highly humified *Sphagnum*. The humification record suggests an initially wet situation with percentage transmission values of *c.*40%. This drops and over the rest of this zone low transmission values reflect greater decomposition suggesting relatively dry conditions prevailed between *c.*4000BC and *c.*2750BC.

From K101:2a, around the late third millennium BC, testates occur in countable numbers enabling reconstruction of the mean water table. From here the water table lies at *c.*-2cm and is maintained at this level until just before close of zone K101:3c around 1200BC. The mean water table curve implies hydrological stability at this location. In contrast, the macrofossil and humification records suggest significant changes in bog moisture conditions. The relatively dry conditions implied by the macrofossil record in K101:S2 are present at the opening of K101:S3. The succeeding dominance of *Sphagnum* suggests implies the prevalence of wetter conditions between *c.*2700BC and

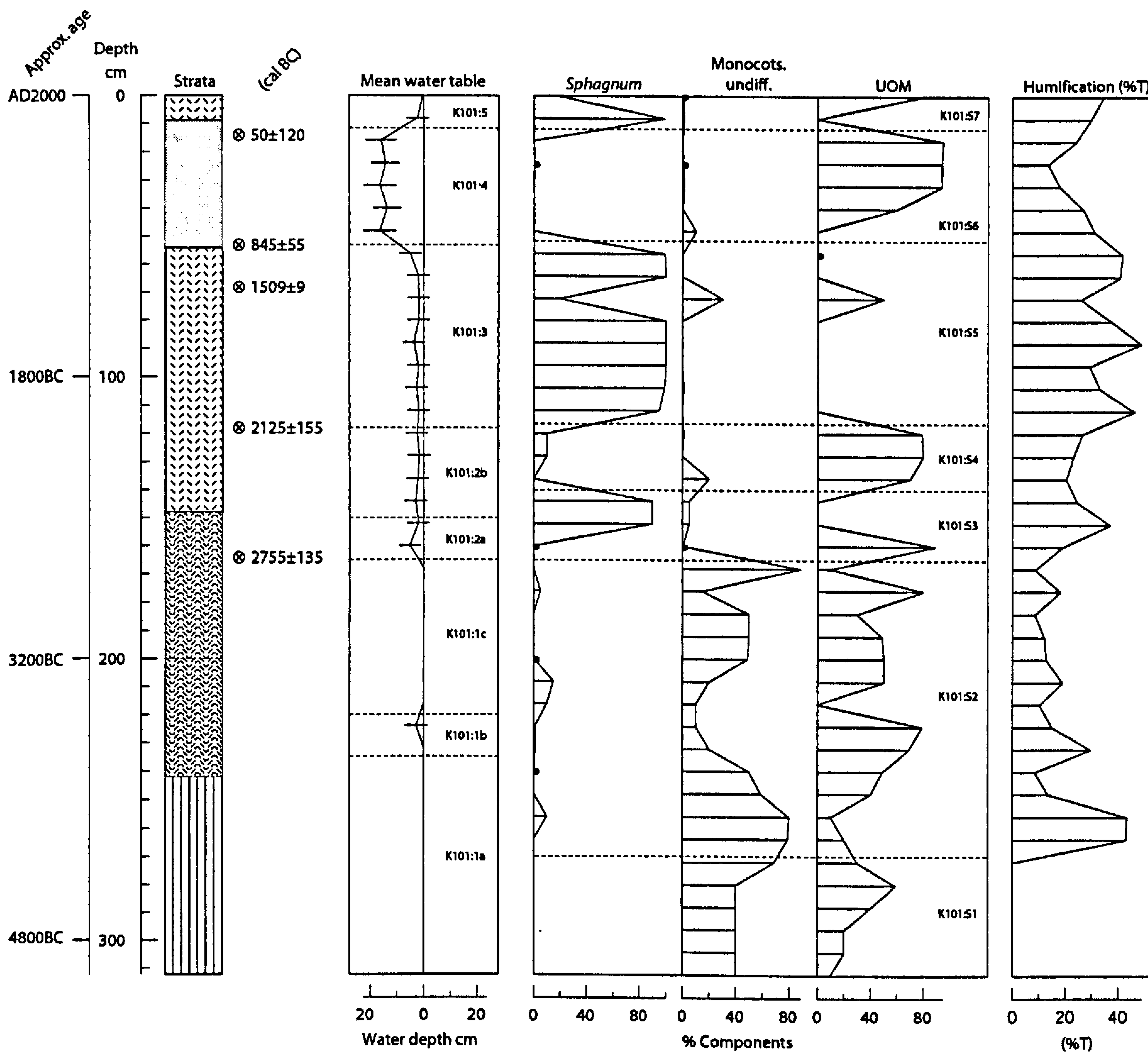

Fig. 9:1 Summary diagram K101, Kilnagarnagh, Co. Offaly. Approximate ages at depth are given based on age-depth model Fig. 7:1.

*c.*2400BC, coinciding with a peak in percentage transmission values which imply reduced decomposition, i.e., a wet shift. This is followed by an abrupt a return to dry conditions in which UOM dominates and humification levels are higher (K101:S4). This dry shift is not reflected in the reconstructed water table curve. The dry shift is succeeded at 2125±155calBC by a return to a wetter situation implied in all three proxies (K101:3 and K101:S5). The water table is high, lying at *c.*-2cm, *Sphagnum* dominates the macrofossil record and transmission values rise to over 40% implying a slow down in decomposition. Small peaks in monocots and UOM and reduced humification values imply the occurrence of brief, drier episodes in an otherwise wet, *Sphagnum* dominated situation. This situation contrasts markedly with succeeding moisture conditions from 845±55BC.

In K101:4 and K101:S6 a clear dry shift occurs from 845±55BC. The water table lies at *c.*-16cm, UOM is dominant and transmission values fall steadily. The water table and the macrofossil record therefore suggest a rapid change in conditions occurring between the ninth and eight centuries BC. The dominance of UOM and of *Hyalosphenia subflava,* a taxon indicative of drained peats (Tolonen 1986), suggest that a sudden lowering of the water table whilst the humification curve implies increased dryness. Dry conditions prevailed for *c.*800 years from the mid-ninth century BC to the mid-first century BC.

In the mid-first century BC a return to wetter conditions is implied in all three proxies (K101:5 & K101:S7). The water table has risen to the bog surface and *Sphagnum* dominates the macrofossil record although the top sample suggests UOM was once again becoming dominant. Humification values continue to rise implying reduced decomposition and hence a wetter situation.

In summary, the transition from fen to raised bog appears to have occurred initially under relatively wet conditions from *c.*4000BC followed by a generally drier situation and the accumulation of highly humified *Sphagnum* peat until *c.*2750BC. Wet conditions were then established but were interrupted by a dry shift between *c.*2400BC and *c.*2100BC. The latter was not registered in the testate record, perhaps because it was masked by *Difflugia pulex*, but is implied in the macrofossil and humification records. There is agreement between proxies following this dry shift from 2125±155calBC. Wet conditions prevailed up to the mid-ninth century BC after which a second dry shift occurred of sufficient magnitude to affect the composition of the testate community and result in the accumulation of UOM reflecting the decomposition of peat-forming plants. This dry shift lasted until around the middle of the first century BC after which time wet conditions resumed.

9:3 K201

9:3:1 Testate Amoebae K201 (Fig. 7:7)

K201:1 300cm-245cm (2765±145calBC-2245±215calBC)

The reconstructed mean water table stabilises at *c.*-2cm implying wetter conditions replace an earlier drier situation.

The prevalence of *Amphitrema flavum* and other taxa favouring wet situations suggests conditions on the bog were generally wet. In the bottom of the zone there is a hint of an earlier drier situation suggested by the occurrence of *Hyalosphenia subflava*, *Nebela flabellum*, *N. militaris* and *Trigonopyxis arcula*-type.

K201:2 245cm-172cm (2245±215calBC-*c.*1100BC)

The zone assemblage is dominated by hygrophilous taxa though *Difflugia pulex* is now better represented in the assemblage. The emergence of *Amphitrema wrightianum* implies the presence of water on the bog surface and increases in *Difflugia pristis*-type, *Arcella discoides*-type and *Assulina seminulum* point to a wetter regime. Conditions are wetter in comparison with the preceding zone although xerophilic taxa such as *Bullinularia indica*, *Heleopera sylvatica*, *Nebela flabellum*, *N. militaris*, and *Trigonopyxis arcula*-type are more diverse. Their presence suggests the continued but perhaps limited availability of drier habitats. The increase in *Difflugia pulex* in the top of the zone occurs at the expense of *Amphitrema flavum* and *A. wrightianum*. Their decline implies that surface wetness was decreasing with a loss of pools on the bog surface from *c.*1300BC-1100BC.

The reconstructed water table shows a higher degree of variability here than in K201:1. The water table initially lies at *c.*-5cm suggesting that conditions have become drier. It recovers to *c.*-2cm but after *c.*120 years it falls to -5cm suggesting another drier episode. Around 1600BC this is followed by a return to a high water table of *c.*-2cm which is maintained for a couple of hundred years after which the water table falls to around -6cm. The zone closes suggesting a shift towards drier conditions.

K201:3 172cm-155cm (c.1100BC-890±90calBC)

This zone represents an interruption in the testate stratigraphy where test numbers have fallen to trace amounts. Testate concentrations have changed little from the previous zone so it is possible that these samples are simply more dilute. Alternatively a change in conditions may be responsible. Major taxa such as *Amphitrema flavum* and *A. wrightianum* are reduced to trace amounts or are absent and this is in keeping with their decline in the previous zone. Other taxa which were increasing as K201:2 closed, such as *Assulina muscorum* and *Difflugia pulex*, have dropped sharply. Thus, the dry shift implied in the water table curve of the preceding zone continues.

K201:4 155cm-53cm (890±90calBC-*c.*AD350)

In this zone testate numbers have returned to countable levels and there is a resumption of conditions identified in K201:2. *Amphitrema flavum*, *A. wrightianum*, *Arcella* spp., *Assulina* spp. and other minor hygrophilous taxa combine to suggest the prevalence of wet surface conditions. Small peaks in *Amphitrema wrightianum* may indicate increased open water on or flooding of the bog surface. Taxa which generally inhabit less wet situations occur sporadically throughout the zone, for example *Nebela militaris* and *Bullinularia indica*.

The mean water table curve implies a generally wet situation with the water table lying between *c.*-1cm and *c.*-3cm up to the third century AD.

K201:5 53cm-28cm (*c.*AD350-595±65calAD)

Increased amounts of *Hyalosphenia subflava* and *Difflugia pulex* and corresponding reductions in *Amphitrema* spp. suggest a reduction in the amount of surplus water on the bog and hence a drier regime. The background fauna hardly changes with taxa such as *Arcella discoides*-type, *Assulina muscorum*, and *Difflugia pristis*-type continuing as before suggesting that the dry shift was not so great as to impact on these taxa.

The mean water table declines over about 150 years to reach an unprecedented low of *c.*-8cm at the top of this zone. Conditions on the bog have altered and are now drier.

K201:6 28cm-0cm (595±65calAD-*c*.AD2000)

Peaks in *Amphitrema* spp. and the decline of *Hyalosphenia subflava* and *Difflugia pulex* suggest the resumption of wetter conditions, around the mid-seventh century AD. A second fall off in testate numbers however interrupts this potential recovery with testate concentration lower than in the under- and overlying samples. Conditions may have become unsuitable for testates to live and/or to be preserved in these levels.

A rise in the water table to *c.*-2cm implies a shift to wetter conditions within a century.

9:3:2 Plant microstratigraphy K201 (Fig. 7:8)

K201:S1 300cm-268cm (2765±145calBC-*c*.2500calBC)

UOM coupled with low level representation of monocots, wood, *Calluna* and *Sphagnum* suggests the prevalence of drier conditions with a reduced water table allowing for greater decomposition. The occurrence of wood as the profile opens suggests proximity to the fen-bog junction.

K201:S2a 268cm-242cm (*c*.2500BC-*c*.2150BC)

In this zone ombrotrophic conditions prevail and the greater representation of *Sphagnum* suggests an increased water table, although the dominance of *S.* section *Acutifolia* implies relatively dry surface conditions.

K201:S2b 242cm-228cm (*c*.2150BC-*c*.2000BC)

Here higher UOM values points to increased aeration and a decrease in the height of the water table. This is a transitory situation succeeded by the accumulation of less well-humified *Sphagnum*.

K201:S2c 228cm-163cm (*c*.2000BC-*c*.1100BC)

Here the dominance of *Sphagnum* peat and decreases in UOM suggests that conditions are wetter, allowing the accumulation of poorly humified peat. The combination of *S. imbricatum*, *S.* section *Acutifolia* and *S.* section *Cuspidata* suggests variation in the micro-topography and moisture conditions on the bog surface although the almost complete dominance of *S. imbricatum* and its wide hydrological tolerance may mask the true situation (Stoneman *et al.* 1993). *S. imbricatum* is both a lawn and a hummock species. The rise in *S.* section *Acutifolia* in the upper half of the zone may reflect the development of hummocks with wetter low points inhabited by *S.* section *Cuspidata*.

K201:S3 163cm-108cm (*c.*1100BC-*c.*350BC)

This zone displays a higher degree of moisture variability than the previous sub-zone. An opening spike in UOM and a mid-zone peak in *Eriophorum* point to drier episodes though the latter may reflect the occurrence of a tussock and need not reflect an overall change to a drier situation. In general, however, conditions favour the accumulation of poorly humified *Sphagnum imbricatum* peat. The occurrence of *S.* section *Acutifolia* implies that hummocks may have provided drier situations.

K201:S4 108cm-52cm (*c.*350BC-*c.*400AD)

Sphagnum imbricatum and lesser amounts of *S.* section *Acutifolia* continue to dominate the record. The disappearance of UOM in the upper half of the zone reflects minimal decay and a high water table. Optimal conditions for the accumulation of poorly humified peat are present though this is changing as the zone closes.

K201:S5 52cm-10cm (*c.*400AD-*c.*AD1500)

This zone is characterised by a major change in hydrological conditions. Here high decomposition is implied as UOM values rise to 80% and monocots replace *Sphagnum* as the dominant type of plant remains. A significantly drier situation prevails though a small peak in *Sphagnum* mid-zone implies a temporary recovery in bog moisture conditions. *Sphagnum imbricatum* is the only taxa able to take advantage of the temporary recovery.

K201:S6 10cm-0cm (c.AD1500-AD2000)

A return to a wetter regime is implied by the recovery in *Sphagnum* representation. Further ecological change is suggested by the replacement of *Sphagnum imbricatum* with *Sphagnum papillosum* as the main peat constituent (see Section 10:2:2).

9:3:3 Combined interpretation of biostratigraphic data sets from K201 (Fig. 9:2)

The testate and plant macrofossil zone boundaries show reasonable correspondence in this core. The testate zone K201:1 equates to the macrofossil zones of K201:S1 and K201:S2a. The mean water table curve opens with the water table at *c.*-4cm, then rises and stabilises at *c.*-2cm implying a high water table. The macrofossil record however, initially implies a relatively dry situation prevailed as UOM is dominant and *Sphagnum* remains are rare. In K201:S2a the wet conditions implied in the water table curve are then matched by an increase in *Sphagnum* values from *c.*2500BC. This is followed by a shift to drier conditions as both water table and *Sphagnum* (K201:S2b) values fall around 2245BC. This is a relatively short lived occurrence as wet conditions (inferred from higher water table values and increased *Sphagnum*) resume about two hundred years later (Fig. 9:2). A second slight dip in the water table occurs but this is not reflected in the plant macrofossil record in which *Sphagnum* continues to increase (K201:S2c) implying sustained wet conditions. In contrast, in the top of testate zone K201:2 the water table falls hitting a new low point of *c.*-7cm. This is followed by a break in the reconstructed water table curve suggesting conditions were possibly too dry for the testates to have lived or to have been preserved. This appears to coincide with a drier episode in the macrofossil record implied by a spike in UOM values and a decline in *Sphagnum* (K201:S3), though this change is represented by a single sample and must therefore be treated with caution. The testate-derived reconstructed water table appears to indicate an earlier and more marked shift in conditions than the plant macrofossil record implies.

Following this possible dry episode, wet conditions resume at *c.*900BC and are sustained up to the late fourth century AD, equating to testate zone K201:4 and plant macrofossil zones K201:S3 and K201:S4. The mean water table record peaks mid-zone (K201:4) and then drops gently to *c.*-3cm. At the same time the *Sphagnum* values rise and UOM disappears implying peat accumulation under wet conditions. The situation changes however with a shift to drier conditions beginning in the late fourth century AD. From this time the reconstructed water table drops steadily hitting its lowest level of *c.*-8cm about two centuries later. At the same time *Sphagnum* values decline and UOM dominates the macrofossil assemblage. Early in the seventh century AD the water table curve implies wetter conditions resumed. This corresponds with a small peak in *Sphagnum* values suggesting a wet episode. There is a break in the water table curve after this point although the final sample suggests it may not have significantly changed. The macrofossil stratigraphy suggests the sequence closes with a shift towards wetter conditions as *Sphagnum* becomes dominant.

In summary the hydrological proxies from this location, K201, correspond quite well. There are three shifts to drier conditions suggested in the reconstructed water table curve. The first, from *c.*2245BC to *c.*2000BC is registered in the plant macrofossil record (K201:S2b). The second dry shift is evident in the upper part of K201:1 from around 1200BC to *c.*900BC. This shift may be represented by a peak in UOM lying at

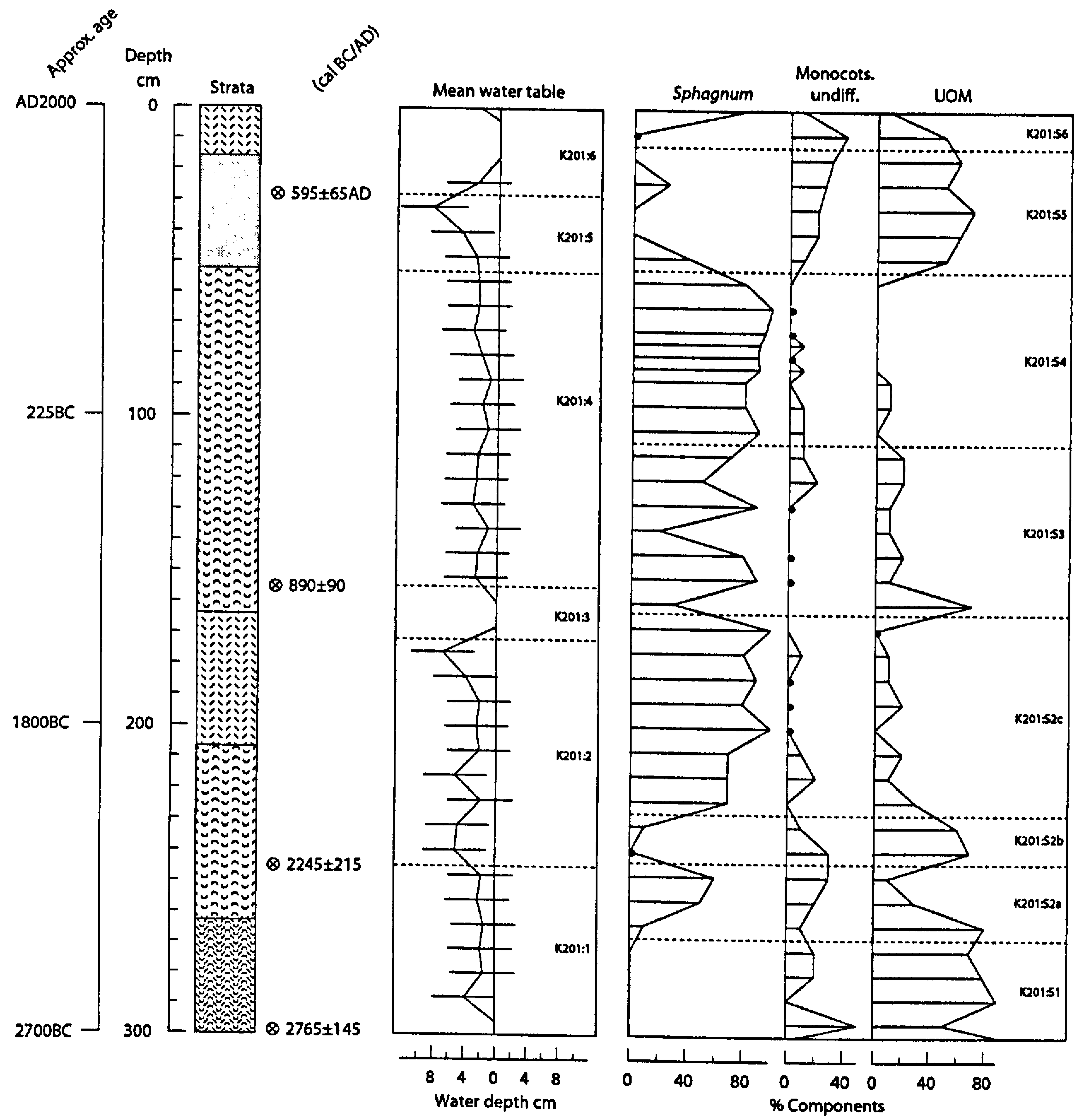

Fig. 9:2 Summary diagram K201, Kilnagarnagh, Co. Offaly. Approximate ages at depth are given based on age-depth model Fig. 7:2.

the same level as the hiatus in the water table record. The third dry shift occurs close to the top of the profile in zones K201:5 and K201:S5. Here, over *c*.200 years from *c*.AD400, the water table falls to its lowest point, around the same time UOM dominates. *Sphagnum* recovers as the sequence closes.

9:4 K301

9:4:1 Testate Amoebae K301 (Fig. 7:9)

K301:2a 283cm-252cm (3825±125calBC-*c*.3500BC)

The mean reconstructed water table falls steadily from an opening high of around *c*.-1cm to *c*.-5cm implying a drier bog surface.

The dominant taxon, *Amphitrema flavum*, peaks at the opening of this sub-zone implying a wet bog surface. This changes within one level (*c*.130 years) - a decline in *A. flavum* and increases in xerophilic taxa such as *Trigonopyxis arcula*-type suggest a drier bog surface. The site is sufficiently moist however to retain background hygrophilous taxa, *Arcella discoides*-type, *Assulina seminulum* and *Cyclopyxis arcelloides*-type.

K301:2b 252cm-242cm (*c*.3500BC-*c*.3100BC)

The water table is maintained in the opening of this sub-zone at *c*.-5cm implying the trend towards relatively drier conditions identified in K201:2c continues.

K301:2c 242cm-180cm (*c*.3100BC-2215±185BC)

Testate numbers return to countable levels in this sub-zone. The hygrophile *Amphitrema flavum* increases in importance and attains overall dominance in the upper half of the zone. *Difflugia pulex* also increases over the zone but the significance of this is difficult to interpret. The background fauna is characterised by other wet taxa such as *Arcella discoides*-type, *Assulina seminulum*, *Cyclopyxis arcelloides*-type though these decline from mid-zone. Dry indicator taxa such as *Trigonopyxis arcula*-type, *Nebela militaris* are concentrated in the bottom half of the sub-zone which reinforces the impression of escalating wetness.

The mean reconstructed water table is rising steadily implying increasingly wet conditions over about 900 years beginning around 3150BC.

K301:3 180cm-132cm (2215±185BC-1045±145calBC)

The trend towards increased wetness is reinforced with the inflation in *Amphitrema wrightianum* values and the continued dominance of *A. flavum*. Of the trace taxa present they mostly represent wetter situations. As the zone closes the trend is reversed as *Amphitrema* spp. are in decline and *Hyalosphenia subflava* is beginning to emerge.

The water table continues to rise and lies almost at the bog surface mid-way in the zone at around 1700BC. From here the water table gradually dips, lying at *c.*-2cm as the zone closes in the middle of the eleventh century BC.

K301:4 132cm-83cm (1045±145calBC-*c.*250BC)

The increased representation of *Hyalosphenia subflava* and the decline in *Amphitrema flavum* and *A. wrightianum* points to a change in the hydrological situation on the bog. *Hyalosphenia subflava* is considered a reliable dry indicator and its ascending abundance here signals a dry shift in the overall sequence.

The reconstructed water table drops to *c.*-10cm implying a move towards a drier milieu. This represents the first major shift in the water table peaking around the middle of the fourth century BC.

K301:5 83cm-60cm (*c.*250BC-130±110calAD)

In this zone increases in *Amphitrema flavum*, *A. wrightianum*, *Arcella discoides*-type and *Difflugia pristis*-type as well as the appearance of *Assulina seminulum* suggest a return to a wetter hydrological situation. *Hyalosphenia subflava* is now a relatively minor assemblage component. Taxa favouring very wet situations which occur in trace amounts, such as *Centropyxis aculeata* and *Heleopera sphagni,* underline the return to a wetter situation.

A rise in the mean water table from a previous low of *c.*-10cm to *c.*-3cm is maintained over a period of about 370 years. This suggests a shift in favour of a wetter regime.

K301:6 83cm-60cm (130±110calAD-545±115calAD)

The renewed predominance of *Hyalosphenia subflava* and the reduced incidence of *Amphitrema flavum* and *A. wrightianum* point to another change in the hydrological character of the bog. There is a shift towards taxa favouring drier conditions most notably *Hyalosphenia subflava,* a xerophilic taxon favouring drained peats (Tolonen 1986). Drier conditions are maintained throughout the zone although a small peak in *Arcella discoides*-type and an increase in *Cyclopyxis arcelloides*-type suggest temporary re-inundation of the bog surface around AD400.

Within about fifty years of this zone opening the water table has dipped eventually falling to a new low of *c.*-15cm. It recovers slightly to *c.*-10cm but then drops back to its previous level. The bog water table lies below *c.*10cm for around 400 years.

K301:7 30cm-0cm (545±115calAD-*c.*AD2000)

In contrast to the previous zone *Hyalosphenia subflava* is now a minor component of the testate community, disappearing completely as the zone closes. The bog has reverted to a wetter hydrological regime dominated by *Amphitrema flavum* and *A. wrightianum* implying the presence of water on the bog surface. This turn around happened in just over a century beginning around the middle of the sixth century AD with a generally wet regime maintained until the top of the sequence.

The reconstructed water table has risen to *c.*-2cm from a previous low of *c.*-10cm in about a century implying that the site's hydrological recovery occurred quickly.

9:4:2 Plant Microstratigraphy K301 (Fig. 7:10)

K301:S1 342cm-228cm (*c.*4800BC-*c.*3000BC)

The combination of wood, UOM and monocots at the base of the profile is interpreted here as wood rich fen peat that represents the top of the fen deposit and the junction with the raised bog above. Low level *Sphagnum imbricatum* representation signals a change towards ombrotrophy. The spike in *Sphagnum* at *c.*284cm suggests reduced minerotrophy and greater acidity. The presence of *S.* section *Acutifolia* and *cf. Sphagnum palustre* and *cf. Sphagnum magellanicum* suggests that conditions have changed sufficiently to allow mosses to establish at the expense of other plants. *Sphagnum palustre* will form loose carpets or tussocks in wet fen woodland (Daniels & Eddy 1990) while *Sphagnum magellanicum*, which is closely related to *S. palustre*, is found on acid bogs (Phillips 1980). Fen peat is being replaced by the accumulation of highly humified peat derived from Sphagna and *Calluna*.

K301:S2 228cm-52cm (*c*.3000BC-*c*.AD250)

Ombrotrophic conditions are by now established and conditions favour the accumulation of highly humified *S.* section *Acutifolia* peat and undifferentiated monocots. This pairing suggests a relatively dry bog surface. The situation changes to wetter conditions above 200cm where *Sphagnum imbricatum* is now the primary peat former and *Sphagnum* section *Cuspidata* and *S. cuspidatum* appear. This combination may reflect mixed wet lawn conditions or perhaps a hummock and hollow situation in which *S. imbricatum* formed the hummocks and *S.* section *Cuspidata* and *S. cuspidatum* occupied the hollows. Decreasing UOM shows that conditions now favour the accumulation of poorly humified *Sphagnum*. In the upper half of the zone the disappearance of hydrophilous Sphagna, the re-emergence of *S.* section *Acutifolia* and increases in monocot values suggest a move towards a drier situation as the zone closes. The rise in *S.* section *Acutifolia* may represent formation of hummocks.

K301:S3 52cm-20cm (*c*.AD250-*c*.AD1000)

The shift towards drier conditions implied at the close of the previous zone is evident. Decomposition levels are high with identifiable Sphagna absent. There appears to have been an unambiguous shift to a drier situation. Bog surface wetness is greatly diminished and this drop in the water table has limited the accumulation of peat.

K301:S4 20cm-0cm (*c*.AD1000-*c*.AD2000)

The *Sphagnum* curve recovers sharply implying that the water table has recovered sufficiently to allow the accumulation of poorly humified *Sphagnum*. *Sphagnum imbricatum* resumes its position as principal peat former with *S.* section *Acutifolia* of minor importance.

9:4:3 Combined interpretation of biostratigraphic data sets from K301 (Fig. 9:3)

The plant macrofossil record shows that the bottom of this core consists of wood-rich fen peat interpreted here as the fen-bog transition which explains the lack of testates in testate zone K301:1 (see Section 4:4:3). In the plant microstratigraphic record, in zone K301:S1, ombrotrophy is attained from *c*.3800BC and with the exception of the *Sphagnum* spike mid-zone the deposit mainly consists of UOM suggesting peat accumulation under relatively dry conditions. The spike in *Sphagnum* corresponds with the first appearance of testates in the record. The reconstructed water table implies that the water table lay initially near the bog surface. From *c*.3600BC it gradually falls and stabilises at *c*.-5cm at the same time as UOM values increase suggesting conditions at this location were relatively dry up to *c*.3100BC-*c*.3000BC.

From *c*.3100BC (the opening of testate zone K301:2c) to *c*.1800BC (the middle of K301:3) the water table curve gradually rises to the bog surface without interruption or significant oscillation. *Sphagnum* is a significant peat component and its increased presence suggests a move towards wetter conditions, at least initially. A peak in UOM between *c*.2750BC-*c*.2450BC infers the establishment of drier conditions. This is a temporary occurrence and does not register in the testate-derived water table curve. *Sphagnum* then returns to dominance implying that wetter conditions have been re-established. A peak in *Sphagnum* registers in advance of the rise to bog surface of the in the testate-derived water table (mid-zone K301:3). Both proxies suggest that generally wet conditions prevail at this location from *c*.2400BC (Figs 7:9-7:10).

From *c*.1800BC the water table gradually falls. At the same time *Sphagnum* values decline gradually. From *c*.900BC-*c*.400BC the fall in the water table is more marked. The site is becoming less wet though the impact on *Sphagnum* peat accumulation is not marked. The water table record and the macrofossil record diverge slightly on either side of the zone boundary between K301:4 and K301:5. Here, around 400BC, the water table has fallen to *c*.-10cm. In contrast *Sphagnum* values have risen suggesting that a wetter situation existed. Around a century later, *c*.300BC, the water table rises to *c*.-3cm while *Sphagnum* values rise and fall though remaining the dominant peat component. The different proxies present differently timed changes in hydrology though both suggest that conditions were relatively wet until the middle of the second century AD.

The clearest and biggest drop in the reconstructed water table curve straddles the testate zones K301:6 and K301:7. Here, between *c*.AD200 and *c*.AD550, the water table lies at *c*.-16cm, recovers to *c*.-10cm and drops again to *c*.-15cm. At the same time (K301:S3) UOM replaces *Sphagnum* as the dominant peat component implying a shift to significantly drier conditions. This dry shift represents the greatest and quickest

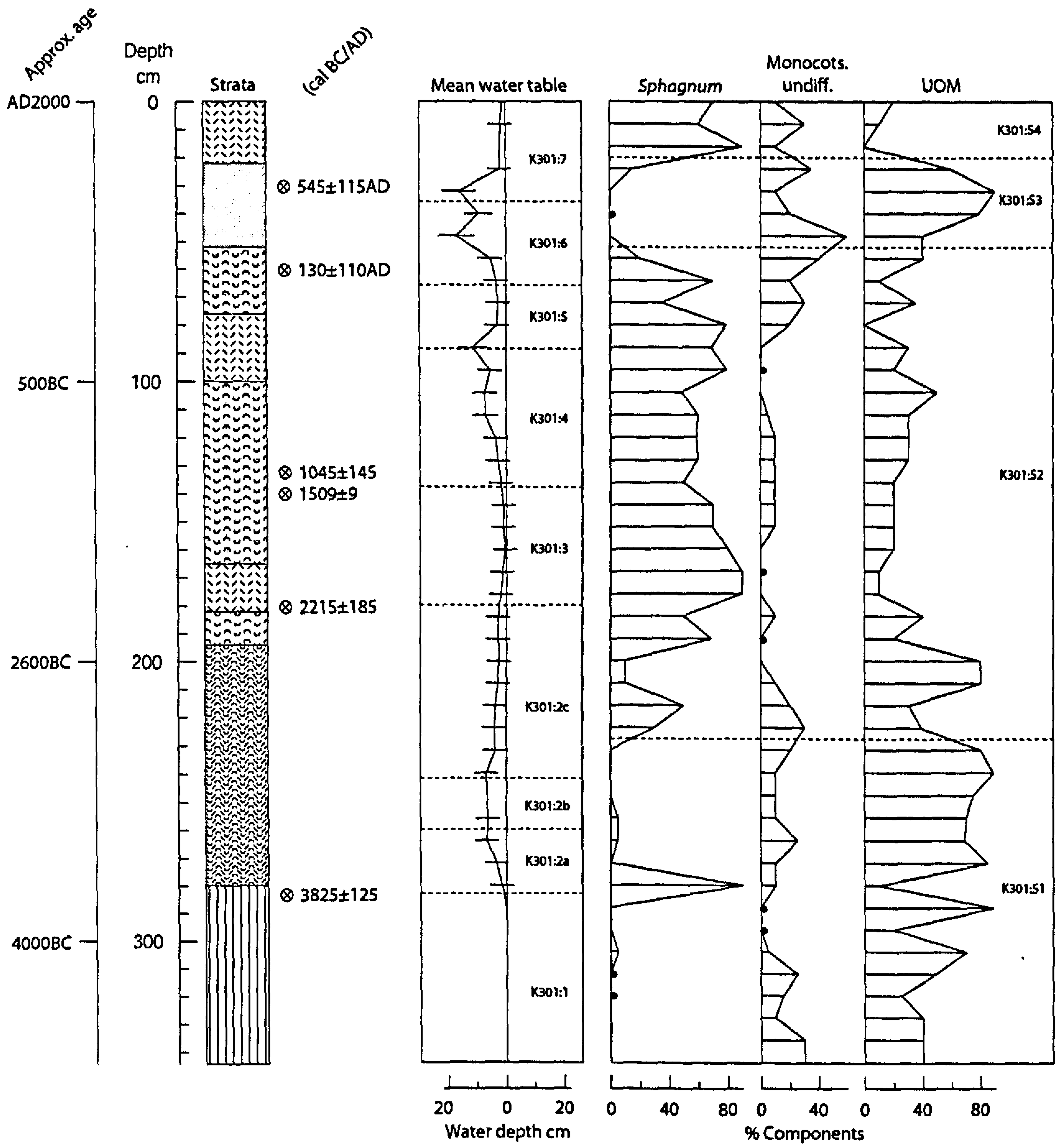

Fig. 9:3 Summary diagram K301, Kilnagarnagh, Co. Offaly. Approximate ages at depth are given based on age-depth model Fig. 7:3.

change from wet to dry conditions at this location; the water table falls from *c*.-3cm to *c*.-16cm between *c*.AD150 and *c*.AD200. A significant drainage or drying event may be responsible for such a rapid and serious drop in the bog water table at this location (see Section 10:2). This situation is maintained for a few hundred years until over the course of the later sixth century AD when the water table recovers and is sustained at *c*.-2cm to the close of the sequence. At the same time *Sphagnum* remains replace UOM as the major peat component suggesting the accumulation of peat under wet conditions again.

In summary the water table and plant macrofossil records suggest that the fen-bog transition occurred here under relatively dry conditions and that the earliest ombrotrophic peats accumulated in a dry environment between *c*.3800-*c*.3600BC. The water table record suggests that the system became increasingly wet until *c*.1800BC. The plant macrofossil record suggests that this trend was interrupted by a dry shift from *c*.2750BC-*c*.2450BC. After 1800BC the site is generally wet though becoming less so over time, with the water table dropping to a new low of *c*.-10cm around 400BC. This is a gradual process rather than an abrupt shift and is more marked in the testate-derived water table curve than in the macrofossil record. After *c*.300BC there is shift to wetter conditions followed by a clear dry shift between *c*.AD200 and *c*.AD550. This represents a significant and relatively rapid change in the hydrology of the site. From *c*.AD550 to the close of the profile wetter conditions are restored.

K102

9:5:1 Testate Amoebae K102 (Fig. 7:12)

K102:1 400cm-359cm (*c*.4000BC-3625±105calBC)

Testates occur in trace amounts in this zone though species diversity and composition is in keeping with the inventory from elsewhere in Kilnagarnagh. This zone straddles the top of the fen and the base of the raised bog. Low testate numbers may reflect the transitional stage of the mire's development.

K102:2a & 2b 359cm-330cm-292cm
(3625±105calBC-*c*.3250BC-2755±235calBC)

In K102:2a, from around the middle of the fourth millennium BC to *c*.3250BC, the taxa represented suggest both wet and dry conditions. The lower samples comprise of hydrophilous taxa dominated by *Amphitrema flavum*, accompanied by *Assulina muscorum* and *Difflugia pristis*-type. *Amphitrema flavum* declines as the sub-zone closes though other wet indicators, such as *Arcella discoides*-type and *Assulina muscorum* are slightly better represented. The xerophile *Trigonopyxis arcula*-type, achieves its highest representation at the top of the zone suggests drier conditions. The reconstructed mean water table falls from *c.*-3cm to *c.*-6cm over the sub-zone suggesting that surface wetness is decreasing.

The sub-zone K102:2b is characterised by countable levels interrupted by levels in which testate concentration was low. This provides for peaks and dips within the individual species curves which are difficult to interpret. This may be a product of changes in moisture conditions and/or be related to preservation. Testate concentration is variable suggesting that either testate communities had difficulty establishing or conditions suitable for preservation were variable. The peak in *Amphitrema flavum* and the increased representation of *Arcella discoides*-type, *Difflugia pristis*-type and other taxa favouring wet conditions in the upper part of the zone suggest that this site was becoming wetter. The mean water table curve, which is based on data from two levels, suggests the water table recovers from a former low of *c.*-6cm to *c.*-2cm.

K102:3 292cm-230cm (2755±235calBC-2010±130calBC)

Rising then declining *Amphitrema flavum* values characterise this zone. The dominance of this taxon and the associated wet faunas, including *Arcella discoides*-type, *Assulina muscorum*, *A. seminulum* and *Difflugia pristis*-type, suggest wet conditions prevailed. Taxa favouring drier situations, with the exception of *Difflugia pulex*, are limited to trace amounts or sporadic appearances.

The reconstructed water table curve suggests a relatively stable and generally wet situation prevailed with the water table between *c.*-2cm and *c.*-4cm.

K102:4 230cm-149cm (2010±130calBC-910±90calBC)

Increases in *Amphitrema wrightianum* and the continued, albeit variable, presence of *Amphitrema flavum* suggest that surface conditions at this site have changed with more water available on the bog surface in pools or hollows. A fall off in minor taxa favouring drier conditions (*Nebela flabellum, N. militaris* and *Trigonopyxis arcula*-type) implies a reduction in the availability of drier habitats on site. *Difflugia pulex* is still well represented which may have implications for its interpretation as a dry indicator species.

The reconstructed water table curve suggests changes in surface wetness from wet to drier to wet to drier. The magnitude of change is small with the oscillations ranging from *c.*-2cm to *c.*-4cm below the mire surface.

K102:5 149cm-60cm (910±90calBC-510±90calAD)

The appearance and double peak distribution of *Hyalosphenia subflava,* the near complete reduction in *Amphitrema wrightianum,* and the lessening dominance of *A. flavum* suggest a change towards drier conditions in this zone. Wetter situations were not entirely lost as the mid-zone increased representation of *Arcella discoides*-type, a taxon which favours generally wet conditions, even standing water, attests.

The water table continues to fall showing continuity with the drier surface implied at the close of the previous zone. It then rises, more or less steadily, to near the mire surface Implying a trend towards increasing wetness. This is followed by a falling water table implying a shift towards drier conditions which peak at *c.*-5cm in the late fourth century AD.

K102:6a & 6b 60cm-0cm (510±90calAD-*c.*AD2000)

In K102:6a the return to dominance of *Amphitrema flavum* and increased representation of *A. wrightianum, A. stenostoma* and other wet-loving taxa such as *Centropyxis aculeata*-type imply a move to a wetter regime. Conditions have apparently become too wet for *Hyalosphenia subflava* which is no longer represented and *Difflugia pulex* is reduced to a relatively minor contributor. This situation changes in K102:6b, where *D. pulex* has increased in representation, although the general picture remains wet regardless of the presence of trace values of xerophilic taxa such as *Nebela flabellum* and *N. militaris.*

The reconstructed mean water table is maintained at *c.*-2cm implying a stable and generally wet situation.

9:5:2 Plant Microstratigraphy K102 (Fig. 7:12)

K102:S1 400cm-310cm (*c.*4000BC-*c.*2900BC)

This zone is represented by well-decomposed monocotyledonous peat with wood which is interpreted here as fen peat. The occasional low occurrence of *Sphagnum* demonstrates increasing acidity of the system and signals a change towards ombrotrophy. The position of wood at the top of the zone suggests a change towards drier conditions at the fen-bog junction.

K102:S2 310cm-244cm (*c.*2900BC-*c.*2200BC)

Ombrotrophy has been attained with *Sphagnum* increasing to become the major peat constituent. *Calluna* and high levels of UOM combine with *S.* section *Acutifolia* to suggest dry conditions. Mid-zone increases in *S.* section *Cuspidata* and *S. cuspidatum* suggest a change towards a wetter situation possibly with standing water on the bog surface. This appears to last for about 200 years after which conditions change in favour of *Sphagnum imbricatum* and *Sphagnum papillosum* suggesting a somewhat drier situation.

K102:S3 244cm-140cm (*c.*2200BC-*c.*800BC)

This zone brackets a period of fluctuation in surface moisture. Increased UOM and monocot values and reduced *Sphagnum* values suggest continuity with the move towards drier conditions implied in the close of the previous zone. This is short-lived as increased *Sphagnum* values suggest a return to better preservation and presumably wetter conditions. This pattern is repeated as mid-zone drier conditions prevail followed by a sequence of wet-dry-wet-dry episodes perhaps reflective of changes in local hydrology. In the lower half of this zone four *Sphagnum* taxa are represented but this changes mid-zone as *Sphagnum imbricatum* dominates the bryophyte record.

K102:S4a 140cm-45cm (*c.*800BC-*c.*AD800)

The overall dominance of *Sphagnum* in this zone suggests that the bog moisture conditions have stabilised implying optimum or good conditions for the accumulation of *Sphagnum* and the growth of a raised bog. Changes in the composition of the *Sphagnum* peat indicate a degree of hydrological change and/or topographic variation.

Sphagnum imbricatum can form lawns and hummocks demonstrating a relatively wide hydrological tolerance (Stoneman *et al.* 1993). This makes its presence here difficult to interpret. Low level and occasional representation of *S. papillosum*, *Calluna* and UOM suggests the sporadic occurrence of drier situations, perhaps hummocks, in an otherwise wetter lawn environment dominated by *S. imbricatum*. *S.* section *Acutifolia* is generally reflective of relatively dry conditions and is composed of species that commonly form hummocks (Clymo 1983). Its increased abundance between 110cm-80cm supports the possibility of drier hummocks having developed at this site. Pools in which *S.* section *Cuspidata* could accumulate suggests that a relatively well-defined hummock-hollow situation may have developed. This is followed by a return to a wet lawn composed of *S. imbricatum*.

K102:S4b 45cm-0cm (*c.*AD800-*c.*AD2000)

Conditions for the accumulation of poorly humified *Sphagnum* are still prevalent but *S. papillosum* is now the main peat constituent and *S. imbricatum* disappears from the record. This is discussed further in Section 10:2:2. *S. papillosum* is a low ridge hummock-former or can inhabit lawn situations (Fig. 4:1). The continued, albeit minor, presence of *S.* section *Cuspidata* and *S.* section *Acutifolia* suggests that a wet lawn situation prevailed until close to the top of the profile where a rise in *S.* section *Acutifolia* implies drier conditions.

9:5:3 Combined interpretation of biostratigraphic data sets K102 (Fig. 9:4)

The testate-derived reconstructed mean water table curve from K102 oscillates frequently between *c.*-6cm and *c.*-2cm. The curve starts from *c.*3625±105BC in the second testate zone, K102:2. Testate zones K102:1 and K102:2a correspond to the plant macrofossil zone K102:S1 and testate zone K102:2b overlaps K102:S1 and K102:S2. The peat deposit here is interpreted as the fen-bog transition and is relatively dry, as the prevalence of UOM and the presence of wood attests (Fig. 7:12). A dry situation is inferred from the water table curve particularly in K102:2a where the water table falls from *c.*-3cm to *c.*-6cm. The water table recovers to *c.*-1cm suggesting renewed wetness prior to *Sphagnum* and an ombrotrophic environment becoming established. After this, the water table falls steadily to *c.*-4cm. At the same time, the macrofossil record suggests that conditions were suitable for the accumulation of highly humified *Sphagnum*.

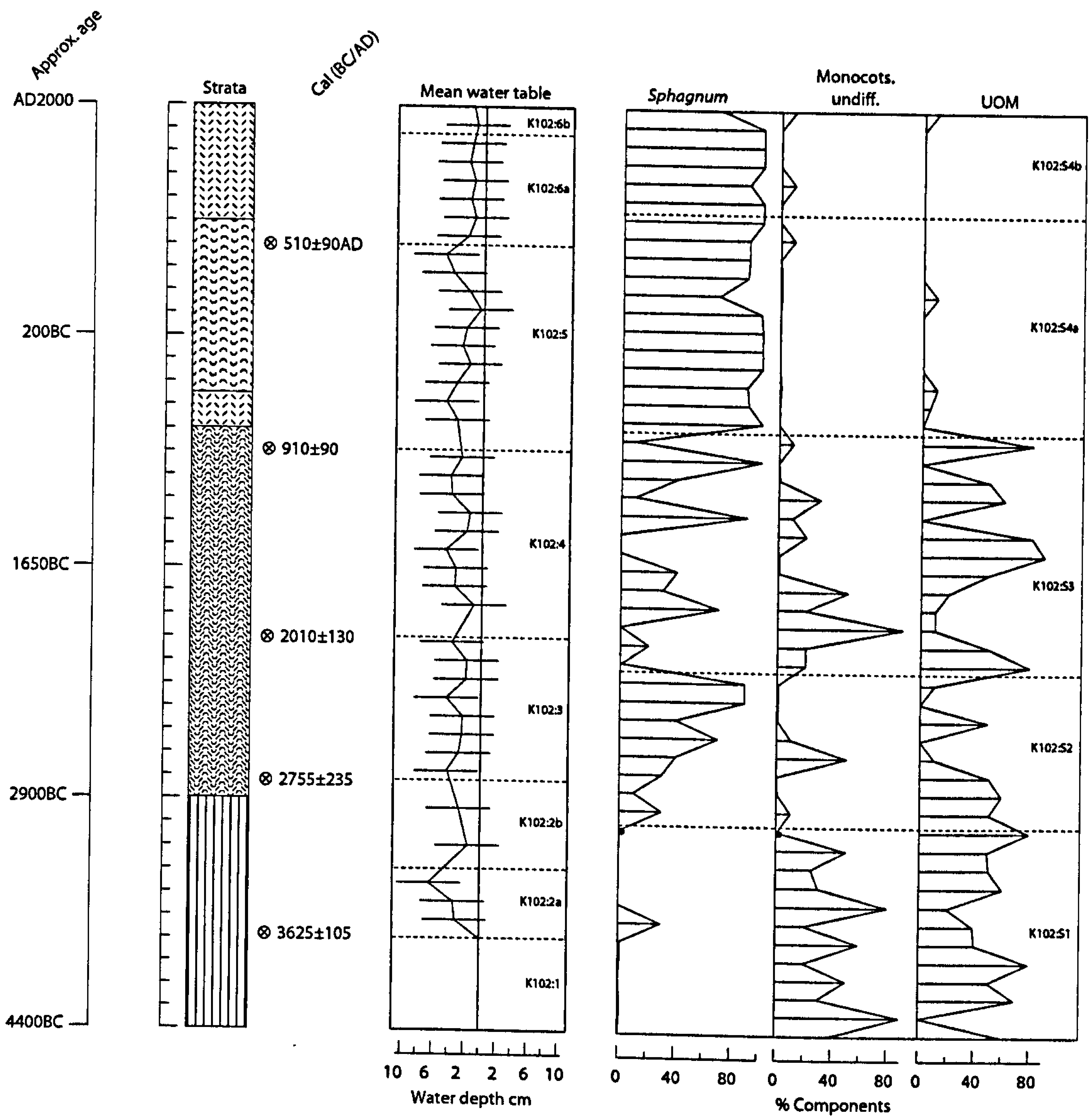

Fig. 9:4 Summary diagram K102, Kilnagarnagh, Co. Offaly. Approximate ages at depth are given based on age-depth model Fig. 7:4.

In the upper half of K102:S2 *Sphagnum* representation improves suggesting the onset of wetter conditions. This is also implied by the reconstructed water table, which generally lies at *c.*-2cm within K102:3. Both proxies suggest there has been a shift to slightly wetter conditions from *c.*2755BC. This situation changes from *c.*2200BC when the plant macrofossil record suggests that a series of wet-dry shifts took place up to *c.*910±90BC. The first dry shift occurred between *c.*2200BC and *c.*1900BC. This was followed by a wet shift that lasted to *c.*1600BC. A second dry shift followed to *c.*1400BC when wetter conditions resumed up to *c.*1200BC. This was succeeded by a period of drier conditions lasting about a century until *c.*1100BC when the system became wetter for a short time and then drier until *c.*800BC. The oscillations in the water table curve in K102:4 infer a similar cycle of hydrological change occurred.

From *c.*800BC, the opening of K102:S4a, *Sphagnum* dominates the macrofossil record with UOM and monocots minor and occasional components. This suggests conditions were generally suitable for the accumulation of poorly humified *Sphagnum*, and that the site was wet but with brief drier spells. At the same time the water table curve is generally rising, coming close to the bog surface around AD100. It then falls to *c.*-5cm suggesting conditions at this location had become drier between AD100 and AD500. Around the same time *Calluna* appears in the macrofossil record (Fig. 7:12) and although *Sphagnum* continues to dominate the presence of *Calluna* suggests drier conditions locally.

These dry conditions are temporary as, shortly after *c.*AD500, the water table rises and stabilises at *c.*-2cm to the close of the sequence. At the same time the plant macrofossil record shows the almost complete dominance of *Sphagnum* implying that conditions were sufficiently wet for the accumulation of poorly decomposed bryophytes. This situation is maintained to the top of the profile. Around AD800 it is accompanied by the replacement of *Sphagnum imbricatum* with *Sphagnum papillosum* (see Section 10:2:2). This change appears to have taken place at this location without the occurrence of a significant change in hydrological conditions.

In summary, this sequence opens with dry fen being replaced by increasingly wetter ombrotrophic conditions that were established by 2755±235calBC. This site is generally wet between 2755±235calBC and *c.*2200BC after which time a cycle of wet-dry shifts occur. These are best represented in the plant macrofossil record but similarly timed fluctuations in the reconstructed water table curve do occur. Dry shifts occur from *c*.2200BC-1900BC, *c*.1600BC-1400BC, *c*.1200BC-1100BC and *c*.1050BC-800BC. Another dry shift is inferred in the water table record between *c*.AD100-AD500 following a period of increasing wetness between *c*.800BC-AD100. From *c*.AD500 to the close of the profile, the site is relatively wet.

CHAPTER 10

SYNTHESIS AND DISCUSSION

10:1 INTRODUCTION

In this chapter the main lines of evidence are compared on a variety of scales including: intra-site comparison and inter-site comparison between other sites in the Irish midlands, the UK and Northwest Europe. The implications of this thesis for the interpretation of archaeological sites in raised bogs and the suitability of Irish raised bogs for climate reconstruction are then discussed.

10:2 SITE, LOCAL AND REGIONAL SYNTHESES

10:2:1 Research site synthesis

In Table 10:1 the main findings of the analyses of the peat and biostratigraphic proxies are presented. In general, there is a reasonable degree of correspondence between the results from each core and the mire-wide peat survey, though not every shift in conditions is replicated across all cores.

In broad terms Kilnagarnagh represents a classic raised bog sequence (Walker 1970), complicated by the underlying basin topography which strongly influences the development of both the earlier fen and succeeding raised bog. All the major stages of raised mire development are represented. An early post-glacial lake basin is infilled with reedswamp, fen and wood-rich fen (Figs. 8:1-8:3). An oligotrophic, ombrotrophic mire system later develops (Figs. 8:4-8:6), the latter characterised by mixed *Sphagnum* lawns and a hummock-hollow system.

The earliest ombrotrophic peat formation took place in the south (K101) and southeast (K301), where the fen-bog transition has been dated to between *c.*4000BC-3800BC. All records suggest this was followed by relatively dry mire surface conditions suitable for the accumulation of highly humified *Sphagnum* (Fig. 8:4). These conditions prevailed for almost a thousand years in the south (K101) and for around 700 years in the southeast (K301). This early ombrotrophic mire co-existed with areas of fen in the southwest (K201) and north (K102).

From around 2800BC those areas already ombrotrophic were becoming wetter and ombrotrophic conditions replaced the fen in the southwest and north. The peat stratigraphy implies somewhat drier conditions then the biostratigraphic data which suggests stable though relatively wet conditions (Table 10:1). The combined results suggest the system was becoming increasingly acidic and wetter allowing new *Sphagnum* communities to establish and the accumulation of less humified *Sphagnum* peat in areas already ombrotrophic.

These wetter conditions were followed by a shift to drier conditions reflected in the core proxy data though not all proxies agree and the timing of the change is not synchronous. In the southeast (K301) an increase in UOM between *c.*2750BC-2450BC suggests a drier episode within an otherwise wet sequence. In the south (K101), between *c.*2400BC and *c.*2100BC, the colorimetric humification data and the plant microstratigraphy suggest a shift to dry conditions. In contrast the water table curve implies an unchanged, stable hydrological situation. In the southwest (K201) the peat stratigraphy, the water table curve and the plant microstratigraphy combine to imply a dry shift beginning around 2200BC and ending *c.*2000BC. This overlaps with a shift to drier conditions implied by all three proxies in the north (K102) between *c.*2200BC-1900BC. Data from the south (K101), the southwest (K201) and the north (K102) suggest drier conditions prevailed between *c.*2400BC-1900BC. The results imply a staggered though overlapping shift to dry conditions across the mire, apart from the southeast where wetter conditions prevailed.

Following this drier period wet conditions are restored, though again the timing is not uniform. In the south (K101) long-term wet conditions prevail until *c.*900BC-800BC. The water table is unchanged, remaining stable at *c.*-2cm and the other proxies imply the accumulation of poorly humified *Sphagnum* peat and the existence of a hummock-hollow system (Fig. 8:6). From *c.*2000BC-1200BC the southwest (K201) experiences relatively stable wet conditions enabling the accumulation of poorly humified *Sphagnum* (Unit H). In the southeast, the mire remains wet though from *c.*1800BC the water table curve suggests this is gradually changing. In the north, the dry shift ending *c.*2000BC is followed by a series of shorter wet-dry shifts lasting between 100 and 200 years until *c*.800BC. This is the only example of such a cycle from Kilnagarnagh which suggests that this pattern reflects local hydrological dynamics rather than mire-wide processes. The last dry episode from *c*.1000BC-800BC overlaps in time with dry shifts inferred at the southern end of the mire: occurring in the southwest (K201) between *c*.1200BC-900BC, in the southeast (K301) between *c*.900BC-400BC, although not all proxies agree (Table 10:1). An unequivocally dry period in the south (K101) lasted from *c*.850BC-50BC and equates stratigraphically with Unit J (see Section 8:3:4), when peat growth was retarded. It represents an abrupt and serious change in mire surface wetness that had long-term consequences for the southern part of the mire. The apparently earlier dry shifts implied in the biostratigraphy from the other cores may signal the onset of the phase of arrested development (Unit J). The water table curves from K201 and K301 show a gradual fall-off in the height of the water table over several centuries (Figs 9:1 & 9:3) implying a trend towards decreased wetness. In contrast, the water table curve from K101 implies a clear and rapid change following a period of stability. This suggests that (a) a different set of hydrological controls were operating towards the mire edges and (b) something may have happened to trigger the collapse of the water table in the centre. This is discussed further in Section 10:2:3 below.

The dry shifts in the south and north were each followed by a return to generally wet conditions. The water table lay at or near the mire surface and conditions allowed for the accumulation of poorly humified *Sphagnum*. A hummock-hollow complex prevailed in the south with more pools present in the southeast than elsewhere (Fig. 8:6). These conditions prevailed in the southwest from *c*.900BC-AD400 in the southeast from *c*.400BC to *c*.AD200. In the north, the wet-dry cycle was followed by around 900 years of predominantly wet conditions. Each proxy reflects well the subsequent interruption in the development of the mire that dating from *c*.AD100 to *c*.AD600 (Fig. 8:7). This is considered a broadly synchronous event, linked by timing, peat stratigraphy, falling water tables and the near-complete replacement of *Sphagnum* by UOM. The gross peat stratigraphy and the plant microstratigraphy reflect this best with water table curves reflecting greater variability (the curves suggest water table lay from *c*.-5cm to *c*.-16cm depending on location).

	K101 (South)	K201 (Southwest)	K301 (Southeast)	K102 (North)
AD2000-AD700	RECOVERY. UNIT H - Return to generally wet conditions. *Sphagnum imbricatum* dominant moss species.	UNIT H - RECOVERY. *Sphagnum papillosum* dominant moss species.	UNIT H - RECOVERY. *Sphagnum imbricatum* dominant moss species.	UNIT H - RECOVERY. *Sphagnum papillosum* replaces *S. imbricatum*.
AD600				
AD500		DRY. UNIT J - Retarded bog growth. UOM dominant. Water table *c*.-8cm.	DRY. UNIT J - Retarded bog growth. UOM dominant. Water table *c*.-16cm.	
AD400				
AD300		UNIT H (PHS). WET. Water table stable *c*.-2cm. *Sphagnum* dominant.		DRY. UNIT J - Retarded bog growth. UOM dominant. Water table *c*.-5cm.
AD200				
AD100			WET. UNIT H (PHS). Water table stable *c*.-3cm. *Sphagnum* dominant.	
0 AD/BC				
100BC	DRY. UNIT J - Retarded bog growth. UOM dominant. Increased humification. Water table *c*.-16cm.			WET. UNIT H (PHS). *Sphagnum* dominant. Water table to surface.
200BC				
300BC				
400BC				
500BC				
600BC			DRY. UNIT H (PHS). Water table continues to fall *c*.-10cm. *Sphagnum* increases.	
700BC				
800BC				
900BC	WET. UNIT H (PHS). *Sphagnum* dominant. Decreased humification. Water table stable *c*.-2cm.			DRY. UNIT F/H. UOM rises. Water table falls.
1000BC		DRY. UNIT H (PHS). *Sphagnum* dominant. Falling water table *c*.-7cm.	Water table gradually falling.	
1100BC				WET. *Sphagnum* & water table rise.
1200BC				DRY. UOM rises. Water table falls.
1300BC		WET. UNIT H (PHS). *Sphagnum* dominant. Water table stable *c*.-2cm.		WET. *Sphagnum* dominant. Water table rises.
1400BC			WET. UNIT H (PHS). *Sphagnum* dominant. Water table to surface.	
1500BC Trackway				DRY. UOM dominant. Water table falls.
1600BC				
1700BC				WET. UNIT F (HHS). *Sphagnum* dominant. Water table rises.
1800BC				
1900BC				
2000BC				DRY. UNIT F (HHS). UOM dominant. Water table falls.
2100BC		DRY. UNIT F/G (HHS/MHS). UOM dominant. Water table *c*.-5cm.		
2200BC	DRY. UNIT H (PHS). UOM dominant. Increased humification. Water table stable *c*.-2cm		UNIT H (PHS). *Sphagnum* dominant.	
2300BC		WET. UNIT F (HHS) *Sphagnum* dominant. Water table *c*.-2cm.	WET.	WET. UNIT F (HHS). *Sphagnum* dominant. Water table stable *c*.-2cm.
2400BC				
2500BC	WET. UNIT G/H (MHS/PHS). *Sphagnum* dominant. Less humification. Water table stable *c*.-2cm.			
2600BC			Dry episode? UOM increases.	
2700BC				
2800BC	DRY. UNIT F (HHS). UOM dominant. Increasing humification. No water table data.	Initially dry	Unit F (HHS). Rising water table. *Sphagnum* dominant.	
2900BC		FBT - UNIT D. FEN UNIT C		FBT - UNIT D. FEN UNIT C
3000BC				
3100BC				
3200BC				
3300BC			DRY. UNIT F (HHS). UOM dominant. Water table *c*.-5cm.	
3400BC				
3500BC				
3600BC				
3700BC				
3800BC				
3900BC			FBT - UNIT D. FEN UNIT C	
4000BC	FBT - UNIT D. FEN UNIT C			
4100BC				
4200BC				
4300BC				
4400BC				
4500BC - 5000BC				

Table 10:1 Synthesis table of the results from each core. The major peat stratigraphic units derived from the gross stratigraphic survey are included, e.g., UNIT H (PHS).

The character of this shift is similar to that recorded from the south (K101) between *c.*850BC-50BC. Stratigraphically these shifts are linked, forming what appears to be a distinct mire-wide band of highly decomposed peat. On the basis of dates derived from the biostratigraphic sequences, these dry shifts are related as there is a slight overlap in time in the dating ranges of each shift (see Section 8:3:4). The water table in the south central part of the mire appears to have collapsed first, followed a few hundred years later by a similar change the rest of the mire system.

Significant hydrological changes & timing

The degree of correspondence between individual cores is variable; some hydrological changes appear to be recorded mire-wide and others only locally. The timing of changes is likely to include a 'time-lag' between the actual change and its impact. The most important changes within the development of the mire are listed in Table 10:2.

Change	Date
Fen peat initiation	*c.*9600BC
Fen-bog transition	*c.*4000BC-3800BC (S & SE) *c.*2800BC (SW & N)
Staggered, overlapping dry shifts	2400BC-2100BC (S.), 2200BC-2000BC (SW), 2200BC-1900BC (N).
	1200BC-900BC (SW), 1000BC-800BC (N), 900BC-400BC (SE), 850BC-50BC (S).
	AD100-AD500 (N), AD200-AD550 (SE), AD400-AD600 (SW)
Recovery	50BC (S), AD500 (N), AD550 (SE), AD600 (SW)

Table 10:2 Important hydrological changes within Kilnagarnagh. S = south (K101), N = north (K102), SE = southeast (K301), SW = southwest (K201).

Synchroneity is typically used to discern whether environmental changes are related to internal or external forces (see Section 2:2:3). In Kilnagarnagh, the change to ombrotrophy occurred at two different times, which suggests that it represents an autogenic process, triggered by the separation of the fen surface from the groundwater supply because of fen peat accumulation. The relationship of these changes to broader climate change is discussed below (see Section 10:2:6). Once ombrotrophy had been attained across the mire, the degree of synchroneity between cores improves though remains imperfect. Changes are also not necessarily recorded by every proxy. For example, some dry shifts implied in the plant microstratigraphy are not replicated in the testate-derived water table curve (e.g., K101, 2400BC-2200BC; K301 2700BC-2400BC; K201 1200BC-900BC). The strongest evidence for synchronous change lies close to the top of each profile, within the upper metre of peat. Between 850BC and AD600 the mire water table fell to unprecedented levels and decomposition exceeded preservation of plant remains inhibiting bog growth and peat accumulation. There appear to have been two episodes of retardation, the first from 850BC-50BC, the second from AD100-AD600. Each can be divided into two phases though the duration of each is not known (See Section 8:3:4). The second episode appears to have affected a larger area than the first. Possible causes and controls are discussed below (see Section 10:2:3).

The description and interpretation of the palaeoenvironmental sequences from Kilnagarnagh have emphasised shifts to drier conditions, because the most marked changes in the mire have been in this direction. Many studies focus on the identification of wet shifts which may be influenced by the fact that allogenic influences on mires which induce a change from drier to wetter conditions can be more readily identified in the palaeoecological record (Bunting & Warner 1999).

10:2:2 The demise of *Sphagnum imbricatum* at Kilnagarnagh

The plant microstratigraphy from Kilnagarnagh indicates the almost complete replacement of *Sphagnum imbricatum* by *Sphagnum papillosum* in some parts of the mire. Following the period of arrested development in the north (K102), post-AD600 *Sphagnum imbricatum* has disappeared from the record (Fig. 7:6). Similarly in the southwest (K201) *Sphagnum papillosum* dominates with *S. imbricatum* now a minor peat component (Fig. 7:8). In the south (K101) and southeast (K301), however, *S. imbricatum* is the main moss constituent until the close of the sequences, i.e., post-*c.*50BC and post-AD600 respectively (Figs 7:10 & 7:12). Thus, it would appear that though the distribution of *Sphagnum imbricatum* was reduced after AD600 it continued to be present on the mire for some time afterwards. Its demise in some parts of Kilnagarnagh may relate to the wider decline of this species at other mire sites.

The decline and frequently the extinction of *Sphagnum imbricatum* from raised bogs across Europe is well documented (Godwin & Conway 1939; Dickson 1973; Barber 1981; van Geel & Middledorp 1988; Stoneman *et al.* 1993). Various reasons for its decline have been suggested, including climate forcing particularly towards increased wetness, anthropogenic causes such as drainage and burning, or competition between *Sphagnum* species. Replacement of *Sphagnum imbricatum* by *Sphagnum papillosum* or *Sphagnum magellanicum* is well recorded (Barber 1981; van Geel & Middledorp 1988; Stoneman *et al.* 1993) as is replacement by *Sphagnum* section *Cuspidata* (Mauquoy & Barber 1999b). Fossil studies generally place the demise of *Sphagnum imbricatum* in the medieval period with records from Irish and UK mires suggesting a timeframe of around AD1000 to AD1450 (van Geel & Middledorp 1988; Mauquoy & Barber 1999b). This is significantly later than the dates from Kilnagarnagh and might suggest that the *Sphagnum imbricatum* decline is temporally more variable or that the final decline is not recorded at Kilnagarnagh. Evidence from Felecia Moss in northern England, suggests *S. imbricatum* declined here between AD670 and AD880 though this was followed by a final extinction *c.*AD1460 (Mauquoy & Barber 1999b).

At Kilnagarnagh *Sphagnum imbricatum* was present both before and after a period of retarded bog growth. This might suggest its demise may not be related to a change in mire wetness either towards increased wetness or dryness. However, the northern record (K102), shows an unequivocal switch from *Sphagnum imbricatum* to *S. papillosum* (Fig. 7:12) contemporary with the wider recovery of the mire after AD600. Thus increased wetness may have caused the decline of *Sphagnum imbricatum* in the north. In this case, wetter conditions can be related to the internal recovery of the system rather than a change in climate as has been suggested at sites in northern England (Mauquoy & Barer 1999b).

10:2:3 Local Synthesis Lemanaghan

In this section, the model of environmental development implied in Kilnagarnagh is compared with other models from the wider complex of raised bog of which Kilnagarnagh is part.

In Section 3:7:3 above, a model of mire development for Tumbeagh bog, which lies south of Kilnagarnagh (Fig. 3:2), was discussed. The accumulation of fen peat had begun *c.*6000BC. By this time the fen at Kilnagarnagh was well-established (see Section 8:3:1). The possible diachroneity of fen initiation between these areas suggests the importance of local hydrological and topographic factors in controlling the development of fen across the Lemanaghan basin.

Fen peat accumulation at Tumbeagh continued apparently uninterrupted up to *c.*1000BC-950BC and reflects a steady rise in the bog water table. Ombrotrophy had already been attained in other parts of the wider mire system, such as Kilnagarnagh (see Section 8:3:3) and, based on observations of the peat stratigraphy, in nearby

Killaghintober bog (Casparie forthcoming). This suggests that local conditions were the determining factor in the change from fen to raised bog.

Kilnagarnagh and Tumbeagh form part of the same raised bog complex which at some point in the past coalesced to form a linked system interrupted only by high points in the mineral substrate, such as Broder's Island, and the modern road network (Fig. 3:2). Hydrological changes in one part of the mire complex may thus have affected adjoining areas. Around the start of the first millennium BC, a drop in the bog water table is inferred from the peat stratigraphy in Tumbeagh. This drop resulted in the formation of a bowl-shaped fen surface. Casparie (forthcoming) suggests this drop was the result of a bog burst that caused the fen to discharge to the south. Within about half-a-century a bog lake developed over the concave fen surface. The development of this lake is contemporary with the drop in the water table inferred in the south central part of Kilnagarnagh at *c.*850BC.

It appears the bog burst of around 1000BC caused the water table in areas lying to the north of the burst to collapse. In Tumbeagh, the effect was the formation of a compressed, concave fen surface that became a low point in the landscape in which water collected. The bog burst may have led to the arrested development of parts of Kilnagarnagh which appears to have occurred slightly later at around 850BC (see Section 10:2:1). Three possible explanations for the difference in timing may be:

(a) an artefact of correlating extrapolated dates with the mid-points of calibrated dates.

(b) a genuine time lag between the bog burst and its effect on other areas of the mire system.

(c) following the bog burst, a new drainage or discharge system developed across Lemanaghan. Water now collected in the depression formed in the fen in Tumbeagh and this area acted as a sump. As well as receiving atmospheric water, such a low-lying area is likely to attract a greater flow of water from surrounding fen and ombrotrophic systems with possible input from surface flow, pipe flow and the storing and movement of water in channels (Ingram 1983; Connolly *et al.* 2002).

Water collected in this part of Tumbeagh for several centuries and two phases have been identified (see Section 3:7:3). The first phase dates from the mid-tenth century BC to the middle of the third century AD followed by a brief period of ombrotrophic bog growth and then a second phase that lasted into the second half of the fifth century AD. The end of this phase is marked by the formation of erosion gullies as the lake burst its banks and discharged (Casparie forthcoming). This period of lake development and final decline correlates well with the period of curtailed and renewed raised bog growth in Kilnagarnagh. This suggests dry conditions prevailed at Kilnagarnagh because of local drainage mechanisms and thus the arrested development of this bog can be viewed as having an autogenic origin.

Following the decline of the lake in the mid-third century AD, ombrotrophic conditions were established over the former lake site in Tumbeagh. The water table was raised sufficiently to allow surrounding ombrotrophic conditions to expand, with poorly humified *Sphagnum* the main peat former. The recovery of the water table in Kilnagarnagh, between 500AD-600AD, is also marked by renewed poorly humified *Sphagnum* peat accumulation (see Section 10:2:1) suggesting that restoration of wet conditions in Kilnagarnagh followed the recovery of the water table of the wider complex.

There is qualitative evidence to suggest that the period of dry conditions described above was not confined to the northern end of the Lemanaghan system. In Curraghalassa Bog, a horizon representative of retarded bog development was traced in peat faces fringing the southern and western ends of the bog (see Section 6:4). Its character and position in the profile suggest it shares a common origin with the horizon identified in Kilnagarnagh.

The above discussion has shown that two mires that form part of the same mire complex had distinct but ultimately linked developmental histories. Given the evidence from Curraghalassa, the entire Lemanaghan complex can probably be viewed as an interactive mass in which significant hydrological change in one part of the mire had extensive knock-on effects. In the case of Kilnagarnagh and Tumbeagh, each mires' early evolution appears to have been relatively independent of one another, e.g., implied by the differently timed fen initiation and the earlier transition to ombrotrophy in Kilnagarnagh. However, from *c.*1000BC, because of a serious and catastrophic drop in the water table, the mire systems were more closely linked and from this time, the palaeohydrological records appear to converge (Charman *et al.* 1999). This suggests that allogenic or climate-related controls on mire development in the Lemanaghan system were subordinate to the internal dynamics of the system.

10:2:4 The Irish midlands

In this section the record from Kilnagarnagh and Lemanaghan is considered in relation to other raised bogs sites in the Irish midlands.

Fen initiation in Ireland has been shown to be time-transgressive with the majority of dated sites having dates between 10,000BC and 8000BC (see Section 2:1:7, Fig. 2:3). In the Lemanaghan complex fen initiation dates to *c.*9600BC and *c.*6000BC (see Section 10:2:3). The earlier date is contemporaneous with the growth of the fen at nearby Clara bog and these represent some of the earliest examples in Ireland of the infilling of the shallow water-filled basins in which fens typically formed. The proximity of these sites to one another might imply regional synchroneity which may reflect a climatically-driven change towards fen peat growth though studies in other countries suggest that the evidence for such synchroneity is inconsistent (see Section 10:3:1). The spread of dates from Ireland, particularly from other midland sites, such as Lough Boora, Co. Offaly and Derryville, Co. Tipperary (Fig. 2:3), would suggest the precise timing of fen initiation clearly varied geographically and was determined by the availability of suitable conditions locally.

There were at least two centres of ombrotrophic development in Kilnagarnagh separated temporally by about one thousand years (see Section 10:2:1). Earlier transitions are recorded from other midland bogs. In nearby Clara Bog, the fen-bog transition has been dated to 5270±210calBC (Beta-65096) and 5000±300calBC (Beta-63927) while in Mongan the same horizon dates from 3500±140calBC (SRR-5731) (Fig. 2:4).

Once ombrotrophic conditions were established at Kilnagarnagh, mire development proceeded relatively uneventfully for a few millennia. There is evidence for a dry shift between 2400BC and 1900BC though the degree of correspondence between the available proxy data is variable. Otherwise the best evidence for significant change dates from the first millennium BC. At this point the mire 'experienced' a serious drop in the water table (Table 10:1).

Records from Tumbeagh and Derryville do not serve as useful comparisons as these mires were still fens at this time (Casparie 1998, forthcoming). However, recent work on two sites in the midlands has provided long plant macrofossil sequences against which the record from Kilnagarnagh can be compared (Fig. 10:1). Following the fen-bog transition, a dry *Eriophorum*-rich environment existed on Mongan Bog, Co. Offaly (Barber *et al.* 2003) between 2600BC and 1300BC. From 1300BC, the mire became increasingly wet and *Sphagnum* vegetation replaced sedges and grasses. The earliest ombrotrophic peat development at Abbeyknockmoy, Co. Galway, took place between 4750BC and 2400BC (Barber *et al.* 2003). This was a dry phase defined by monocots and Ericaceae and was followed by a long wet phase, (*c.*2400BC-200BC) characterised by a mixed *Sphagnum* wet lawn with occasional peaks in heathers and monocots.

At both Mongan and Abbeyknockmoy, the earliest ombrotrophic peat development appears to have occurred under relatively dry mire conditions. The possible dry shifts implied at Kilnagarnagh, between 2400BC and 1900BC, are broadly contemporaneous with this dry yet ombrotrophic phase at Mongan, and may overlap with the end of the dry phase at Abbeyknockmoy. However, at Mongan and Abbeyknockmoy the dry phase represents the earliest stages of ombrotrophic peat growth, while at Kilnagarnagh the dry shifts occur within an already well established and previously wet ombrotrophic system. It is therefore hard to determine if this is a coincidence or linked to region-wide processes such as climate.

From *c.*1900BC to *c.*1200BC Kilnagarnagh appears to have been a stable and wet bog (Fig. 10:1). The sequence from the north (K102) shows a cycle of wet-dry changes which are not replicated in other cores from Kilnagarnagh and thus may primarily relate to local hydrological dynamics (see Section 10:2:1). This period correlates with a longer wet phase in Abbeyknockmoy (see above) and overlaps with the initial dry ombrotrophic phase in Mongan. The latter ends around 1300BC and is followed by a long wet phase dating between *c.*1300BC and *c.*AD550 in which variable conditions are implied between 1300BC and 750BC. The wet phase in Kilnagarnagh ended as the situation in Mongan became wetter and there was no significant change in conditions in Abbeyknockmoy. It is evident that there is no clear relationship between the palaeohydrological records from these mires.

In Kilnagarnagh, the testate-derived water table implies a series of staggered dry shifts in different parts of the mire from 1200BC (Table 10:1). There are no immediate parallels for these shifts in Mongan or Abbeyknockmoy (Fig. 10:1) (Barber *et al.* 2003) and they overlap with both wet and dry phases from Derryville Bog, Co. Tipperary (Caseldine *et al.* 1998, 2005). The later dry phase at Derryville was a product of a bog burst which caused the water table to drop across the mire at around 800BC (*ibid.*) and is suggested to be autogenic in origin (Caseldine *et al.* 1998, 2005). The issue of control and bog bursts is returned to in Section 10:3:3 below.

It has been suggested above that change to the overall drainage pattern of the Lemanaghan complex caused the water table in south central Kilnagarnagh to drop from 850BC. As part of this bog became drier, wet conditions still prevailed at Abbeyknockmoy and Mongan (Barber *et al.* 2003). This dry situation is also at odds with records of mire surface records from other sites in Britain and Europe, from which a late Holocene climatic deterioration at around 800BC has been implied (see Section 10:2:4). The start of the arrested development at Kilnagarnagh is broadly contemporaneous with the bog burst implied in Derryville at around 800BC (Fig. 10:1), though conditions suitable for the accumulation of poorly humified *Sphagnum* peat were restored in Derryville within a century (Casparie 1998, 2001) followed by another bog burst at around 600BC (*ibid.*). The period of mire-wide retarded bog growth at Kilnagarnagh is considerably longer, only ending around AD600 (Table 10:1). Within this period wet and dry phases are implied from midland sites other than those already mentioned. Multi-proxy analyses have been carried out on ombrotrophic peat cores from Ardkill, Co. Kildare and Cloonoolish, Co. Galway between *c.*200BC and the present (Blundell 2002). The opening of each sequence implies bog development in relatively wet conditions (Fig. 10:1) but dry shifts, lasting for about two hundred years, are implied in Ardkill from *c.*AD20-AD280 and in Cloonoolish from *c.*AD260 and from *c.*AD590 (*ibid.*). The dates and the duration of these shifts suggest that these are mire-specific rather than climatically driven.

The palaeohydrological sequences from Kilnagarnagh following recovery of the bog water table are not particularly informative. This may be because of compression of the peat deposit or because of slow bog growth (see Section 7:1). From *c.*AD600, the water table at Kilnagarnagh appears to have recovered with a return to wet conditions inferred

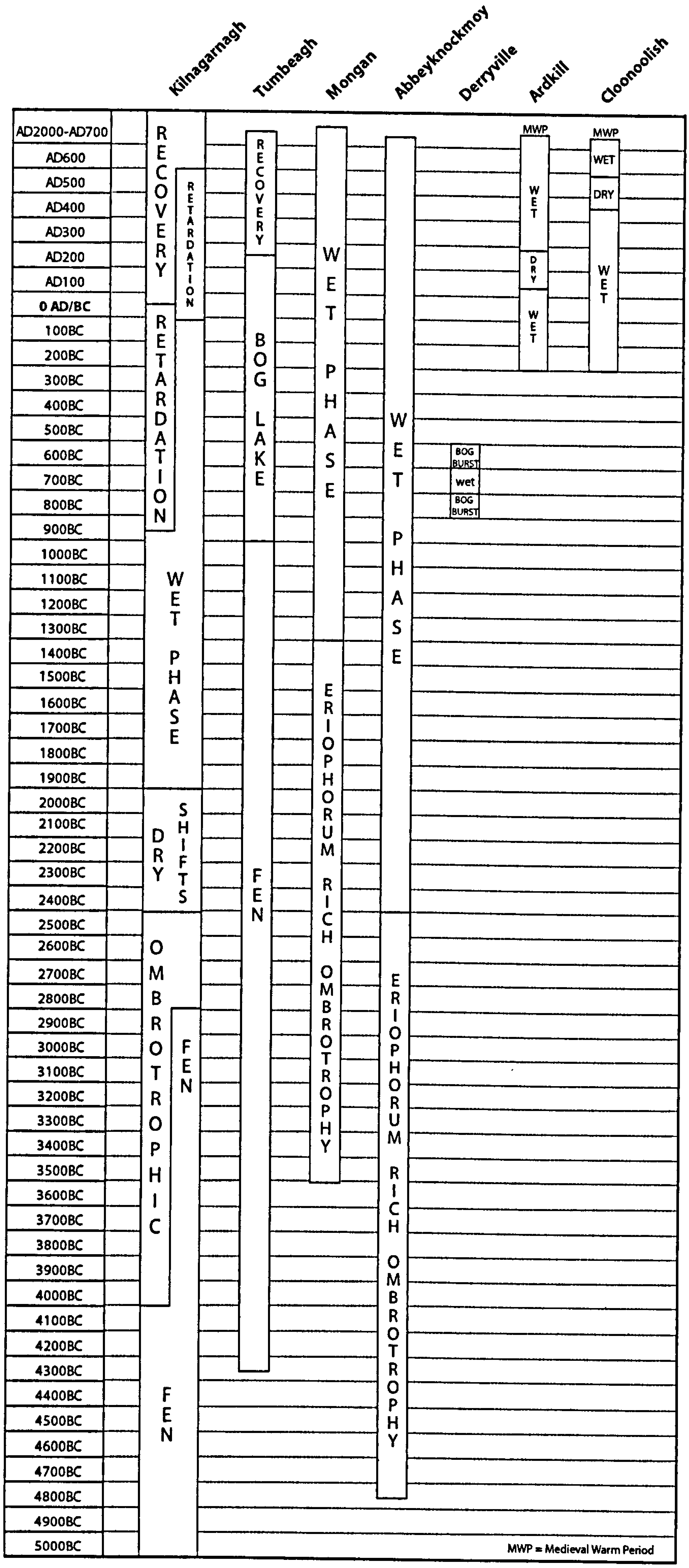

Fig. 10:1 Comparison of major peat and hydrological changes from seven sites in the Irish midlands.

until relatively recently. Elsewhere, wet phases were already in progress with Mongan and Abbeyknockmoy bogs become increasingly wet over the first and second millennium AD – in Mongan until about AD1730 when anthropogenic activity may have caused a shift to drier surface conditions, and in Abbeyknockmoy where wet lawn communities persisted until at least *c.*AD1000 (Barber *et al.* 2003). Wet conditions prevailed at Cloonoolish from *c.*AD700 until *c.*AD1040 and in Ardkill from *c.*AD280 to *c.*AD900, when the influence of the Medieval Warm Period is suggested to have caused a change to drier conditions (Blundell 2002). Post-AD600 and up to about AD1000 wet phases appear to prevail in mires across the Irish midlands.

10:2:5 Summary

The hydrological shifts implied in Kilnagarnagh appear to occur independently of developments in other mire systems. The lack of synchroneity across palaeohydrological sequences from different mires implies internal processes are primarily responsible for the hydrological and environmental changes that took place in Kilnagarnagh. A good example of the influence of autogenic controls on Kilnagarnagh is the period of arrested development dating from around 850BC to around AD600. This dry phase can be linked to changes in the wider Lemanaghan drainage system which resulted in the formation of the bog lake in Tumbeagh which acted as a sump for surrounding mires leading to the retarded growth of Kilnagarnagh and possibly Curraghalassa. These developments may ultimately have been driven by a bog burst.

10:3 CONTROLS ON BOG PROCESSES

In this section controls on bog processes at Lemanaghan are considered against a wider regional and northwest European background. The discussion begins with a consideration of fen initiation followed by the switch to ombrotrophy and finally a discussion of the most significant events that occurred within the succeeding ombrotrophic system.

10:3:1 Initiation of fen peat accumulation in Northwest Europe

With the onset of the Holocene, conditions became suitable for the formation of mires across North West Europe. However, the timing of peat initiation shows considerable spatio-temporal variation. It has already been shown in Ireland that the development of initial fens and the later switch to ombrotrophy was time-transgressive (see Section 10:2:4) and this appears to be the case from other parts of Europe also. In some cases where synchroneity has been inferred some researchers interpret this as representing climatic causation of peat initiation. For instance, in northern England, Walton Moss, Solway Moss, Glasson Moss and Bolton Fell Moss, have returned fen initiation dates starting around 8250BC (*c.*10,200 cal BP) (Hughes *et al.* 2000). In southern Finland, peats began accumulating by around 8700BC with a more intense phase of initiation from 6000BC-5300BC (Korhola 1995). A second intense phase dates from *c.*2300BC that involved paludification of new areas of wet mineral soils and lateral expansion of pre-existing peat bodies (*ibid.*). Korhola (1995) suggests increased humidity may have enabled the initiation and expansion of mires in Finland. Elsewhere however, research from the Bergslagen region of central Sweden has suggested that local site conditions are more important than climate (Almquist-Jacobson & Foster 1995). Here, fen initiation occurred under a broad range of regional moisture conditions between 6600BC and 1500BC. For example, three sites lying only 1km apart within the one drainage system returned the following dates for fen peat growth: Norra Römyren *c.*5700BC; Havsjömossen *c.*3900BC and Nittenmossen *c.*4100BC. The balance of the evidence, including the dating results from Ireland, suggests that, once suitable climate conditions are present, fen initiation may be viewed as time transgressive and determined by local factors.

10:3:2 Change to ombrotrophy

The fen-bog transition is typically viewed as an autogenic hydroseral stage in the development of a raised bog (Tallis 1983; Charman 2001) but one which may provide an indication of a change to a more oceanic climate regime (Walker 1970). The change in vegetation that marks the fen-bog transition can be viewed mainly as a response to changes in the position of the groundwater relative to the accumulating peat surface. These changes are controlled by autogenic processes (Burrows 1990). The accumulation of fen peat leads to the progressive exclusion of ground and surface water supplies. Eventually meteoric moisture is the sole or most important source of water and there is a change in vegetation to plants capable of extracting their nutrients from rainfall. Given the primacy of internal processes in the fen-bog transition, it is not surprising that this stage displays considerable spatio-temporal variation. Sites from across Ireland (see Section 10:2:3, Fig. 2:3), the UK and Scandinavia have shown a degree of variability in the timing of this stage of development. Early transitions occurred in several mires in Cumbria, England within a few hundred years around *c.*7800BC (Hughes *et al.* 2000). In Wales, and at sites across middle and northern England, the fen-bog transition has been dated between 6100BC and 2300BC (Hughes & Barber 2003). The switch to ombrotrophy at Kilnagarnagh took place between 4000BC and *c.*2800BC (see Section 10:2:1), and has few Irish parallels. In southern Sweden (Almquist-Jacobson & Foster 1995) the fen-bog transition occurs between *c.*2800BC and *c.*2000BC. This coincides with a period of ombrotrophic peat initiation and expansion in Finland which has been interpreted as representative of widespread and increased humidity from *c.*2300BC (Korhola 1995).

Recently Hughes (2000) and Hughes & Barber (2003; 2004) have argued that both the timing and the vegetational character of the fen-bog transition can be influenced by the prevailing climate regime, and autogenic processes need not be the primary driving agent. They argue that the separation of ground and meteoric water supplies necessary for the progression to ombrotrophy can occur because of a lowering of the regional water table due to decreasing effective precipitation or anthropogenic factors and is not necessarily contingent on the elevation of the fen surface due to an accumulating peat deposit alone. Where a dry pioneer raised bog community becomes established, for example, *Eriophorum*-rich peat in Bolton Fell Moss, England (Hughes & Barber 2004) and Tregaron Bog, Wales (Hughes & Barber 2003), this may reflect a lowering of the regional water table rather than autogenic hydrological isolation. At Tregaron (*ibid.*), river channel dynamics may have influenced the water table in the mire causing it to fluctuate and enabling a dry oligotrophic environment to establish. In Bolton Fell Moss (Hughes & Barber 2004), the development of ombrotrophy, via a dry pathway, coincides with a lengthy period of low effective precipitation inferred from oxygen-isotope records from ice and lake cores. On the other hand, a major period of climate cooling, identified in ice cores and dating to around 6200BC, may have resulted in higher effective precipitation and facilitated the move to ombrotrophy at Abbeyknockmoy, Ireland (*ibid.*) via a wet fen-bog transition.

However, it is difficult to see how the transition to raised bog at Kilnagarnagh can be viewed as response to allogenic change. The gross stratigraphic survey has shown the fen-bog transition (Unit D, see Section 8:2:5) to vary in character across the mire with both dry (e.g., Units D3-4) and wet (e.g., Units D1-2) pathways present. In addition, it has already been shown that this transition was time-transgressive (see Section 8:3:2).

Such variability suggests that the fen-bog transition appears to be closely linked to the overall drainage and vegetation patterns of the fen and mineral ridge environments. Once ombrotrophy was attained at Kilnagarnagh relatively dry, oligotrophic conditions prevailed enabling the accumulation of highly humified *Sphagnum* with *Calluna*, *Eriophorum* and occasionally other monocotyledonous remains.

The detail in which the fen-bog transition has been mapped at Kilnagarnagh contrasts with surveys of this boundary from the mires mentioned above. Though this difference in resolution makes comparison of the transitions difficult the results from Kilnagarnagh suggest that it is possible to have different pathways to ombrotrophy within a mire, as well as between mires. Thus, this stage of mire development may be more complex then previously demonstrated and require greater consideration in future studies.

10:3:3 Controls on ombrotrophic mire processes

It has been shown that following the change to ombrotrophy at Kilnagarnagh the mire appears to have been insulated from the potential affects of climate or regional hydrological change until around 850BC. Between *c*.4000BC and *c*.2800BC, in those parts of the mire that were already ombrotrophic, conditions favoured the accumulation of highly humified peat implying that relatively dry conditions prevailed. Around the same time palaeoecological records from blanket and raised mires in northwest Europe imply a series of wet shifts, dating between *c*.4200BC and *c*.2850BC (Barber *et al.* 2003).

After *c*.2800BC ombrotrophy prevailed across the mire at Kilnagarnagh and the system entered a generally wet phase until *c*.2400BC when a return to dry conditions is inferred that may have lasted until *c*.1900BC (Table 10:1). Broadly, this was a period of cooler continental conditions in Ireland marked by recurrence surfaces in raised bogs and the widespread initiation of blanket bog (Mitchell *et al.* 1996). Drier episodes within this period enabled *Pinus* sp. to become established on mire surfaces in western Ireland and in the midlands (*ibid.*). Elsewhere in Europe wet shifts are implied from *c*.2690BC to *c*.1780BC (Barber *et al.* 2003).

From *c*.1900BC to *c*.850BC conditions at Kilnagarnagh are generally stable and wet. Other European mires show shifts towards wetter conditions within this time span with a series of wet shifts dating to *c*.1750BC, 1650BC, 1600BC, 1500BC, 1460BC, 1400BC, 1370BC, 1200BC, 1150BC and 1020BC (Barber *et al.* 2003). These are followed by a second set of wet shifts dating from 900BC-550BC which may correspond to a wetter climate between 850BC-760BC at Lemanaghan (see Section 10:2:4).

It has been shown above that from around 850BC the Lemanaghan system underwent change in two directions, i.e., increased wetness and greater dryness. Other Irish mires do not present such a duality, but imply stable wet conditions prevailed for centuries either side of the developments in Lemanaghan. This shows the difficulty of comparing records from multiple-mire systems such as Lemanaghan with records from mires that at least appear to represent a single system. There is one contemporary parallel for a change to dry conditions, namely at Derryville, where a bog burst resulted in a serious drop in the water table and limited *Sphagnum* peat accumulation for almost a century. Bog bursts have been interpreted as internal hydrological management devices that prevent a raised bog from 'drowning' (Casparie 2001). In Derryville, they occurred repeatedly at unequal intervals over the course of the mire's evolution (Casparie 2001, 2005).

The dry phases from Derryville and Lemanaghan contrast with a seemingly global shift to wetter conditions dating to around 850BC (van Geel *et al.* 1996; Speranza *et al.* 2000). Van Geel *et al.* (1996) used multiple mire sites and sources of evidence from around the globe to suggest a period of climatic deterioration between *c.*850BC and *c.*760BC. Broadly contemporary wet shifts have been inferred from raised bogs and blanket mires in northwest Europe (Hughes *et al.* 2000), though the evidence from Ireland is not as convincing (Barber *et al.* 2003). This period was previously referred to as the transition from the Sub-Boreal to the Sub-Atlantic when the climate moved from a continental to a more oceanic regime and may also equate with Weber's original *Grenzhorizont* (see Section 2:2:2).

It has been shown above that wet conditions prevailed at some Irish sites for centuries either side of 850BC. The absence of an unequivocal wet shift may be because:

(a) no such shift in conditions occurred,

or

(b) these particular mires were insensitive to an increase in effective precipitation at this time, or

(c) that some mires may have responded to deteriorating conditions in a very different manner, i.e., bog bursts.

A bog burst occurs because a mire is over-saturated with water (see above). An increase in effective precipitation may push some mires beyond their threshold for storing and managing their water supply. The seemingly universal deterioration in conditions between 850BC and 760BC (van Geel *et al.* 1996) may have triggered bursts in mires existing on the edge of their water storage capacity threshold. Thus dry shifts in systems such as those in Derryville and Lemanaghan, which display strong autogenic controls on their development, may be reflecting the same general climate trend. Mire responsiveness to climate change may be determined by existing internal environmental conditions which are largely the result of autogenic factors. However, only climate change of a certain magnitude may have affected sites where bog growth was not otherwise limited by precipitation.

The above discussion has shown the complexities of deciphering proxy records from raised bogs and raises questions about mire sensitivity on a variety of scales, regional, local and site-by-site. There appears to be little degree of correspondence between the palaeoecological record from Kilnagarnagh and other sites in Ireland or northwest Europe other than at *c*.850BC. This may imply:

(a) Kilnagarnagh was not sensitive to climate change in the way other mires may have been.

(b) Only climatically induced change of a certain magnitude would be registered in Kilnagarnagh.

(c) Particular conditions must be in place before climate induced changes would affect the hydrology of the mire, e.g. over-saturation.

(d) Not all dry shifts, despite synchroneity, reflect changing climate conditions. Some represent bog bursts though these may have been triggered by a shift to wetter conditions.

10:4 CROSSING THE BOG

10:4:1 Introduction

In this section, the archaeological/cultural interpretation of the plank walkway in Kilnagarnagh is discussed. The environmental context of the Bronze Age walkway from Kilnagarnagh is discussed relative to the character of the mire surface at the time the trackway was constructed and to longer-term trends in the development of the raised bog. These results are then used to explore the relationship between the environment and the spatial and temporal distribution of archaeological sites within the Lemanaghan complex (see Section 10:4:3). Again, how this relationship influences interpretation of the archaeological record is also considered. The implications this may have for interpreting human activity on mires is then discussed (see Section 10:4:4).

10:4:2 Cultural interpretation of the trackways in Lemanaghan

The location and length of the Bronze Age walkway in Kilnagarnagh suggests it was intended to cross the bog and to provide a local link between areas of dryland. Later prehistoric tracks, such as those in Killaghintober Bog dating to the eleventh and tenth centuries BC (Fig. 3:4), served the same purpose. The repeated construction of trackways across Killaghintober (see Section 3:3:4) might suggest this route was more important than in previous centuries when only one walkway, the site in Kilnagarnagh, was constructed. The type of sites built, i.e. single plank walkways, represent relatively simple and easily assembled structures quite different from the more elaborate and sturdier corduroy or paved roads frequently interpreted as representative of wider communication networks (see Section 2:5:5). In the Lemanaghan area wider regional links were probably achieved via the system of eskers lying in the north (Fig. 3:2) which provided safer and firmer passage, and perhaps via the River Brosna situated to the south. This may have been the case until the sixth and seventh centuries AD when the monastic settlement in Lemanaghan was established. From this time, multi-phased wooden and stone roadways connect the island at Lemanaghan with the surrounding dryland (see Section 3:3:4).

10:4:3 Testing hypotheses of trackway construction

One of the objectives of this thesis was to reconstruct the mire surface on which the Bronze Age plank walkway, located in the southern end of the mire, was placed (see Section 1:3). Reconstructing the environment in which the trackway was built involves formulation of two environmental models each with different temporal resolutions. The first attempts to reconstruct the environment at a specific point in time, in this case *c.*1500BC. The second places this reconstruction within a model of broader and longer-term environmental change.

Based on the gross stratigraphic survey it has been suggested that the walkway ran from a dry wooded area, occupying a ridge in the mineral substrate, and extended eastwards across a hummock-hollow complex into a wetter part of the mire (see Section 8:4:4). Wetter conditions in the east meant that the site was either incomplete or that it was more susceptible to damage (see Section 8:4:2). It may or may not have spanned the full width of the mire. The trackway appears to have been placed to take advantage of dry situations provided by the ridge and the hummock-hollow complex. This suggests that around 1500BC the bog surface was relatively dry except perhaps in the east. Contemporary plant microstratigraphy generally supports this impression of a dry bog surface occupied by hummocks of *Sphagnum imbricatum*. In contrast, the contemporary testate-derived water table implies that a relatively stable wet situation prevailed, and trackway construction occurred at a time of optimum peat growth (Table 10:1). The preceding centuries reflect relatively homogenous, poorly humified *Sphagnum* peat accumulation with a single bryophyte species, *Sphagnum imbricatum*, dominating the mire surface. The testate-derived water table curves suggest stable wet conditions implying a change towards a drier situation a few centuries after trackway construction (Table 10:1).

The above suggests two apparently contrasting pictures of environmental conditions at Kilnagarnagh. This episode of trackway construction may reflect seasonal or a longer period of drier conditions too short-lived to be picked up in the higher resolution proxies. Closer sampling intervals and tighter chronological control of peat samples above and below the trackway may have improved the chances of identifying shorter episodes of hydrological change if present. Nonetheless, the trackway appears to have been built at a time when the mire was efficiently 'managing' its water supply over several centuries during a relatively long wet phase in the mire's evolution and at a time when no significant shifts in hydrology took place. This is reflected in the continued accumulation of poorly humified *Sphagnum* peat, the growth of the hummock-hollow complex and the stable water table. In the succeeding centuries, there is a lack of trackway construction in Kilnagarnagh possibly related to the longevity of these environmental conditions. In the eleventh and tenth centuries BC the focus for site construction lies to the south though this is interrupted by developments in Tumbeagh (Fig. 3:4) (see Section 3:6:3).

Two questions arise from the suggested environmental context of the plank walkway from Kilnagarnagh:

(1) How do the models of mire surface wetness presented above relate to the hypotheses presented in Section 1:5 and reiterated below?

(2) What are the implications for understanding anthropogenic activity on mires?

Null hypothesis:
There is no link between trackway construction and hydrology.

Alternative hypothesis 1:
Trackway construction is primarily determined by cultural factors although these may coincide with hydrological change.

Alternative hypothesis 2:
Trackway construction is inextricably linked to hydrology, as this is the primary determinant in access to the mire. Construction is primarily determined by a hydrological shift which affects the accessibility of the mire and thus the connectivity between the mire and the surrounding dryland.

The palaeoenvironmental reconstruction of the trackway in Kilnagarnagh has shown that an unequivocal shift in environmental conditions is absent. Rather the trackway was built during a long wet phase in the mire's evolution. This might suggest the needs of the trackway builders outweighed the obstacle posed by a wet bog and thus, alternative hypothesis 1 can be accepted. However, the trackway appears to have been built across a developing hummock-hollow complex (see Section 6:2:2), suggesting that on at least one occasion this surface was sufficiently accessible and dry to allow trackway construction, though the correlation between proxy records from Kilnagarnagh may not be sufficiently strong to support this suggestion. This may mean that trackway construction can be viewed as an opportunistic venture, one made possible by a swing in favour of access, even if this access was short-lived. Thus trackway construction may be linked to hydrology, i.e., accept alternative hypothesis 2, despite the absence of an unequivocal shift in environmental conditions.

The above shows the difficulty of trying to 'marry' single points in time with wider, longer-term trends. A similar situation occurs at Derryville where excavations show trackway construction across a range of environments, many of which existed side-by-side at the same time (Casparie 1998, 2005). In Derryville, in the Early Bronze Age (2350BC-1750BC) site construction was confined to the fen margins, as the fen was too wet to be crossed (Cross *et al.* 1998; Cross May *et al.* 2005). Subsequently, between 1700BC and 1000BC, by which time ombrotrophy had been achieved in the mire centre, trackways were in place that traversed wet zones in the bog and spanned the full width of the bog. In broad terms, site construction took place during a period of relatively low water table (Caseldine *et al.* 1998, 2005). A local record however, provides a contrasting picture. A plank walkway dating from 1590±9BC was constructed through part of the bog that was becoming increasingly wet (*ibid.*). In this case, the track appears to have been laid in response to deteriorating conditions within an otherwise accessible environment.

The above discussion has shown that trackway construction and hydrology are closely linked and that the accessibility of the mire is fundamental to the construction of trackways and by implication, to all other archaeological structures built in raised bogs. There appears to be a complex inter-play between the environment and the cultural needs of the past populations which may only be discerned through integrated archaeoenvironmental research. There is a clear need for more detailed work on a trackway-by-trackway basis particularly as the sequence of environmental change derived from long-term records may provide a misleading picture of environmental conditions contemporary to trackway construction.

10:4:4 Environmental controls on wider patterns of archaeological mire-use in the Lemanaghan complex

Lemanaghan has been shown to be rich in archaeological remains with nearly 750 archaeological sites known (see Section 3:3). Table 3:4 and Fig. 3:3 show the distribution of dated sites from the raised bog complex. Archaeological deposits have been made in this complex for at least the last 3250 years. The intensity of deposition, and therefore activity requiring trackway construction, differed across time. Dating implies episodic rather than continuous activity with a crude estimate of the rate of site construction being one site every 14 years (see Section 3:3:3).

The specific environmental context in which dated structures were deposited has not been investigated though cursory peat stratigraphic records suggest that the majority lie either in ombrotrophic deposits or close to the fen-bog transition (IAWU unpublished data). Nonetheless, Casparie (forthcoming) suggests that the temporal and spatial distribution of trackways in Lemanaghan may be used to infer changes in mire surface wetness. The earliest period of trackway construction dates from the sixteenth century BC to the tenth century BC (Fig. 3:4). The positions of the trackways suggest they were placed at the narrowest crossings through the bog, connecting upland to upland or allowing access to the island in the centre of the complex.

Casparie (forthcoming) focused on the absence of trackways in the period covering the existence and demise of the bog lake at Tumbeagh (see Section 10:2:2) between the tenth century BC and the fifth century AD. The most intense periods of trackway construction bracket this period, i.e., 11th & 10th centuries BC and the 6th & 7th centuries AD (Table 3:4). Casparie has suggested that the gap in trackway construction reflects an increasingly wet mire surface – in Tumbeagh, following a bog burst, a lake formed over several centuries. The lake eventually discharged leaving behind an irregular and gully-marked bog surface around the middle of the third century AD. The lake, the damaged bog surface and the absence of trackways imply the Lemanaghan system was inaccessible. Trackway construction only resumed once conditions on the bog became drier, enabling access and the construction of plank walkways.

The palaeohydrological record from Kilnagarnagh implies the drop in water table that led to the depression in the fen surface in Tumbeagh where the bog lake formed. However, rather than supporting the idea of an increasingly wet bog surface across the Lemanaghan system, the rest of the mire system became increasingly dry and in at least two bogs peat accumulation came to a standstill (see Section 10:2:2). The lack of trackway construction may imply the mire surface away from the lake was sufficiently dry and that trackway construction was unnecessary. If this situation only pertained to the bogs fringing the edge of the Lemanaghan system then this may have suited local populations as the shortest routes across these bogs generally lay at the junction between each bog and the central expanse of bog known as Lemanaghan. Thus rather than attribute the absence of trackways to increased levels of mire surface wetness (Casparie forthcoming), the lack of trackway construction may reflect the prevalence of a desiccated and more easily accessed mire surface.

10:4:5 Relating archaeological & environmental records to theories of human behaviour & trackway construction

In Section 2:6 environmental models of human behaviour within raised bogs were discussed. Raftery (1996) and Bailie & Brown (1996) have suggested that in general trackway construction occurred during dry periods with local environmental conditions subordinate to the needs of the trackway builders. Brindley & Lanting (1998) have suggested that trackways were built in both wet and dry periods and local conditions were a primary influence on site construction. The evidence from Lemanaghan and Derryville favours the second model suggested. In Lemanaghan environmental factors strongly influenced trackway construction or the lack thereof. Sites were built during generally wet periods with an absence of site construction during drier phases and in very wet parts of the mire complex. In Derryville (see Section 10:4:1) construction occurred in both wet and dry phases of mire development but was clearly influenced by local conditions.

Analysis of the palaeoenvironment in which trackways were constructed combine to allow some general 'rules/guidelines' useful for examining mire access and episodes of trackway construction. For example:

- in very wet mires or, in wet parts of a mire, trackways were unnecessary.
- in very dry mires or, in dry parts of a mire, trackways were unnecessary.
- where a mire or, part of it, was dry but became progressively wetter, access was maintained by building a trackway.
- where a mire or, part of it, was wet but became drier, access was obtained through trackway construction.

Changes towards wetter or drier conditions may have been short-lived. In these cases, trackways may be viewed as opportunistic ventures designed to take advantage of temporary access.

The combined palaeoenvironmental and archaeological records from Lemanaghan demonstrate:

(a) the complexities of mire development and the difficulties these present in interpreting past human behaviour

and

(b) that the temporal and spatial distribution of archaeological sites is insufficient to infer the type of environmental conditions in which trackways were constructed as the direction of any such change is uncertain in the absence of palaeoenvironmental records.

Trackway construction in mires was governed by a range of variables (Table 2:2) though not necessarily always of equal importance or relevance. Environmental conditions however, could determine where and when a trackway was constructed. The type of trackway constructed was probably also influenced by the accessibility of the mire surface. Trackway construction in Lemanaghan occurred during transitional or wet mire phases. Plank walkways may have been favoured because they were better suited to the environment than heavier corduroy or stone constructions, hence, the preponderance this site type in Lemanaghan in comparison with other raised bog systems (see Section 3:3:4). If, in Lemanaghan, mire conditions determined the type of journey that took place then certain kinds, such as those with animals or wheeled vehicles, could not take place until well into the historic period when larger, heavier roads were built. How much this relates to improvements in engineering rather than a change in surface conditions is unknown not least because the relevant peat deposits have been cut away.

This does not mean that single plank walkways automatically imply the presence of generally/typically wet conditions in the mires where such walkways are found, though it does suggest that human activity on mires was strongly influenced by environmental conditions.

10:5 CONCLUSIONS

This thesis has demonstrated the value of applying a multi-proxy approach to environmental reconstruction and the importance of the gross peat stratigraphic survey to the interpretation of higher resolution proxy records from raised bogs. Firstly, there is good correspondence between the higher resolution proxies where strong clear changes are implied and, where weaker trends are suggested in individual proxies, these may find correspondence in some but not all data sets. Thus, individual proxies are less capable of inferring significant changes. Secondly, the biostratigraphic sequences from Kilnagarnagh appear to infer fewer significant shifts in hydrology than comparable sequences from other raised bogs (e.g. Blundell 2002, Mauquoy & Barber 1999a, 2002). This may relate to problems with analogues, e.g., in the case of the plant microstratigraphy the dominance of *Sphagnum imbricatum* may obscure changes (see Section 4:5). Similarly with regard to testates, the prevalence of *Difflugia pulex* may mean the reconstructed water table curve is not as good as it might be (see Section 4:4:3). The sequences were taken from locations where the peat deposits were less likely to reflect complicated local sequences of change, such as in the wooded zone in the centre or above ridges in the mineral substrate. This may have implications for interpretation of sequences from mires where little is know about the overall development of the system. Local or internal changes in hydrology may be misinterpreted as representative of the mire system and as evidence for wider/regional environmental change.

This thesis has used records of environmental change to reconstruct the environment in which a trackway crossed the bog at Kilnagarnagh and to suggest reasons why trackway construction was more prevalent in some periods then others. It has been shown that surface wetness directly influences trackway construction. In Kilnagarnagh the trackway builders appear to have availed of dry situations in a generally wet bog, though correlating short and longer-term records would be improved by closer interval sampling and analysis of peat above and below the trackway. In Lemanaghan, site construction occurred during periods of increasing wetness with an absence of construction during dry episodes. Developing environmental models of trackway construction applicable to other mire sites is therefore complicated by the importance of local and potentially short-term conditions. While there remains a lack of detailed mire and trackway-specific studies, this thesis has shown that interpreting episodes of trackway construction as a reflection of either wet or dry conditions may be inappropriate.

CHAPTER 11

CONCLUSIONS & RECOMMENDATIONS FOR FUTURE WORK

11:1 CONCLUSIONS

The stated aim of this thesis was the palaeohydrological reconstruction of a small raised bog in order to investigate the mire's potential for wider palaeo-environmental reconstruction and to examine potential environmental controls on human interaction with the mire, as expressed by archaeological structures preserved within the bog (see Section 1:3). The main conclusions arising from this research are presented in three parts. The first deals with issues of mire development, namely autogenic and allogenic controls on mire processes and the implications this has for discerning patterns of climate change from mire-based palaeo-records. The second and the third outline respectively, the main conclusions in relation to mire accessibility and trackways and the methodologies employed. The chapter closes with recommendations for future work (Section 11:2).

11.1.1 Environmental reconstruction

Raised bogs share similar overall developmental patterns. However, no two bogs are the same, as local factors such as location, topography and drainage can produce significant developmental differences. The latter can influence the degree to which autogenic or allogenic influences may be preserved in the fossil record. This thesis has shown that Kilnagarnagh is largely an autogenically-driven system closely linked to the wider Lemanaghan complex. With the exception of one period or event, dating to around 850BC, there is no evidence for synchronicity between Kilnagarnagh and other mires suggesting autogenic factors are the main control on mire processes. It would appear that the availability of water was not a limiting factor in the development of either Kilnagarnagh or the Lemanaghan complex as a whole. These mires developed in a climate regime where there was always a water surplus necessary to progress mire development. The same was found to be the case at Derryville where bog development progressed apparently regardless of changes in the level of precipitation (Caseldine *et al.* 2005). Following on from the work of Walker and Walker (1961) this thesis is now the third study to suggest that Irish mires may therefore not be responsive to changes in effective precipitation in a way that would allow patterns of climate change to be identified. However, the Kilnagarnagh study suggests that mires have individual thresholds for responding to changes in hydrology. Climate change may occasionally push some mires beyond their threshold causing them to burst as appears to have been the case at Kilnagarnagh, Lemanaghan and also Derryville. This means that only threshold events may be recorded in Irish mires and the possibility of identifying cycles or change of lesser magnitude may be limited.

Different types of fen-bog transition were identified at Kilnagarnagh that may have implications for the interpretation fen-bog pathways in general. The fen-bog transition in mires examined by Hughes & Barber (2003) consisted either of a dry or wet pathway taken as wholly representative of a given mire system. At Kilnagarnagh, multiple pathways are present within the one system and ombrotrophy was achieved asynchronously. Arguably, the two studies may not be directly comparable as they differ in the resolution of the investigations undertaken, i.e. Hughes and Barber's stratigraphic investigations were limited in comparison but they carried out higher-resolution plant macrofossil analysis. The Kilnagarnagh data suggest however that the fen-bog transition might be less uniform within individual mires and potentially more complicated than Hughes and Barber (2003) have suggested.

11.1.2 Archaeology & mire surface wetness

This thesis has shown that mire access and hydrology are closely linked. Mire surface wetness greatly influenced mire access in Lemanaghan as expressed by the presence or absence of trackways. Contemporaneous very wet and very dry situations saw an absence of trackway construction. Areas once dry but which later became wet a renewal in trackway construction. The trackways may be interpreted as an attempt to maintain access to or across an increasingly wet bog surface. In Lemanaghan, it would appear that trackways were constructed during periods of transition when the mire was moving from one set of conditions to another. Trackway construction therefore may be best viewed as occurring in periods of environmental transition, when the mire was not too wet or dry to negate the need for site construction. In addition, trackway construction may also be viewed as an opportunistic venture, i.e., taking advantage of a short window of time in which mire access was possible. For example, the Bronze Age walkway in Kilnagarnagh appears to have been constructed during a less-wet episode in a broadly wet-phase in the mire's development. It is important therefore to apply wider patterns of environmental change cautiously when interpreting human behaviour within systems that maybe subject to change within short periods difficult to reconstruct.

11.1.3 Methodologies

In this thesis, there is a good degree of correspondence between the chosen proxies, i.e., testate amoebae, plant macrofossils, humification and peat stratigraphic data. This implies that testate amoebae perform well as a means of palaeohydrological reconstruction in Irish mires and supports the use of the UK-derived transfer function on Irish data sets.

The work undertaken in Kilnagarnagh has shown that the combination of a multi-proxy and multiple core analyses is the best approach to reconstructing environmental change. In general, changes in hydrology were found to correspond between proxies and were replicated between cores. Where differences were present, these were representative of local rather than mire-wide conditions. Distinguishing between local and wider conditions is particularly pertinent when attempting to identify patterns of hydrological change in mires that may be related to changes in climate. In addition, this study has shown that interpretation of high-resolution proxies is greatly enhanced with reference to models of mire development derived from gross peat stratigraphic survey. In particular, gross stratigraphic survey has provided information not available from coring alone. For example, while coring may imply the presence of a hummock-hollow system a stratigraphic survey of exposed peat faces allows actual topographic and spatial structures to be mapped. This has consequences for the selection of core sampling sites within mires as the locations most appropriate for addressing particular research questions may be identified.

In terms of data presentation, DEMs have been shown to be a useful means of portraying mire development through time. They can provide 3-D representations of different evolutionary stages which when 'layered' can be used to examine the spatial and topographic relationship between given horizons, for example, the extent of ridges in the mineral substrate and their inundation by fen and later raised bog peat in Kilnagarnagh.

In palaeoecological studies age-depth models are commonly produced in order to aid interpretation of biostratigraphic sequences. This thesis has shown that such models should be used cautiously for sequences from drained or compacted peats as rates of peat accumulation based on a compressed deposit will return an artificially higher value than rates derived from un-drained peats.

11:2 RECOMMENDATIONS FOR FUTURE WORK

11:2:1 Comprehensive stratigraphic surveys

Mires subject to extensive industrial exploitation, such as those in the Irish midlands and for example in Estonia and Poland, represent finite resources that are being rapidly destroyed. These mires represent ideal landscapes for carrying out comprehensive stratigraphic surveys as the drained and open nature of the peatlands mean both stratigraphic and archaeological deposits are visible at the same time. Detailed stratigraphic surveys of the kind carried out in Kilnagarnagh, may be considered time consuming, but the record provides considerable scope for fine-tuning both sampling and excavation strategies. In addition, interpretation of both biostratigraphic and archaeological records are enhanced when the evolution of their physical context is well understood.

11:2:2 Targeted close-interval sampling

Archaeological excavations of trackways and other structures within raised bogs should include analysis of the deposits immediate to the site but should also consider the wider mire system. This study applied an 8cm sampling interval in combination with a gross stratigraphic survey in order to reconstruct the immediate environment of a Bronze Age trackway. This has been shown to be successful but it could be improved upon. Trackways in bogs tend to represent a short time period, generally between 10 and 20 years. Given the variable rate of peat accumulation at Kilnagarnagh, e.g., from 1cm in 9.6 years to 1cm in 24 years, a closer sampling interval, such as 1cm, would have provided a more detailed picture of the contemporary environment. Future studies should seek to combine close-interval analysis with approaches, such as gross stratigraphic survey and wide-interval multi-proxy approaches, aimed at reconstructing broader developments.

11:2:3 'Time-slice' DEMs

Higher resolution stratigraphic surveys combined with a more comprehensive dating programme would allow for the construction of 'time-slice' DEMs and the production of ecotype maps based on fossil records. This would enable the exploration of past spatial patterning of vegetation communities. In the absence of dates, DEMs based on stratigraphic survey results will allow construction of conceptual models of mire development in which archaeological sites and therefore human activity and behaviour may be better understood.

11:2:4 Chronological control

Significant peat horizons identified by gross peat stratigraphic survey should be dated independently of cores to avoid potential problems introduced by correlating sequences made at different resolutions. Extrapolating from a core to a lower resolution and wider stratigraphic record will not necessarily be as straightforward as at Kilnagarnagh where for example, changes in testate stratigraphies corresponded very well with changes in the gross stratigraphic record. In addition, independent dating of significant peat horizons can provide a broad chronological framework in advance of laboratory-based analyses. Typically, horizons for dating are selected based on testate or plant macrofossil zones boundaries. Thus, this means dating occurs later in the research programme but also that dates are more closely related to changes in the sub-fossil record than they are to broader mire evolution.

APPENDIX 1: DATES USED IN FIGS 2:3 & 2:4

Site	Uncalib.	±BP	cal 95% (BC/AD)	Mid pt	Full range	Error	Source	Code
Clara Bog West	10020	90	10150-9250	9700	900	450	Connolly 1999	Beta-68737
Kilnagarnagh	9966	73	10000-9200	9600	800	400	This thesis	Wk-14130
Clara Bog East	9890	80	10000-9150	9575	850	425	Connolly 1999	Beta-63929
Sluggan	9475	145	9250-8300	8775	950	475	Smith & Goddard 1991	UB-443
Sluggan	9360	150	9150-8250	8700	900	450	Smith & Goddard 1991	UB-225F
Meenadoon	9015	335	9300-7300	8300	2000	1000	Pilcher & Larmour 1982	UB-2137
Ballyscullion	*c.*9000	0	8265-8210	8292.5	55	27.5	Mitchell 1986	none cited
Lough Boora	8980	360	9300-7300	8300	2000	1000	O'Kelly 1993	UB-2268
Lough Boora	8475	76	7610-7320	7456	290	145	O'Kelly 1993	UB-2199
Derryville	7150	20	6080-5920	6000	160	80	Casparie 1998	none cited
Tumbeagh	5417	90	4450-4000	4225	450	225	Casparie forthcoming	Wk-12086
Ardee Bog	*c.*5000	0	3800-3710	3755	90	45	Mitchell & Tuite 1995	none cited
Ballydermot/Blackriver	1710	100	AD80-AD560	320	480	240	Hammond 1968	none cited

Table 1:1 Fen initiation dates from Irish raised bogs (see Fig. 2:3). All dates calibrated using OxCal version 3.9.
The dates from Ballyscullion and Ardee Bogs are estimates as provided in the original texts but are calibrated for use here.

Site	Uncalib.	±BP	cal 95% (BC)	Mid pt	Full range	Error	Source	Code
Clara	8290	80	7530-7080	7305	450	225	Connolly 1999	Beta-65096
Ballydermot/Blackriver	7540	125	6650-6050	6350	600	300	Hammond 1968	none cited
Bog of Allen	*c.*7500	0	6420-6250	6335	170	85	Mitchell 1986	estimated
Abbeyknockmoy	7420	45	6400-6100	6250	300	150	Hughes & Barber 2004	SRR-5734
Meenadoon	7280	110	6400-5910	6155	490	245	Pilcher & Larmour 1982	UB-2112
Sluggan	6760	90	5720-5625	5672.75	95	47.25	Smith & Goddard 1991	UB-221A
Ballyscullion	6430	85	5480-5360	5420	120	60	Smith & Goddard 1991	UB-119
Clara	6330	80	5300-5296	5298	4	2	Connolly 1999	Beta-65095
Kilnagarnagh K102	4858	42	3730-3520	3625	210	105	This thesis	Wk-14131
Mongan	4705	45	3640-3360	3500	280	140	Hughes & Barber 2004	SRR-5731
Corlea 9	4680	125	3550-3000	3275	550	275	Raftery 1996	GrN-16831
Kilnagarnagh K301	*c.*4404	0	3090-2920	3005	170	85	This thesis	extrapolated
Kilnagarnagh K101	4192	41	2890-2620	2755	270	135	This thesis	Wk-14126
Kilnagarnagh K201	4218	47	2910-2620	2765	290	145	This thesis	Wk-14139
Ballycon	3730	65	2340-1930	2135	410	205	McNally & Doyle 1984a/b	UB-2454
Glashabaun	3510	60	2020-1680	1850	340	170	McNally & Doyle 1984a/b	UB-2449
Tumbeagh	2540	60	810-410	610	400	200	Casparie forthcoming	UCD 01108
Corstown West, Ardee	2530	0	800-560	680	240	120	Mitchell & Tuite 1995	I-16605

Table 1:2 Ombrotrophic initiation dates from Irish raised bogs (see Fig. 2:4). All dates calibrated using OxCal version 3.9.

APPENDIX 2

STRATIGRAPHIC LOGS

DRAIN 1

CORE 1:8	OD (m)	Depth (cm)	Description
FIELD SURFACE - UNIT H (PHS)	56.25m	0-8cm	PHS (H1-2)
UNIT J	56.13m	8-12.5cm	Well decomposed soft peat, with reed?
		12.5-14cm	*Sphagnum cuspidatum.*
		14-18cm	MHS.
		18-23cm	HHS with *Calluna.*
		23-37cm	PHS.
		37-42cm	HHS with *Eriophorum.*
		42-51cm	PHS with *Calluna.*
		51-54cm	MHS with *Calluna.*
UNIT H (PHS)	55.71m	54-72cm	PHS and MHS shallow layers, difficult to separate layers.
		72-81cm	PHS (H1).
		81-95cm	HHS (H7) with *Calluna* and laminated *Sphagnum cuspidatum.*
		100-131cm	PHS (H3) very loose with *Calluna.*
UNIT G (MHS)	54.94m	131-160cm	MHS (H4-H6) with *Eriophorum* and *Calluna.*
UNIT F (HHS)	54.65m	160-171cm	HHS with *Calluna* and *Eriophorum.*
		171-211cm	HHS, fibrous and soft, lacking structure (H8) with *Calluna* and *Eriophorum.*
UNIT C (FEN)	54.14m	211-239cm	HHS with reed and wood. Crumbly oxidises rapidly from dark brown to black.
		239-280cm	Compact yellow-brown fen peat with decayed wood and minor reed.
		280-300cm	Reed peat.
		300-350cm	Homogenous yellow-brown reed and sedge peat. Many vertical roots and well decomposed.
		350-400cm	Softer fen with hardly any reed and less vertical roots.
		400-418cm	Well decomposed yellow-brown fen peat with wood.
		418-430cm	Compact red-brown fen, minor sedge. Thin dark bands possibly charcoal with wood at 429-430cm.
		430-462cm	Compact fen, crumbly, no reed, minor sedge.
UNIT B (MINERAL SUBSTRATE)	51.63m	462-463cm	Organic soil layer - yellow-grey.
		463-500cm	Sticky blue clay.

CORE 1:6	OD (m)	Depth (cm)	Description
FIELD SURFACE	56.56m	0-4cm	Fresh *Sphagnum* peat.
UNIT J		12-18cm	Shallow alternating layers of PHS and MHS.
UNIT H (PHS)	56.29m	27-32cm	Laminated *Sphagnum cuspidatum* layer with *Eriophorum*.
		32-37cm	MHS. Transition from HHS below vague.
		37-42cm	*Sphagnum cuspidatum* layer.
		42-71cm	Fresh to PHS, upper 5cm somewhat laminated otherwise homogenous.
		71-80cm	*Sphagnum cuspidatum*.
		80-180cm	PHS (H2-H3) with *Sphagnum cuspidatum, Eriophorum* and *Calluna*.
UNIT G (MHS)	54.76m	180-210cm	MHS. Transition from HHS below vague.
UNIT F (HHS)	54.46m	210-250cm	HHS. Transition from fen unclear.
UNIT C (FEN)	54.06m	250-330cm	Fen peat with minor reed and no wood.
		330-340cm	Fen with some reed but no wood.
		340-375cm	Fen with slightly more reed present. Oxidises to brown.
		375-430cm	Homogenous sedge rich fen peat with many roots and stems - sedge and not reed peat. Yellow-brown and oxidises to yellow.
		430-440cm	Sedge fen peat
		440-473cm	Red-brown fen peat with some wood.
		473-513cm	Highly decomposed yellow-black wood layer.
		513-530cm	Well decomposed mud-like layer with few plant remains, more or less laminated, yellow-brown with rapid oxidation.
		530-537cm	Transition layer, no sand or silt. The base is mud-like, cracks like mud. No minerals 20mm above mineral subsoil.
UNIT B (MINERAL SUBSTRATE)		537-585cm	Very sticky, blue clay-blue grey clay, upper 10cm some organic inclusions. No gravel or grit.

Drain Face 1:7	OD (m)	Depth (cm)	Description
FIELD SURFACE - UNIT H (PHS)	56.99m	0-14cm	Fresh *Sphagnum*.
UNIT J	56.85m	14-19cm	MHS, some cracking.
		19-22cm	PHS.
		22-26cm	MHS.
		26-32cm	PHS.
		32-36cm	Almost MHS.
		36-38cm	PHS, thin layer.
		38-41cm	MHS, some Calluna, hummock vegetation, to SE more pool fill.
		41-45cm	PHS.
UNIT G (MHS)	56.40m	45-48cm	MHS.
		48-62cm	Thick layer of MHS. Some cracking, some thin PHS lenses.
UNIT H (PHS)	56.23m	62-64cm	*Sphagnum cuspidatum* lense ending at survey point = NW end of hollow fill.
		at 77cm	Base of hollow but to SE of survey point.
		64-90cm	Poorly humified hummock peat with *Calluna*.

CORE 1:1	OD	Depth (cm)	Description
FIELD SURFACE-PHS	57.12m	0-12cm	Fresh *Sphagnum* peat.
	57.00m	12-18cm	MHS.
	56.94m	18-24cm	PHS.
UNIT J	56.88m	24-28cm	Gyttja-like.
	56.84m	28-34cm	PHS.
	56.78m	34-36cm	Dark MHS with *Eriophorum* extending eastwards.
UNIT H (PHS)	56.76m	36-38cm	PHS.
	56.74m	38-42cm	*Sphagnum cuspidatum.*
	56.70m	42-46cm	MHS (H3-H4) with *Eriophorum* and *Sphagnum cuspidatum.*
	55.66m	46-120cm	PHS with *Eriophorum* and *Sphagnum cuspidatum.*
	55.92m	120-130cm	MHS (H3-H4) with *Eriophorum.*
UNIT F (HHS)	55.82m	130-235cm	HHS with *Eriophorum* levels and minor *Calluna.*
UNIT C (FEN)	54.77m	235cm	Top of fen peat with wood. Transition to fen not sharp.
		at 250cm	*Eriophorum* tussock
		at 315cm	Minor wood and reed level.
		335-340cm	Wood level.
		340-375cm	Fen, no wood.
		375-380cm	Fen with some reed.
		380-410cm	Highly decomposed fen with little wood.
		410-413cm	Reed level.
		413-480cm	Sedge fen peat.
		490-498cm	Wood level.
		498-593cm	Sedge fen peat.
UNIT B (MINERAL SUBSTRATE)	51.19m	593-680cm	Sticky blue clay

CORE 1:2	OD (m)	Depth (cm)	Description
FIELD SURFACE	57.45m	0-30cm	Fresh to PHS (≤H3).
UNIT J	57.15m	30-45cm	HHS (H6-H7) and *Eriophorum* overlying thin layer of *Sphagnum cuspidatum* and dried highly cracked laminated HHS.
	57.05m	45-57cm	Laminated *Sphagnum cuspidatum.*
UNIT H (PHS)	56.88m	57-75cm	*Eriophorum.* Hummock?
		80-83cm	Top of structureless PHS, thin *Sphagnum cuspidatum* layers present.
		83-130cm	Structureless PHS. No layers. Fresh-H1.
		130-170cm	Structureless PHS with minor *Eriophorum.*
UNIT G (MHS)	55.75m	170-225cm	MHS (H6). Transition from underlying HHS difficult to define - gradual.
UNIT F (HHS)	55.20m	224-245cm	HHS.
UNIT C (FEN)	55.00m	245-250cm	Smooth transition from Fen to HHS.
		250-290cm	Real fen peat, wood and reed present, minor reed.
		290-330cm	Fen with some wood and reed.
		330-347cm	Soft fen, no wood.
		347-355cm	Darker layer, some wood, slightly laminated.
		355-367cm	Brighter fen peat with less wood.
		367-370cm	Darker fen, some wood.
		370-409cm	Yellow fen peat with some reed
		409-420cm	Red-brown fen with less wood then darker layer above
		420-437cm	Fen peat, dark with little wood, well decomposed.with some reed but not reed peat. Red-brown colour.
		437-520cm	Yellow-brown, less well decomposed with reed and sedges but no wood. Homogenous. Some sand in lower 10cm.
UNIT B (MINERAL SUBSTRATE)	52.25m	520cm	Top of mineral substrate.

CORE 1:4	OD (m)	Depth (cm)	Description
FIELD SURFACE - FRESH - PHS	57.55m	0-22cm	PHS with MHS layer at 16-22cm.
FLUCTUATION HORIZON	57.33m	22-58cm	Laminated system of MHS-PHS. Gully with laminated, cracked base overlies laminated system.
MHS	56.91m	58-65cm	MHS with local differences and weak transitions.
UNIT H (H2) PHS	56.84m	65-68cm	PHS.
		68-71cm	*Eriophorum*.
		71-109cm	PHS.
		109-117cm	MHS.
		117-124cm	*Eriophorum*.
		124-132cm	PHS.
		132-148cm	MHS.
		148-157cm	PHS.
		157-164cm	MHS.
		164-175cm	PHS with *Eriophorum* at 175cm.
UNIT F (HHS)	55.80m	175-253cm	HHS with *Eriophorum* at 225-233cm and 244-252cm.
FEN	55.02m	253-438cm	Top of fen, highly decomposed. Fen peat with wood and reed.
		330 & 438cm	*Eriophorum* and wood.
		438-463cm	Reed and sedge peat.
		463-490cm	Fen with minimal wood and reed from 486-490cm.
		490-592cm	Sedge fen with decreasing reed.
		at 584cm	Wood, below this level the fen is more decomposed.
		592-627cm	Sedge peat, some reed and wood at 598cm.
UNIT B (MINERAL SUBSTRATE)		627cm	Top of mineral soil. Top 2cm blue-brown organic, below this sticky plastic blue clay.

Drain Face 1:5	OD (m)	Depth (cm)	Description
FIELD SURFACE - UNIT H (PHS)	57.62m	0-9cm	Fresh *Sphagnum*.
UNIT H (PHS)	57.53m	9-13cm	Dark brown, slightly cracked - an old surface?
	57.49m	13-32cm	PHS.
		32-36cm	Dark MHS.
		36-56cm	PHS with local MHS layers.
		56-60cm	Dark MHS.
		60-71cm	PHS (H1-H2).
		71-96cm	Homogenous PHS practically fresh (H1).
		96-98cm	Thin layer of *Sphagnum cuspidatum*.

CORE 1:9	OD (m)	Depth (cm)	Description
FIELD SURFACE- UNIT H (PHS)	57.35m	0-30cm	PHS with *Eriophorum* and *Sphagnum cuspidatum*.
	57.05m	30-50cm	PHS with shallow layers H1-H3.
	56.85m	50-100cm	PHS with local MHS.
UNIT G (MHS)	56.35m	100-152	MHS
UNIT H (PHS)	55.85m	152-175cm	PHS
UNIT G (MHS)	55.60m	175-282cm	MHS (H6) with lenses of PHS and *Eriophorum*.
UNIT F (HHS)	54.53m	282-292cm	HHS
		292-293cm	*Sphagnum cuspidatum*.
UNIT C (FEN)	54.42m	293-305cm	Fen peat - transition zone.
		305-330cm	Well decomposed dark fen peat without wood or reed.
		330-365cm	Highly decomposed fen with wood and reed.
		365-430cm	Highly decomposed sedge fen peat, no wood, some reed.
		430-434cm	Reed peat.
		434-474cm	Homogenous highly decomposed sedge peat with some reed.
		474-590cm	Sedge peat with reed and wood at 510cm and 576cm.
UNIT B (MINERAL SUBSTRATE)	51.45m	590-650cm	Mineral soil, homogenous blue plastic clay, no lamination or gravel.

Drain Face 1:10	OD (m)	Depth (cm)	Description
FIELD SURFACE - UNIT H (PHS)	57.54m	0-12cm	Fresh *Sphagnum.*
UNIT H (H2) (PHS)	57.41m	12-22cm	PHS
		22-24cm	*Sphagnum cuspidatum.*
		24-33cm	PHS.
		33-35cm	*Sphagnum cuspidatum*, runs to NW for over 1m, sloping downwards.
		35-56cm	PHS with local *Sphagnum cuspidatum* layer at 0.45m.
UNIT H (H2) MHS	56.97m	56-68cm	MHS (H4) with *Eriophorum*: hummock peat.
UNIT H (H2) PHS	56.85m	68-103cm	PHS (H1).
UNIT H (H2) MHS	56.50m	at 103cm	Top of MHS peat (H6). A lot of small stems and roots.

CORE 1:11	OD (m)	Depth (cm)	Description
FIELD SURFACE	57.30m	0-30cm	Fresh to MHS with *Calluna* and some wood remains. Well decomposed. Wood visible in drain face to NW & SE.
SEDGE-MOSS PEAT	57.00m	30-38cm	Highly decomposed sedge peat with wood. Dark black to brown, oxidised in past. Floating horizon?
	56.92m	38-96cm	Mix of sedge peat and moss *(Sphagnum?)* (H7) with *Eriophorum.*
UNIT H (PHS)	56.34m	96-110cm	PHS (H2).
		110-130cm	No record.
		130-150cm	PHS with *Sphagnum cuspidatum* layers.
UNIT G (MHS)	55.80m	150-188cm	Poor to moderate *Sphagnum* peat with *Calluna* in top 3cm and thin *Sphagnum cuspidatum* layer at 185cm.
UNIT F (HHS)	55.42m	188-247cm	HHS with *Eriophorum* and *Calluna.*
UNIT C (FEN)	54.83m	247-265cm	Fen-like peat, reed and wood present.
UNIT F (HHS)	54.65m	265-274cm	HHS with *Eriophorum.*
UNIT C (FEN)	54.56m	274-280cm	Well decomposed fen peat with wood from 280-285cm.
	54.36m	294-330cm	Very dark oxidised fen peat.
UNIT E3	54.0m	330-345cm	Oxidised black fen, well decomposed, loose not compact, wood peat.
	53.85m	345-375cm	Wood peat.
UNIT C (FEN)	53.55m	375-430cm	Highly decomposed sedge peat with some reed, no wood or bog bean.
	53.00m	430-452cm	Reed peat with wood at 452cm.
	52.78m	452-575cm	Reed peat, not compact with more highly decomposed components and wood at 557cm & 570-575cm.
	51.55m	575-585cm	Sedge peat with some reed.
	51.45m	585-590cm	Light brown mix of fen peat and clay.
UNIT B (MINERAL SUBSTRATE)	51.40m	590cm	Top of blue clay, no gravel

CORE 1:12	OD (m)	Depth (cm)	Description
FIELD SURFACE - UNIT G (MHS)	57.50m	0-22cm	MHS with intervening layer of PHS (H1-2) and wood.
UNIT E3	57.28m	22-25cm	Crumbly wood and reed peat, mix of fibrous plants.
		25-40cm	Sedge peat with reed and possible non-*Sphagnum* moss.
		40-58cm	Sedge peat with traces of bog bean.
		58-62cm	Fen peat with *Sphagnum.*
		52-72cm	Reed peat.
		72-85cm	Well decomposed fen with wood (alder leaf).
		85-90cm	Fen peat with bog bean.
		90-100cm	No record.
		100-130cm	Fen peat with possible non-*Sphagnum* moss.
		130-153cm	Sedge peat, mosses still present.
UNIT H (PHS)	55.97m	153-180cm	PHS (H3) with *Calluna.*
UNIT F (HHS)	55.70m	180-230cm	HHS (H8) with MHS; wood at 212-214cm and PHS at 214-217cm.
UNIT C (FEN)	55.20m	230-265m	Top of fen, brown, well decomposed with wood.
UNIT G (MHS)	54.85m	265-280cm	MHS.
UNIT F (HHS)	54.70m	280-300cm	HHS.
NO RECORD	54.50m	300-335cm	No record, push down.
UNIT E3	54.05m	335-360cm	Crumbly black wood peat.
UNIT C (FEN)	53.90m	360-368cm	Sedge peat with reed.
UNIT I	53.82m	368-400cm	Loose, no record.
UNIT E3	53.50m	400-470cm	Crumbly wood peat with sedge and reed present.
UNIT I	52.80m	470-500cm	Loose, no record.
UNIT C (FEN)	52.50m	500-565cm	Sedge and reed peat with some wood. Peat still black but less wood.
		565-580cm	Loose, no record.
		580-590cm	Sedge peat with wood, wood-like peat.
		590-612cm	Sedge and reed peat, yellow without wood.
UNIT B (MINERAL SUBSTRATE)	51.38m	612-680cm	Top of mineral substrate, homogenous blue grey clay.

CORE 1:13	OD (m)	Depth (cm)	Description
UNIT H (PHS)	57.73m	0-80cm	PHS (H1-2) with *Sphagnum cuspidatum* layers, *Calluna* and MHS from 65-68cm.
		80-100cm	Loose, no record.
		100-155cm	PHS with *Eriophorum* at 140cm and *Sphagnum cuspidatum* at 145-147cm.
		155-200cm	Loose, no record.
	55.50m	200-223cm	*PHS with Calluna.*
UNIT F & UNIT I (HHS & LOOSE PEAT)		2.23-2.30	Loose MHS (H4).
		230-254cm	HHS with *Calluna* and *Eriophorum.*
		254-335cm	HHS, loose, not compact with high water content.
		335-366cm	HHS with minor wood.
	54.07m	366-400cm	Recorded as vague transition from fen to raised bog, no real fen peat present.
UNIT I	53.73m	400-430cm	Loose peat, much water.
UNIT C (FEN)	53.43m	430-440cm	Transition from fen to raised bog.
		440-450cm	Loose fen, no structure - floating vegetation, oxidised from floating in water.
		450-460cm	Reed peat, still very loose
		460-470cm	Slightly less reed.
		470-510cm	Fen peat with reed and wood.
	52.63m	510-530cm	Loose moss peat.
	52.43m	530-600cm	Loose, oxidised sedge peat.
UNIT B (MINERAL SUBSTRATE)	51.73m	600-611cm	Yellow smooth marl - decayed limestone?
		611-618cm	Blue grey sand, fine to medium grain.
		618-619cm	Sticky clay.
		619-650cm	Coarse sand.
		650-670cm	Sticky clay.

Drain Face 1:14	OD (m)	Depth (cm)	Description
FIELD SURFACE - UNIT H (PHS)	57.95m	0-43cm	PHS (H1-2) with local lenses of MHS (H4).
UNIT G (MHS)	57.52m	43-70cm	MHS (H5) with Eriophorum layer at 62cm.
UNIT H (PHS)	57.25m	70-80cm	PHS with *Eriophorum* tussock and *Calluna.*
UNIT F (HHS)	57.15m	80-116cm	HHS (H8), very little structure.
UNIT H (PHS)	56.79m	116-12cm	PHS.
UNIT G (MHS)	56.74m	121-135cm	MHS (H6-H7).

CORE 1:15	OD (m)	Depth (cm)	Description
UNIT H (PHS)	58.41m	0-5cm	Upper aerated loose peat.
		5-7cm	*Sphagnum cuspidatum.*
		7-16cm	MHS.
		16-20cm	PHS.
		20-34cm	MHS.
		34-150cm	PHS, mostly H1 with *Sphagnum cuspidatum* at 118-121cm.
		150-158cm	*Sphagnum cuspidatum* with some PHS.
		158-195cm	PHS with *Eriophorum* at 165-170cm, *Sphagnum cuspidatum* at 180-183cm.
		195-200cm	MHS (H3-H4).
		200-212cm	PHS (H3).
		212-228cm	MHS (H5), darker.
		228-260cm	PHS.
		260-270cm	MHS.
UNIT I	55.71m	270-400cm	No record, core not recovered, HHS occasionally present.
UNIT F (HHS)	54.41m	400-420cm	HHS, red-brown with some wood at 416cm. Base of FBT at 420cm.
UNIT C (FEN)	54.21m	420-436cm	Yellow-brown fen peat with some reed.
		436-460cm	Reed peat.
		460-461cm	Wood.
		461-533cm	Reed peat, no darker levels or structure.
		533-570cm	No record, core lost.
		570-603cm	Structureless loose decomposed peat.
		600-616cm	Fen with wood and some reed.
UNIT B (MINERAL SUBSTRATE)	52.25m	616-618cm	Top of mineral soil, represented by organic soil.
		618-640cm	Sharp boundary with mineral soil of sticky blue grey clay.
		640-670cm	Still sticky but with more gravels, stone at 6.40m.

Drain Face 1:16	OD (m)	Depth (cm)	Description
FIELD SURFACE - UNIT H (PHS)	58.72m	0-10cm	Fresh *Sphagnum.*
UNIT J	58.60m	10-12cm	Laminated *Sphagnum cuspidatum.*
		12-14cm	PHS, laminated.
		14-16cm	*Sphagnum cuspidatum.*
		16-20cm	PHS.
		20-23cm	*Sphagnum cuspidatum.*
		23-29cm	PHS.
		29-32cm	*Sphagnum cuspidatum.*
		32-37cm	PHS.
		37-43cm	*Sphagnum cuspidatum.*
UNIT H (PHS)	58.29m	43-118cm	PHS to fresh *Sphagnum* with *Eriophorum* through out.
UNIT G (MHS)	57.54m	118-137cm	MHS.

CORE 1:17	OD (m)	Depth (cm)	Description
FIELD SURFACE - UNIT H (PHS)	58.79m	0-3cm	PHS, aerated and oxidised.
UNIT J?	58.76m	3-16cm	MHS (H6), compact.
		16-26cm	PHS (H3) compact.
		at 26cm	Thin *Sphagnum cuspidatum* layer.
		26-36cm	PHS.
		36-40cm	MHS.
UNIT H (PHS)	58.40m	40-75cm	PHS with *Eriophorum.*
		75-100cm	No record, peat may have broken on a *Sphagnum cuspidatum* level.
		100-130cm	PHS with *Eriophorum.*
UNIT G (MHS)	57.49m	130-154cm	MHS with *Sphagnum cuspidatum* 140-146cm.
UNIT F (HHS)	57.25m	154-206cm	HHS (H5-H7) with *Sphagnum cuspidatum* and *Eriophorum.*
		206-240cm	MHS with PHS inclusions (H4).
		240-300cm	No record, core lost.
		300-325cm	Loose MHS peat.
		325-358cm	HHS (H6-7) with *Calluna.*
		358-403cm	HHS (H8). Possibly floating peat remains, without structure.
UNIT D	54.76m	403-430cm	Transition horizon. Wood at top and bottom, crumbly forest peat with some reed between wood layers.
UNIT C (FEN)	54.40m	430-485cm	Homogenous fen peat, rich in reed and sedge with minor wood.
		485-500cm	No record, core lost.
		500-585cm	Homogenous reed sedge fen peat with wood and reed levels.
		635-652cm	Highly decomposed fen peat with sedge and reed, more compact than fen above.
BASE OF UNIT C	52.24m	652-655cm	Transition to dark grey organic clay, possibly an old surface or a palaeo-soil. Base not observed.

Drain Face 1:18	OD (m)	Depth (cm)	Description
FIELD SURFACE - UNIT H (PHS)	59.06m	0-10cm	Fresh *Sphagnum.*
UNIT J	58.96m	10-14cm	MHS.
		14-29cm	PHS.
		29-36cm	MHS.
		36-43cm	PHS.
		43-47cm	MHS.
		47-54cm	PHS.
		54-63cm	Moderately humfied *Eriophorum* with *Calluna* on bottom.
UNIT H (PHS)	58.43m	63-107cm	PHS (H2) without interruption until 73-88cm: *Eriophorum* tussock. Below 88cm *Sphagnum cuspidatum* and *Eriophorum.*
		88-107cm	*S. cuspidatum* layer at base.
UNIT F (HHS)	57.99m	106-143cm	HHS (H7) with much *Eriophorum.* Increasing amounts below 100cm.

CORE 1:19	OD (m)	Depth (cm)	Description
FIELD SURFACE -PHS	59.19m	0-3cm	PHS.
UNIT J?	59.16m	3-9cm	Dark layer with *Eriophorum.*
		9-35cm	PHS, banding.
		35-40cm	MHS.
UNIT H (PHS)	58.83m	40-125cm	PHS.
		125-128cm	*Sphagnum cuspidatum.*
		128-144cm	PHS.
		144-154cm	*Sphagnum cuspidatum.*
		154-164cm	PHS.
		164-168cm	*Sphagnum cuspidatum.*
UNIT G (MHS)	57.51m	168-200cm	MHS (H6-H7).D336
UNIT F (HHS)	57.25m	200-270cm	HHS with *Sphagnum cuspidatum* from 221-223cm, *Eriophorum* at 235cm.
		270-300cm	No record, core lost.
		300-426cm	HHS (H7-8) with wood at 355cm.
UNIT C (FEN)	54.93m	426-480cm	Fen with reed and wood.
		480-500cm	Reed peat, no structure.
		500-515cm	No record, core lost.
		515-590cm	Reed fen peat, homogenous with wood at 550cm.
		590-600cm	Dark fen layer without reed.
		600-620cm	No record, core lost.
		620-641cm	Dark fen layer with some reed.
UNIT B (MINERAL SUBSTRATE)	52.76m	641-643cm	Organic grey-yellow palaeo-soil.
		643-665cm	Mineral soil, lake marl.
		665-675cm	White-blue fine grained sand.
		675-690cm	Blue grey fine sand.

Drain Face 1:20	OD (m)	Depth (cm)	Description
FIELD SURFACE - UNIT H (PHS)	59.32m	0-8cm	Fresh *Sphagnum* peat.
UNIT J	59.24m	8-13cm	Dark MHS.
		13-19cm	PHS.
		19-23cm	MHS with *Eriophorum.*
		23-29cm	PHS with *Eriophorum.*
		29-37cm	MHS with *Eriophorum.*
		37-43cm	PHS.
UNIT G (MHS)	58.89m	43-83cm	MHS (H6) with lenses of PHS and minor *Calluna.*
		at 56cm	Black horizon, more decomposed with charcoal.
		at 64cm	*Eriophorum.*
		83-93cm	PHS (H2).
		93-106cm	MHS.
UNIT F (HHS)	58.26m	106-133cm	HHS.

CORE 1:21	OD (m)	Depth (cm)	Description
FIELD SURFACE -PHS	59.28m	13-23cm	PHS.
UNIT K (GULLIES)	58.92m	23-30cm	MHS, dark brown almost black.
		30-38cm	MHS.
	58.77m	38-65cm	PHS.
	58.45m	65-70cm	MHS with *Calluna* from 65-68cm.
UNIT F (HHS)	58.22m	70-105cm	HHS (H7)
UNIT H (PHS)	57.87m	105-128cm	PHS (H3).
		128-141cm	MHS.
		141-150cm	HHS.
		150-162cm	PHS.
UNIT F (HHS)	57.53m	162-252cm	HHS with some *Calluna.*
		252-255cm	Highly decomposed *Sphagnum cuspidatum* peat.
		255-300cm	No record, core lost.
UNIT C (FEN)	56.15m	300-315cm	Yellow-brown fen peat.
		315-353cm	Fen peat with wood at top and bottom.
		353-400cm	Highly decomposed fen, no reed, oxidised black.
		400-473cm	Fen with some wood, no reed.
		473-500cm	Darker fen peat.
		500-600cm	Reed peat with darker layers in lower 30cm, peat dark and loose.
		600-637cm	Reed peat with wood at 637cm.
		at 665cm	No record, core lost.
UNIT B? (MINERAL SUBSTRATE)	52.35m	at 680cm	Mineral substrate probably, met resistance but base not observed.
		at 690cm	Deepest point.

Drain Face 1:22	OD (m	Depth (cm)	Description
UNIT K (PHS - GULLY FILL)	59.33m	0-50cm	PHS gully fill.
		50-59cm	*Sphagnum cuspidatum* = phase 2 at 1:21.
		59-68cm	Gully base, Phase 1.
		68cm	Top of PHS peat.

Drain Face 1:23	OD	Depth (cm)	Description
FIELD SURFACE - UNIT H (PHS)	59.38m	0-24cm	Almost fresh *Sphagnum* (H1).
UNIT J (phase 2)	59.14m	24-32cm	*Sphagnum cuspidatum* with PHS from 27-29cm. Intercalating of layers here, to NW layers merge.
		32-35cm	PHS.
		35-39cm	MHS, slightly darker with restricted extent.
		39-51cm	Highly decomposed main dark layer (H8) with 1cm black (charcoal) top.
UNIT J (phase 1)	58.87m	51-56cm	PHS.
		56-72cm	Less pronounced MHS dark layer with *Sphagnum cuspidatum* &*Eriophorum.*
UNIT H (PHS)	58.66m	72-92cm	PHS.
		92-112cm	MHS.
		112-134cm	PHS with some *Calluna.*

CORE 1:24	OD (m)	Depth (cm)	Description
FIELD SURFACE - UNIT H (PHS)	59.20m	0-25cm	PHS with 5cm deep MHS top.
UNIT J	59.20m	20-27cm	HHS, dark brown.
		27-30cm	PHS.
		30-37cm	*Sphagnum cuspidatum* with thin layers of PHS.
		37-43cm	PHS - almost fresh.
		43-50cm	MHS, dark brown.
		50-65cm	MHS, red-brown.
		65-70cm	*Eriophorum* tussock and non-*Sphagnum* mosses.
UNIT H (PHS)	58.50m	70-80cm	PHS.
		80-100cm	No record, core lost.
		100-105cm	PHS, dark (H2/3).
		105-107cm	HHS.
		107-116cm	MHS.
		116-118cm	Almost fresh *Sphagnum*.
		118-132cm	MHS (H3/4).
		132-137cm	HHS, almost mud-like.
		137-152cm	PHS with *Calluna*.
		152-160cm	MHS (H3/4).
		160-167cm	Almost fresh *Sphagnum*.
		167-180cm	HHS (H7).
		180-186cm	PHS.
		186-200cm	No record, core lost.
UNIT F (HHS)	57.20m	200-205cm	MHS with some *Calluna*.
		205-230cm	HHS with *Eriophorum* and *Calluna*.
		230-240cm	HHS, dark brown with *Eriophorum*.
		240-255cm	Highly decomposed peat - *Sphagnum?*
		255-256cm	*Eriophorum* and *Calluna* level.
		256-300cm	HHS with *Calluna*.
		300-307cm	MHS.
		307-321cm	PHS.
LOOSE HHS	55.99m	321-358cm	HHS with minor *Eriophorum* and *Calluna*, loose and wet.
		358-400cm	No record, core lost - lost transition, peat very loose and wet.
UNIT C (FEN)	55.20m	400-421cm	Sedge fen with some reed, black and oxidised, without structure or wood.
		421-428cm	Red-brown moderately decomposed mosess, *Sphagnum*?
		428-440cm	Sedge fen with reed.
		440-500cm	No record, core lost.
		500-517cm	Sedge rich fen peat with some reed, black and oxidised and wood at 517-519cm and 520-522cm.
		522-531cm	Black oxidised fen, less rich in sedge, no reed and highly decomposed.
		531-549cm	Sedge fen with wood.
		549-605cm	Fen with less sedge, more reed and wood.
		605-613cm	Wood.
		613-630cm	More compact with sedge and less reed, black and wood at bottom.
		630-670cm	Homogenous fen, less reed with bog bean. Lower 30cm yellow fen with some reed and highly decomposed. Lower 15cm no structure, wood peat-like. No grit in lower 20cm but did not recover mineral soil.

Drain Face 1:25	OD (m)	Depth (cm)	Description
FIELD SURFACE -UNIT H (PHS)	59.01m	0-13cm	PHS to fresh *Sphagnum*.
UNIT J	58.88m	13-20cm	MHS.
		20-24cm	PHS.
		24-30cm	MHS.
		30-35cm	PHS.
		35-40cm	MHS.
		40-49cm	PHS.
		49-63cm	Highly decomposed with 3cm black top & bottom, middle brown.
UNIT H (PHS)	58.38m	63-124cm	PHS (H1).

CORE 1:26	OD (m)	Depth (cm)	Description
FIELD SURFACE	59.00m	0-12cm	PHS with intervening MHS and *Calluna*.
UNIT J	58.88m	12-22cm	MHS, dark.
		22-26cm	MHS, red-brown.
		26-29cm	Laminated *Sphagnum cuspidatum*.
		29-36cm	PHS, almost fresh.
		36-42cm	HHS with black top 20cm thick.
UNIT H (PHS)	58.58m	42-55cm	PHS, almost fresh to H2.
		55-65cm	MHS with some *Calluna* (H5).
		65-70cm	PHS.
		70-100cm	No record, core lost.
		100-129cm	PHS.
		129-133cm	Laminated *Sphagnum cuspidatum*.
		133-176cm	PHS with minor *Calluna*.
		176-200cm	No record, core lost.
		200-213cm	PHS.
Sphagnum cuspidatum	56.87m	213-214cm	*Sphagnum cuspidatum*.
		214-218cm	PHS and *Eriophorum*.
		218-231cm	*Sphagnum cuspidatum*, laminated, muddy, lenses of PHS in lower 5cm.
		231-239cm	HHS, somewhat laminated.
		239-242cm	*Sphagnum cuspidatum*.
		242-245cm	PHS (H3).
		245-250cm	Laminated *Sphagnum cuspidatum*.
UNIT F (HHS)	56.50m	250-256cm	MHS (H6) with minor *Eriophorum*.
		256-264cm	HHS with *Calluna*.
UNIT I	56.36m	264-300cm	No record, core lost.
		300-322cm	Possibly push down, loose and structureless, PHS.
UNIT H (PHS)	55.78m	322-348cm	PHS, very loose, crumbly with minor *Calluna*.
UNIT G (MHS)	55.52m	348-368cm	MHS.
		368-373cm	PHS.
		373-380cm	MHS.
		380-381cm	Wood.
		381-400cm	MHS-PHS (H3).
UNIT C (FEN)	55.00m	400-413cm	Highly decomposed black peat with some reed, possibly fen.
		413-415cm	Wood and possibly *Eriophorum*.
		415-480cm	No record, core lost.
		480-512cm	Loose black-dark brown crumbly peat with wood - Wood peat.
		512-550cm	More sedge present, peat still crumbly and oxidised with minor wood.
		550-580cm	Slightly more compact sedge peat with reed, minor wood. No trace of grit but peat almost structureless. Could not push corer further, possibly hit a wood level as corer did not grate.

Drain Face 1:27	OD (m)	Depth (cm)	Description
FIELD SURFACE - UNIT H (PHS)	58.82m	0-4cm	PHS.
UNIT J?	58.78m	4-7cm	*Sphagnum cuspidatum.*
		7-9cm	PHS.
		9-11cm	*Sphagnum cuspidatum.*
		11-18cm	PHS.
		18-21cm	MHS.
		21-33cm	PHS.
		33-36cm	MHS.
		36-40cm	PHS.
		40-45cm	MHS, runs into a tussock.
UNIT J (Phase 2)	58.25m	57-66cm	Highly decomposed main layer - top & bottom dark brown, middle black.
		66-70cm	PHS.
UNIT J (Phase 1)		70-75cm	Highly decomposed black layer with *Calluna* and *Eriophorum*.
UNIT H (PHS)	58.07m	75-141cm	PHS with *Eriophorum* at 122cm.

CORE 1:28	OD (m)	Depth (cm)	Description
FIELD SURFACE - UNIT H (PHS)	58.53m	0-12cm	PHS, almost fresh.
UNIT J	58.27m	12-26cm	Dark band of moderately to HHS with *Calluna.*
		26-40cm	Dark MHS with *Calluna.*
		36-40cm	PHS.
		40-48cm	PHS, dark (H3) with some *Calluna.*
		48-50cm	PHS, almost fresh.
		50-52cm	Dark MHS.
UNIT H (PHS)	57.87m	52-83cm	PHS, almost fresh.
		83-100cm	No record, core lost. Could not push corer further, no grit or mineral soil retrieved.
		100-103cm	Black, highly decomposed peat.
	57.36m	103-122cm	PHS, somewhat laminated.
		122-123cm	*Sphagnum cuspidatum?*
		123-193cm	PHS.
		139-140cm	*Sphagnum cuspidatum?*
		140-162cm	PHS.
		162-163cm	*Sphagnum cuspidatum?*
		163-173cm	PHS.
Sphagnum cuspidatum	56.66m	173-184	Well laminated *Sphagnum cuspidatum*, almost muddy, well decomposed with thin PHS at 180-181cm.
UNIT G (MHS)	56.55m	184-186cm	MHS.
		186-187cm	PHS.
		187-200cm	MHS.
		200-205cm	PHS.
		205-206cm	Possible reed.
		206-225cm	MHS, loose.
Unit F (HHS-LOOSE)	56.14m	225-256cm	HHS with some *Calluna*, very loose dark soft peat.
		at 256cm	Wood.
		256-279cm	Structureless well decomposed peat with *Calluna* and some *Eriophorum.*
		279-292cm	Nearly amorphous peat, mud-like, no structure, very well decomposed.
UNIT C (FEN)	55.47m	292-300	Fen peat with reed and wood.
		300-320cm	Highly decomposed *Sphagnum.*
		320-333cm	Loose, crumbly oxidised mosses.
		333-367cm	Sedge peat, loose and crumbly with negligble wood.
		367-386cm	Sedge peat, slightly more compacted with reed.
		386-400cm	No record, core lost.
		400-435cm	Homogenous sedge peat with reed, vertical roots.
		435-454cm	Pushdown.
		454-490cm	Sedge peat with wood at 455cm and 487-490cm.
		490-510cm	Wood peat - very black, almost muddy, compact, almost soil like with lower 6cm mixed with sedge.
		510-527cm	Yellow reed fen peat with bog bean, almost dry and soil like.
	53.12m	527-535cm	No record, core lost. Could not push corer further, no grit or mineral soil retrieved.

Drain Face 1:30	OD (m)	Depth (cm)	Description
UNIT J	58.42m	0-52cm	Bright & dark sequence of *Sphagnum* layers.
UNIT H (PHS)	57.90m	52-150cm	PHS.

Drain Face 1:29	OD (m)	Depth (cm)	Description
FIELD SURFACE - UNIT F (HHS)	57.25m	0-37cm	HHS.
UNIT E2	56.88m	37-150cm	Wood peat - marginal.
		150-200cm	Wood growing in mineral soil but overgrown by peat = landfall site. Oak and ash rooting in mineral substrate.
UNIT B (MINERAL SUBSTRATE)	55.25m	at 200cm	Mineral substrate.

DRAIN 2

CORE 2:1	OD (m)	Depth (cm)	Description
FIELD SURFACE - UNIT H (PHS)	58.08m	0-6cm	PHS to fresh *Sphagnum*.
UNIT J	57.96m	6-12cm	MHS.
		12-31cm	HHS with *Eriophorum* at 20cm.
		31-36cm	PHS.
		36-42cm	MHS.
UNIT H (PHS)	57.66m	42-73cm	PHS.
		73-105cm	No record, core lost.
		105-172cm	PHS with *Eriophorum*, very loose and wet.
		172-200cm	No record, core lost.
		200-205cm	PHS.
UNIT F (HHS)	56.01m	205-300cm	HHS (H7) slightly laminated with *Calluna*, *Eriophorum* and minor wood.
UNIT C (FEN)	55.08m	300-370cm	Fen peat, yellow-brown with sedge, small wood fragments.
		370-385cm	No record, core lost.
		385-387cm	Wood.
		387-406cm	Yellow fen peat no sedge or reed, possibly *Sphagnum cuspidatum* 394-396cm.
		406-485cm	Fen, crumbly, well decomposed, dry, almost like soil, with sedge, some wood.
	53.23m	485cm	Deepest point, could not push corer deeper, no mineral soil retrieved, probably hit wood level, no grating or grit.

Drain Face 2:2	OD (m)	Depth (cm)	Description
FIELD SURFACE - UNIT H (PHS)	58.02m	0-24cm	PHS, almost fresh *Sphagnum* with MHS from 17-19cm.
UNIT J	57.78m	24-38cm	MHS-HHS, dark brown with minor *Calluna* (H6).
		38-46cm	MHS-HHS, black with minor *Calluna* (H6+).
		46-50cm	MHS-HHS, dark brown.
		50-56cm	*Eriophorum* tussock, 2cm black top.
		56-73cm	PHS with *Eriophorum* tussock at base.
UNIT G (MHS)	57.29m	73-106cm	Alternate bands of MHS-PHS, difficult to discern boundaries.
UNIT H (PHS)	56.96m	106-135cm	Homogenous almost fresh *Sphagnum*.

CORE 2:3	OD (m)	Depth (cm)	Description
FIELD SURFACE - UNIT H (PHS)	57.80m	0-5cm	MHS.
		5-9cm	Fresh to PHS.
UNIT J		9-14cm	MHS.
		14-15cm	PHS.
		15-37cm	MHS to HHS layers (H7), difficult to distinguish individual horizons.
		37-43cm	PHS (H3).
		43-46cm	HHS.
		46-49cm	PHS (H1).
		49-56cm	HHS with *Calluna*.
UNIT H (PHS)	57.24m	56-156cm	PHS with *Eriophorum* and *Calluna*.
		156-159cm	*Sphagnum cuspidatum+D67*
		159-162cm	PHS (H1).
		162-166cm	HHS.
		166-207cm	PHS.
UNIT G (MHS)	55.59m	207-222cm	MHS (H6) with *Eriophorum* at 221-222cm.
		222-234cm	HHS (H7) with *Calluna*.
		234-243cm	MHS, less compact.
		243-245cm	PHS (H3).
UNIT F (HHS)	55.35m	245-274cm	Well decomposed with small *D57* fragments. HHS?
		274-285cm	*Calluna* and *Eriophorum*.
		285-300cm	Well decomposed, possibly HHS (H7/8).
		300-322cm	Pushdown.
UNIT C (FEN)	54.58m	322-321cm	Fen peat with minor wood, mosses present and bog bean at 325cm.
		331-402cm	Yellow-brown fen peat with sedge, minor reed and small wood fragments. Well decomposed with vertical roots.
		402-405cm	*Eriophorum*.
		405-410cm	Yellow-brown fen peat with wood at 410-411cm.
		411-474cm	Sedge peat with reed and minor wood.
		474-535cm	Sedge peat, no reed, minor wood, well decomposed & homogenous.
		535-546cm	Wood.
		546-586cm	Sedge fen with some reed and wood.
UNIT B (MINERAL SUBSTRATE)	51.94m	586-590cm	Mineral substrate, sharp transition to sticky blue clay.

Drain Face 2:4	OD	Depth (cm)	Description
FIELD SURFACE - UNIT H (PHS)	57.81m	0-15cm	Fresh *Sphagnum*.
UNIT J	57.66m	15-30cm	MHS (H6), dark brown to black with *Calluna*.
		30-33cm	MHS (H6+), black.
		33-35cm	MHS (H6), dark brown to black.
		35-39cm	MHS (H6+), black.
		39-52cm	Alternating dark brown to black *Sphagnum*, difficult to discern levels.
UNIT H (PHS)	57.29m	52-63cm	PHS to MHS with *Eriophorum* and *Calluna*.
		63-90cm	PHS to fresh *Sphagnum*.
		90-91cm	*Sphagnum cuspidatum*.
		94-106cm	*Eriophorum* tussock.
		106-110cm	*Sphagnum cuspidatum*.

CORE 2:5	OD (m)	Depth (cm)	Description
FIELD SURFACE - UNIT H (PHS)	57.78m	0-13cm	MHS.
		13-30cm	Fresh *Sphagnum*.
UNIT J	57.43m	30-35cm	MHS.
		35-44cm	PHS.
		44-47cm	MHS.
		47-60cm	PHS.
		60-64cm	HHS.
		64-66cm	*Eriophorum*.
		66-71cm	HHS.
		71-77cm	MHS.
UNIT H (PHS)	57.01m	77-129cm	PHS, loose almost fresh.
		129-131cm	*Sphagnum cuspidatum*.
		131-186cm	PHS with some *Calluna*.
	55.92m	186-200cm	No record, core lost.
		200-300cm	Discontinuous core, very loose PHS.
		300-367cm	PHS, loose and wet, *Eriophorum* & bark at 350-351cm, wood at 361-363cm.
UNIT C (FEN)	54.11m	367-395cm	Well decomposed dark brown peat with some sedge. Transition peat?
	53.98m	380-443cm	Fen peat, crumbly, some sedge and wood, no reed and well decomposed.
		443-488cm	Sedge fen peat with wood at 457-460cm, 470-488cm.
		488-543cm	Fen peat, well decomposed, dark yellow-brown, some sedge, no reed, loose not compacted.
		543-592cm	Fen peat, well decomposed, with some reed and wood at 560cm.
UNIT B (MINERAL SUBSTRATE)		592-625cm	Very sharp transition to mineral soil, sticky blue clay, no grit or banding.

Drain Face 2:6	OD	Depth (cm)	Description
FIELD SURFACE - UNIT H (PHS)	57.98m	0-21cm	Fresh-PHS with MHS from 15-19cm.
UNIT J	57.79m	21-28cm	MHS with lenses of PHS.
		28-34cm	PHS.
		34-36cm	MHS, black.
		36-38cm	PHS.
		38-40cm	MHS, black.
		40-45cm	PHS.
		45-53cm	MHS (H6), black.
UNIT H (PHS)	57.45m	53-112cm	PHS-fresh *Sphagnum* with occasional *Sphagnum cuspidatum* levels 1-2cm thick.

CORE 2:7	OD (m)	Depth (cm)	Description
UNIT J	58.02m	0-2CM	PHS.
		2-10cm	HHS (H7), dried out and black.
		10-12cm	PHS.
		12-37cm	MHS (H6), black and compact.
UNIT G (MHS)	57.66m	37-71cm	MHS (H6) with PHS (H2) inclusions, red-brown and soft.
UNIT H (PHS)		71-89cm	PHS.
		89-100cm	No record.
		100-119cm	PHS, almost fresh.
		119-121cm	*Sphagnum cuspidatum.*
		121-129cm	PHS.
UNIT G (MHS)	56.73m	129-143cm	MHS with *Calluna* and PHS inclusions.
UNIT F (HHS)	56.59m	143-228cm	HHS, laminated with *Calluna. Sphagnum cuspidatum* at 220-222cm and *Eriophorum* at 225-228cm.
UNIT C (FEN)	55.74m	228-240cm	Well decomposed dark peat with mix of *Sphagnum cuspidatum* and tree leaves at 231-232cm and wood from 232-240cm.
		240-280cm	Yellow reed fen, laminated with thin black layers, possibly *Calluna*, and wood at 313-315cm.
		315-385cm	Yellow-brown fen peat, homogenous and well developed, vertical roots, wood at 325-327cm, reed at 366-367cm.
		385-444cm	Sedge and reed fen peat, compact, well decomposed with decayed wood, possibly charcoal, at 442-444cm.
		444-459cm	Softer sedge peat with charcoal.
		459-473cm	Wood and bark.
MINERAL SUBSTRATE?	52.78m	473-500cm	No record, core lost.
		525cm	Deepest point, base not observed.

Drain Face 2:8	OD (m)	Depth (cm)	Description
FIELD SURFACE - UNIT H (PHS)	58.50m	0-19cm	Fresh to PHS, some MHS lenses with *Eriophorum* and *Calluna.*
UNIT J (phase 2)	58.31m	19-25cm	HHS (H7), black top.
		25-38cm	Alternating MHS-HHS. Transitions difficult to discern.
		38-45cm	HHS (H7), black top.
PHS	58.05m	45-66cm	PHS (H3) with *Calluna* and *Eriophorum.*
UNIT J (phase 1)	57.84m	66-84m	Eriophorum within HHS, follow to NW as lower dark band/desiccation layer, not cracked.
UNIT H (PHS)	57.66m	84-110m	PHS laminated *Sphagnum cuspidatum* from 102-105cm and 107-110cm.

CORE 2:9	OD (m)	Depth (cm)	Description
FIELD SURFACE - PHS	58.71m	0-5cm	HHS to MHS.
		5-10cm	PHS, almost fresh.
UNIT J	58.61m	10-21cm	MHS (H6).
		21-23cm	PHS.
		23-24cm	MHS.
		24-26cm	PHS.
		26-31cm	HHS (H7), yellow vertical roots, almost black.
		31-35cm	HHS, red-brown (H7).
		35-38cm	MHS (H6), dark brown, yellow vertical roots.
		38-49cm	PHS (H2).
		49-64cm	MHS (H4).
		64-72cm	PHS (H2).
		72-76cm	MHS (H6) with *Calluna*.
UNIT H (PHS)	57.86m	76-87cm	PHS with *Eriophorum* at 85-87cm.
		87-100cm	No record, core lost.
		100-121cm	PHS, very loose.
		121-131cm	PHS (H1-2), slightly more compact with *Calluna*.
	57.40m	131-136cm	MHS (H6) with *Calluna* and *Eriophorum*.
		136-152cm	PHS, loose.
UNIT G (MHS)	57.19m	152-179cm	MHS (H4), loose with *Calluna* and *Eriophorum* and PHS at 159-160cm.
UNIT F (HHS)	56.92m	179-193cm	HHS (H7), reed at 179cm and *Eriophorum* at 193-194cm.
		194-200cm	No record, core lost.
		200-238cm	Loose, very soft HHS (H7) with a lot of *Calluna*.
		238-247cm	PHS (H2-3).
		247-256cm	MHS (H5), loose, wet with minor *Calluna*.
	56.15m	256-272cm	HHS, red-brown, fibrous with *Calluna*, bark and *Eriophorum* (Transitional horizon?).
		272-300cm	No record, core lost.
UNIT C (FEN)	55.72m	300-324cm	Yellow fen peat with reed and *Calluna*, well developed and laminated. *Menyanthes trifoliata* at 311-312cm and wood 321-324cm.
		324-330cm	Fen peat, no reed.
		330-341cm	Reed fen peat with *Menyanthes trifoliata*, well developed, well decomposed.
		341-383cm	Yellow-brown fen peat with decayed wood. Oxidises rapidly to red-brown/black. Less reed, charcoal present at 351cm.
		383-400cm	Well decomposed, very soft, loose fen peat with *Menyanthes trifoliata*, no reed.
		365-458cm	Fen peat with sedge and reed and wood. Well developed, compact, yellow-brown.
		458-462cm	Well decomposed fen with few plant remains, loose.
UNIT B (MINERAL SUBSTRATE)	54.10m	462-465cm	Mineral substrate

Drain Face 2:10	OD (m)	Depth (cm)	Description
FIELD SURFACE - UNIT H (PHS)	59.07m	0-23cm	Fresh *Sphagnum* with *Sphagnum cuspidatum* forming base of a shallow pool from 12-14cm.
		23-29cm	MHS.
		25-29cm	Fresh *Sphagnum*.
UNIT J	58.78m	29-74cm	Bands of MHS, HHS and PHS - mostly MHS. Boundaries difficult to distinguish. MHS and HHS with *Calluna* and *Eriophorum*. Layers 1-3cm thick.
UNIT H (PHS)	58.33m	74-132cm	PHS with occasional shallow MHS layers. Lower PHS with *Eriophorum*.

CORE 2:11	OD (m)	Depth (cm)	Description
FIELD-SURFACE - UNIT H (PHS)	59.30m	0-17cm	MHS, dark brown (H6).
		17-22cm	PHS (H2).
		22-30cm	*Sphagnum cuspidatum*-like, well decomposed.
		30-42cm	PHS (H2-3), lots of vertical stems.
UNIT J	58.88m	42-55cm	Many vertical roots and occasional reed, well decomposed (H6).
		55-61cm	PHS.
		61-64cm	HHS with noticeably less vertical roots.
		64-80cm	PHS.
		80-84cm	HHS.
		84-88cm	PHS.
		88-91cm	MHS (H6).
		91-96cm	PHS with *Calluna* (H3).
		96-99cm	Reed.
UNIT H (PHS)	58.31m	99-110cm	PHS, very wet and loose (H2).
		110-123cm	HHS with lenses of PHS with some *Calluna* (H7).
		123-129cm	MHS, very loose.
		129-149cm	PHS (H2) with *Eriophorum* 129-130cm.
		143-152cm	*Calluna* and *Eriophorum*.
		152-166cm	PHS with *Sphagnum cuspidatum* at 159-161cm.
		166-170cm	MHS (H5).
		170-190cm	PHS (H2) with MHS 178-180cm.
		190-196cm	MHS (H5).
		196-216cm	PHS, loose (H2).
UNIT F (HHS)	57.14m	216-221cm	HHS with *Eriophorum*.
		221-241cm	MHS, dark brown with black stems, very soft and loose (H5).
		241-270cm	HHS (H7) with *Calluna*, somewhat laminated, not compact.
		270-272cm	*Eriophorum*.
		272-279cm	HHS with *Calluna*, very soft (H8).
		279-293cm	MHS (H6).
		293-294cm	*Sphagnum cuspidatum*.
		294-297cm	HHS, yellow (H7).
		297-300cm	*Eriophorum*?, very soft.
		300-310cm	Pushdown.
UNIT C (FEN)	56.20m	310-358cm	Yellow reed peat interrupted by sloppy well decomposed peat with wood from 318-335cm.
		358-420cm	Well decomposed red-brown fen with few vertical roots, less reed and small wood fragments.
MINERAL SUBSTRATE?	55.10m	420cm	Deepest point, did not hit mineral soil, could not push corer further.

Drain Face 2:12	OD (m)	Depth (cm)	Description
FIELD SURFACE - UNIT H (PHS)	59.57m	0-12cm	Fresh *Sphagnum*.
		12-14cm	MHS
		14-20cm	PHS to fresh *Sphagnum*.
		20-24cm	MHS
		24-28cm	PHS to fresh *Sphagnum*.
UNIT J	59.29m	28-41cm	MHS (H4) with *Eriophorum* and *Calluna*.
		41-43cm	HHS (H7+), weathered to grey.
		43-52cm	MHS.
		52-58cm	PHS with *Calluna*.
		58-60cm	MHS, weathered greyish.
UNIT H (PHS)	58.50m	60-107cm	Relatively homogenous PHS with *Eriophorum* at 80cm, 85cm and 95cm.

CORE 2:13	OD (m)	Depth (cm)	Description
FIELD SURFACE - UNIT H (PHS)	59.76m	0-2cm	MHS.
		2-6cm	PHS.
		6-20cm	PHS & MHS, difficult to distinguish boundaries.
		20-44cm	Mostly PHS (H3), oxidised dark/brown.
UNIT J	59.32m	44-59cm	HHS, very dark-brown/black (H8).
		59-64cm	MHS (H4).
		64-67cm	HHS (H7).
UNIT H (PHS)	59.09m	67-145cm	PHS (H2) with MHS at 113-118cm and *Calluna* at 120cm.
		145-175cm	PHS, almost fresh with *Eriophorum* at 150-152cm and MHS (H6) at 152-155cm.
		175-200cm	PHS with thin layers of *Sphagnum cuspidatum*, not well developed.
UNIT F (HHS)	57.76m	200-217cm	HHS (H7) with *Eriophorum* and *Calluna.*
		217-220cm	*Sphagnum cuspidatum*, well developed with thin dark centre.
		220-224cm	*Eriophorum.*
		224-245cm	HHS, structureless, with *Calluna* and *Eriophorum* from 242-245cm.
		245-255cm	HHS - transition to fen peat.
UNIT C (FEN)	57.21m	255-263cm	*Sphagnum cuspidatum* and reed, well decomposed and yellow.
		263-298cm	Mixed wood, *Calluna* and reed horizon, mostly reed, leaves and laminated.
		298-309cm	Fen peat, looser crumbly red-brown peat with wood and less reed.
		309-395cm	Brown crumbly wood peat, little reed, well decomposed oxidised to black.
		395-400cm	Organic silt.
UNIT B (MINERAL SUBSTRATE)	55.76m	400-410cm	Mineral soil, wood in mineral soil at 403cm and 410cm.

Drain Face 2:14	OD (m)	Depth (cm)	Description
FIELD SURFACE - UNIT H (PHS)	59.91m	0-30cm	Fresh to PHS.
UNIT J	59.61m	30-32cm	MHS with a black top.
		32-36cm	PHS (H3).
		36-47cm	MHS and PHS.
		47-51cm	*Eriophorum.*
		51-53cm	PHS.
		53-62cm	MHS (H5), weathered black with brighter lenses.
UNIT H (PHS)	59.29m	62-136cm	PHS (H2), with *Calluna* at 68cm, *Eriophorum* 88-100cm and *Sphagnum cuspidatum* at 117-118cm.

CORE 2:15	OD (m)	Depth (cm)	Description
FIELD SURFACE - HHS	60.02m	0-19cm	PHS (H1-H3) with HHS from 4-10cm.
UNIT J	59.83m	19-23cm	MHS (H6).
		23-33cm	PHS (H3).
		33-38cm	MHS (H6).
		38-41cm	PHS (H2).
		41-47cm	HHS (H7).
		47-71cm	PHS, almost fresh.
		71-77cm	HHS with *Eriophorum.*
UNIT H (PHS)	59.25m	77-145cm	PHS (H2), homogenous.
		145-150cm	MHS.
		150-182cm	PHS with *Calluna* and *Sphagnum cuspidatum* 182-183cm.
		183-300cm	PHS, very loose and wet, some *Eriophorum.*
UNIT C (FEN)	57.20m	282-312cm	Possibly fen, well decomposed, structureless but with *Calluna* and reed at 297cm.
		312-342cm	Very loose with wood and reed fragments, well decomposed though may not be *in situ* sediment.
		342-382cm	More compact, well decomposed red-brown fen with some fragments of wood.
UNIT B (MINERAL SUBSTRATE)	56.22m	382cm	Top of mineral substrate.

CORE 2:16	OD (m)	Depth (cm)	Description
FIELD SURFACE - PHS/MHS	59.93m	0-3cm	MHS.
		3-7cm	PHS.
		7-10cm	MHS.
		10-11cm	PHS.
		11-15cm	MHS.
		15-22cm	PHS.
UNIT J	59.71m	22-33cm	MHS (H4) with *Eriophorum.*
		33-44cm	HHS (H7-8) with *Calluna.*
		44-45cm	Black peat, well decomposed, mud-like.
UNIT H (PHS)	59.29m	45-64cm	MHS.
		64-76cm	PHS.
		76-79cm	MHS (H6).
		79-82cm	PHS.
		82-84cm	HHS.
		84-86cm	PHS.
		86-89cm	HHS.
		89-91cm	PHS.
		91-94cm	HHS.
		94-158cm	PHS (H3), loose, occasional *Eriophorum.*
		158-165cm	*Sphagnum cuspidatum.*
UNIT G (MHS)	58.28m	165-215cm	MHS (H5), very loose with *Eriophorum.*
UNIT F (HHS)	57.79m	215-234cm	HHS with *Eriophorum* and *Calluna.* Well decomposed.
UNIT C (FEN)	57.59m	234-239cm	Fen peat with reed, well decomposed, yellow.
		239-251cm	Fen with wood and sedge, compact and well developed.
		251-283cm	Well developed red-brown fen with wood, charcoal, minor reed.
		283-340cm	Fen peat, well decomposed, with wood but no reed.
UNIT B (MINERAL SUBSTRATE)	56.53m	340-383cm	Transition to homogenous sticky blue clay very sharp.

Drain Face 2:17	OD (m)	Depth (cm)	Description
UNIT H - UNIT G	59.85m	0-4cm	Edge of tussock of *Eriophorum*.
		4-8cm	MHS layers drying to very dark to black.
		8-13cm	PHS lense.
		13-19cm	*Calluna* layer within MHS.
		19-20cm	Edge of PHS lense originating to SE.
		20-22cm	*Calluna*.
		22-23cm	Edge of PHS lense originating to NW.
		23-30cm	*Calluna* layer within MHS.
		30-58cm	Mixed layers MHS & PHS.
UNIT D	59.27m	58-96cm	Well decomposed crumbly wood peat - with *Eriophorum*, bark, twig and root fragments.
UNIT C (FEN)	58.73m	96-138cm	Fen with wood and reed.

CORE 2:26	OD (m)	Depth (cm)	Description
FIELD SURFACE -PHS	60.07m	018cm	MHS (H6) with Calluna.
		18-30cm	PHS (H2), loose.
UNIT J	59.77m	30-33cm	HHS (H6+).
		33-37cm	PHS (H3), loose and crumbly.
		37-46cm	HHS with *Eriophorum* and *Calluna*.
		46-50cm	MHS.
		50-55cm	PHS.
		55-68cm	HHS with Calluna and *Eriophorum*.
UNIT H (PHS)	59.39m	68-92cm	MHS (H6) with PHS from 75-77cm.
		92-107cm	PHS with *Eriophorum* at base.
		107-117cm	HHS, red-brown, structureless with PHS from 116-117.
		117-132cm	MHS (H4) with *Eriophorum* from 122-127m.
		132-141cm	HHS.
	58.66m	141-200cm	PHS (H3), loose with HHS, *Eriophorum* and *Calluna* from 155-160m.
UNIT G (MHS)	58.07m	200-233cm	MHS (H4), very loose with *Calluna* and *Sphagnum cuspidatum* at 218cm.
UNIT F (HHS)	57.74m	233-288cm	HHS (H8) with *Eriophorum*, some *Calluna*, structureless
	57.19m	288-300cm	MHS (H6) with *Calluna*.
		300-310cm	Loose, dark, well decomposed peat, transitional?, no moss structure evident.
UNIT C (FEN)	56.95m	313-324cm	Wood.
		324-328cm	Well decomposed red-brown fen peat.
		328-356cm	Well decomposed red-brown wood fen peat, minor reed.
		356-363cm	Transition horizon, organic silt.
UNIT B (MINERAL SUBSTRATE)	56.44m	363-370cm	Sticky blue clay.

CORE 2:27	OD (m)	Depth (cm)	Description
FIELD SURFACE - PHS	59.85m	0-9cm	PHS and MHS.
UNIT J	59.76m	9-15cm	HHS (H7).
		15-25cm	MHS (H4).
		25-49cm	PHS (H2).
		49-67cm	HHS with *Eriophorum* and *Calluna* from 51-56cm.
UNIT H (PHS)	59.18m	67-74cm	PHS (H3).
		74-77cm	*Calluna.*
		77-117cm	PHS (H2-3), loose, dark brown with MHS, 108-111cm and *Eriophorum*, 117cm.
		117-135cm	Mix of MHS and PHS, difficult to distinguish boundaries.
UNIT F (HHS)	58.50m	135-160cm	HHS, red-brown.
		160-165cm	PHS (H3) with *Calluna.*
		165-173cm	HHS with *Eriophorum.*
UNIT I	58.12m	173-200cm	HHS with *Calluna*, loose.
		200-233cm	PHS, loose, wet.
		233-267cm	Mostly HHS, sloppy with *Calluna* at 250cm & 267cm.
		267-300cm	No record, deposit not retained in chamber.
		300-320cm	HHS (H8) with *Eriophorum* and *Calluna.*
UNIT C (FEN)	56.65m	320-421cm	Fen peat with minor wood fragments, some sedge, yellow-grey, compact, very well decomposed.
BASE OF UNIT C?	55.62m	421-423cm	Fen peat with some gritty silt. Base not observed.

Drain Face 2:28	OD (m)	Depth (cm)	Description
FIELD SURFACE - UNIT H (PHS)	59.58m	0-10cm	Fresh *Sphagnum* with lenses of MHS.
UNIT J	59.48m	10-20cm	Mostly MHS with lenses of PHS, weathered as a grey-black band.
		20-23cm	MHS.
UNIT H (PHS)		23-28cm	PHS.
		28-34cm	MHS.
		34-38cm	HHS (H7).
		38-63cm	PHS (H1). From 46-51cm MHS with *Eriophorum* tussock immediately to NW and *Sphagnum cuspidatum* layer to SE at 50cm.

CORE 2:29	OD (m)	Depth (cm)	Description
FIELD SURFACE - PHS	59.78m	0-6cm	Fresh *Sphagnum*.
		6-19cm	MHS (H4) with *Sphagnum cuspidatum* from 10-11cm.
		19-34cm	PHS (H2) with *Calluna*.
		4-41cm	MHS.
		41-47cm	PHS almost fresh.
UNIT J	59.31m	47-53cm	HHS with occasional PHS inclusions and *Eriophorum*.
		53-64cm	HHS to MHS (H6+) with *Calluna* and black vertical roots.
UNIT H (PHS)	59.14m	64-71cm	PHS almost fresh.
		71-90cm	PHS with *Calluna* (H2).
		90-100cm	No record.
		100-126cm	PHS (H2), loose.
		126-128cm	*Eriophorum*.
		128-139cm	Poorly humified to fresh *Sphagnum*.
		139-148cm	*Sphagnum cuspidatum*, laminated.
UNIT F (HHS)	58.30m	148-159cm	Very well decomposed, red-brown, possibly HHS.
		159-160cm	*Calluna*.
		160-168cm	HHS (H8).
UNIT H (PHS)	58.10m	168-178cm	MHS with PHS inclusions.
		176-190cm	PHS with *Eriophorum*.
UNIT F (HHS)	57.90m	190-223cm	HHS with *Calluna*.
UNIT H (LOOSE-PHS)	57.55m	223-240cm	PHS to almost fresh *Sphagnum*.
		240-304cm	Loose, PHS.
		304-310cm	PHS.
UNIT C (FEN)	56.58m	310-320cm	Well decomposed with *Calluna*, *Eriophorum* and sedge. Possibly FBT.
		320-386cm	Well decomposed red-brown fen with sedge, reed, wood and many roots.
UNIT B (MINERAL SUBSTRATE)	55.92m	386-400cm	Sharp transition to mineral soil, sticky clay with grit and sand.

Drain Face 2:30	OD (m)	Depth (cm)	Description
FIELD SURFACE - UNIT H (PHS)	59.66m	0-7cm	Fresh *Sphagnum*.
UNIT H (PHS)	59.59m	7-13cm	MHS.
		13-18cm	PHS.
		18-23cm	Mostly MHS.
		23-27cm	PHS.
		27-28cm	MHS.
		28-30cm	PHS.
		30-32cm	MHS.
		32-39cm	PHS.
		39-44cm	MHS.
		44-63cm	Mostly dark brown PHS with layers of MHS.
		63-105cm	PHS (H1) with *Eriophorum* and from 84-101cm *Sphagnum cuspidatum*, well laminated, darker green base 10mm.

CORE 2:31	OD (m)	Depth (cm)	Description
FIELD SURFACE - UNIT H (PHS)	59.52m	0-25cm	Fresh - PHS with shallow MHS layers.
UNIT H (PHS)	59.27m	25-163cm	PHS with *Sphagnum cuspidatum* 41-43cm and 117-126cm.
UNIT F (HHS)	57.89m	163-172cm	HHS and *Eriophorum.*
		172-187cm	MHS.
UNIT I	57.65m	187-200cm	No record, loose.
		200-257cm	Very loose PHS (H3), wet.
		257-300cm	No record, no resistance.
		300-400cm	No record, no resistance.
		400-435cm	MHS with *Eriophorum.*
		435-500cm	No record, no resistance.
UNIT C (FEN)	54.52m	500-510cm	Dark well decomposed, possibly *Eriophorum*, fen?
		510-514cm	Shallow soil like horizon, structureless but compact.
		514-526cm	Wood.
		526-558cm	Very well decomposed fen peat with wood and reed, crumbly and dark.
		558-635cm	Sedge peat with wood and reed.
BASE OF UNIT C?	53.17m	635cm	Could not push corer deeper, no grit in lowest sediment.

EAST OF DRAIN 2

Core 2:20	OD (m)	Depth (cm)	Description
UNIT L (REED FIELDS)	60.50m	0-55cm	Very compact well decomposed oxidised reed peat with *Calluna.* Little other identifiable plant parts. Homogenous.
		55-60cm	Denser reed peat, red-brown, somewhat laminated and well decomposed.
		60-78cm	As from 0-55cm, black laminated reed peat, well decomposed with wood at base.
UNIT B (MINERAL SUBSTRATE)	59.72m	78-85cm	Organic silt, dirty white.
		85-100cm	Mineral soil, off white/yellow with sand and stones >8mm

Core 2:21	OD (m)	Depth (cm)	Description
UNIT L (REED FIELD)	60.88m	0-86cm	Raised bog peats, compact with *Eriophorum* and *Calluna*, layers of PHS - pools/areas of open water within reed bed, 60-90cm across, 5-15cm deep.
		86-130cm	Wood fragments present, small twigs and branches, bark, mostly *Calluna. Eriophorum* present. Raised bog peat.
		130-147cm	Black reed peat well decomposed vertically compressed reed, small wood fragments, not as compact as upper peats.
		147-158cm	Red-brown, softer, well decomposed, soft mud-like feel to peat.
UNIT B (MINERAL SUBSTRATE)	59.30m	158-161cm	Top of organic soil, angular stone, 20mm, yellow and sandy.
		161-195cm	Sticky blue clay.

DRAIN 3

CORE 3:2	OD	Depth (cm)	Description
FIELD SURFACE - UNIT H (PHS)	56.76m	0-16cm	PHS & MHS with *Eriophorum.*
UNIT J	56.62m	16-25cm	MHS (H6).
		36-37cm	HHS (H7), blacker with some *Calluna* and black vertical roots.
		36-37cm	PHS.
		37-41cm	MHS to HHS, soft, very dark with *Calluna.*
	PHS	41-62cm	PHS (H3) with *Calluna* within HHS from 46-48cm.
		62-64cm	MHS.
		64-70cm	PHS.
		70-79cm	HHS (H7), red-brown.
UNIT H (PHS)	55.97m	79-166cm	PHS from almost fresh to H3. *Sphagnum cuspidatum,* muddy & laminated from 129-131cm.
Sphagnum cuspidatum	55.10m	166-184cm	*Sphagnum cuspidatum* with PHS (H3) from 167-170cm.
UNIT F (HHS)	54.92m	184-251cm	HHS (H8), muddy and structureless, with *Sphagnum cuspidatum,* minor *Calluna* and *Eriophorum.* Almost amorphous.
		251-260cm	Laminated horizon, some tiny wood fragments, HHS (H8).
		260-261cm	MHS (H7).
		261-266cm	Highly decomposed, no visible plant remains except short fibres.
UNIT C (FEN)	54.10m	266-277cm	Wood and reed.
		277-400cm	Loose and crumbly, well decomposed, some decayed wood, sedge.
		400-497cm	Sedge and reed fibrous, vertical roots, yellow-brown, decayed wood.
		497-500cm	Fen somewhat crumblier and not as laminated.
		500-527cm	Very dark, oxidises black, reed and wood.
		527-561cm	Compact laminated sedge peat, well decomposed.
UNIT B (MINERAL SUBSTRATE)	51.15m	561-562cm	Mix of mineral soil and sedge, sharp transition.
		562-600cm	Blue sticky clay.

CORE 3:1	OD	Depth (cm)	Description
FIELD SURFACE	57.10m	0-25cm	PHS & MHS with *Eriophorum.*
UNIT J - phase 2	56.85m	25-36cm	MHS (H4).
PHS	56.74m	36-52cm	Loose PHS (H3).
UNIT J - phase 1	56.58m	52-55cm	MHS (H6), fibrous and crumbly.
		55-56cm	PHS.
		56-66cm	MHS.
		66-72cm	Somewhat laminated HHS (H7) red-brown.
		72-82cm	HHS (H7) with occasional PHS.
UNIT H (PHS with *Sphagnum cuspidatum*)	56.28m	82-112cm	PHS (H1).
		112-114cm	*Sphagnum cuspidatum.*
		114-120cm	PHS.
		120-122cm	*Sphagnum cuspidatum,* laminated.
		122-125cm	PHS (H2).
		125-127cm	*Sphagnum cuspidatum,* less well defined.
		127-128cm	Mix of *Sphagnum cuspidatum* and PHS.
		128-130cm	PHS.
		130-131cm	*Sphagnum cuspidatum.*
		131-137cm	PHS, almost fresh.
		137-138cm	*Eriophorum.*
		138-139cm	*Sphagnum cuspidatum,* well laminated.
		139-147cm	PHS, almost fresh with *Eriophorum* 145-146cm. **Trackway level.**
		147-152cm	*Sphagnum cuspidatum,* very well laminated.
		152-153cm	PHS.
		153-155cm	*Sphagnum cuspidatum.*
		155-156cm	*Eriophorum* within *Sphagnum cuspidatum.*
		156-166cm	Mix of *Sphagnum cuspidatum* and PHS, less than 5mm bands.
		166-170cm	PHS, almost fresh.
		170-171cm	*Eriophorum.*
		171-174cm	PHS.
		174-180cm	Mostly *Sphagnum cuspidatum* with some PHS.
		180-183cm	MHS (H5) with occasional visible plant fragments.
		183-200cm	PHS (H2-H3), loose, with *Eriophorum* at 187-188cm.
UNIT F (HHS)	55.10m	200-205cm	HHS (H7).
		205-209cm	PHS with *Eriophorum.*
		209-211cm	*Sphagnum cuspidatum.*
		211-223cm	HHS (H7-H8) with *Calluna.*
		223-225cm	*Sphagnum cuspidatum.*
		225-284cm	HHS (H7), soft and fibrous with *Calluna.*
UNIT C (FEN)	54.26m	284-380cm	Wood peat with sedge, well decomposed, loose, crumbly, with decayed wood, occasionally reed.
		380-395cm	Loose sedge and reed peat
		395-445cm	Homogenous reed and sedge peat, very well developed.
		445-461cm	Sedge reed peat with decayed wood.
		461-485cm	Sedge less dominant, less rooty.
		485-500cm	Softer, looser, less sedge and reed.
		500-556cm	Wood and reed peat, well decomposed, oxidises to black, loose when broken.
		556-588cm	Compact yellow-brown fibrous sedge fen with decayed wood, well decomposed.
UNIT B (MINERAL SUBSTRATE)	51.22m	588-589cm	Yellow inorganic.
		589-600cm	Blue sticky clay.

CORE 3:3	OD	Depth (cm)	Description
UNIT J	57.15m	0-19cm	MHS (H6+) fibrous and dried out with *Eriophorum* from 8-9cm.
		19-37cm	HHS, black, less plant fibres - equates to upper cracked horizon visible on drain face.
		37-41cm	MHS (H4) with *Calluna,* loose.
		41-49cm	HHS (H7) with Calluna.
		49-51cm	MHS (H4), dark brown.
		51-52cm	HHS (H8).
		52-55cm	PHS, almost fresh.
Sphagnum cuspidatum	55.69m	55-64cm	*Sphagnum cuspidatum,* well developed, laminated occasionally PHS inclusions, darker bottom, well decomposed.
		94-81cm	MHS (H4).
		81-91cm	*Sphagnum cuspidatum.*
UNIT H (PHS & *Sphagnum cuspidatum*)	56.24m	91-114cm	PHS, H2 to almost fresh, with *Calluna.*
		114-121cm	MHS, red-brown (H6).
		121-153cm	PHS (H1) with several *Sphagnum cuspidatum* levels.
		153-155cm	MHS (H4) and *Calluna.*
		155-165cm	Very thin bands of HHS and PHS, boundaries indistinct, some HHS maybe *Sphagnum cuspidatum.*
		165-167cm	PHS.
		167-176cm	HHS (H8) with inclusions of PHS.
		176-196cm	PHS (H3) with *Sphagnum cuspidatum* at 189-194cm.
UNIT F (HHS)	55.19m	196-200cm	No record.
		200-240cm	HHS (H7-H8), soft with *Sphagnum cuspidatum* and *Calluna* at 208cm.
		240-242cm	*Eriophorum.*
		242-265cm	HHS (H8), slightly more compact with *Calluna* from 246-253cm.
UNIT C (FEN)	54.50m	265-300cm	Well decomposed fibrous fen peat with many roots, reed and wood.
		300-324cm	No record, from here hole filled with water after each core.
		324-352cm	Sedge and wood peat with reed.
		352-367cm	Peat very soft without structure.
		367-460cm	Sedge and reed peat, homogenous, yellow-brown, fibrous, well decomposed, many vertical roots, more sedge than reed, with wood. Charcoal from 354-355cm.
		460-555cm	Well decomposed fen, some sedge, wood. Not sedge peat like above. Compact, decayed wood, less vertical fibres. *Menyanthes trifoliata* at 555cm.
		555-595cm	Very yellow-green, well developed and fibrous, with wood in lower half. *Menyanthes trifoliata* seeds at 365cm.
UNIT B (MINERAL SUBSTRATE)	51.20m	595-624cm	Sharp transition to sticky blue clay.

Drain Face 3:4	OD (m)	Depth (cm)	Description
UNIT H (PHS)	57.29m	0-5cm	PHS to fresh.
		5-7cm	*Eriophorum.*
		7-8cm	MHS.
		8-16cm	PHS.
UNIT J	57.13m	16-23cm	Laminated light brown to brown HHS, very thin lenses.
		23-29cm	Almost black HHS (H7-8).
		29-35cm	HHS (H7), brown.
		35-48cm	HHS, brown to black, difficult to distinguish horizon from 23-48cm, compact, with *Calluna*, 'soil like'.
UNIT H (PHS)	56.81m	48-103cm	PHS, *Calluna* and *Eriophorum. Calluna* level at 90cm.
		103-108cm	*S. cuspidatum* with darker top and bottom.
		108-130cm	PHS.
		at 122cm	*Eriophorum.*

CORE 3:5	OD (m)	Depth (cm)	Description
FIELD SURFACE	57.38m	0-10cm	MHS (H6).
		10-14cm	PHS (H3).
UNIT J	57.24m	14-40cm	HHS with *Calluna* (H7).
		40-42cm	*Eriophorum.*
		42-61cm	Highly to MHS with black and yellow roots (H6), very muddy last 30cm.
UNIT H (PHS)	56.77m	61-136cm	PHS (H1-H3) with several *Sphagnum cuspidatum* & HHS levels
UNIT F (HHS)	56.02m	136-179cm	HHS (H8) with *Eriophorum.*
		179-210cm	No record.
		210-265cm	HHS with *Eriophorum* and *Calluna.*
UNIT C (FEN)	54.73m	265-315cm	Fen peat, loose with small, well decayed wood remains.
		315-400cm	Loose - wet and sloppy.
		400-425cm	Uncompacted sedge and reed peat, yellow-brown.
		425-480cm	More compact well developed sedge peat, fairly homogenous, occasional change yellow-dark with wood.
		480-505cm	Less compact sedge with fewer plant fibres, very well decomposed.
		505-517cm	Wood with reed at 512cm.
		517-574cm	Dark yellow fen peat oxidises rapidly to black, compact with reed and sedge and decayed wood.
		574-589cm	Mix of organic plant fibres and silt.
UNIT B (MINERAL SUBSTRATE)	51.49m	589-600cm	Sticky blue clay.

Drain Face 3:6	OD (m)	Depth (cm)	Description
FIELD SURFACE HHS (PHS)	57.48m	0-6cm	Fresh *Sphagnum.*
UNIT J	57.42m	6-38cm	Mostly MHS with wood at 14cm, 31-34cm, very dried out.
		38-50cm	Yellow-brown HHS (H7), sligthly laminated.
		50-54cm	*Eriophorum.*
		54-64cm	HHS (H7) with MHS layers.
		64-68cm	Black wood horizon.
		68-102cm	Very soft MHS (H6/7), buttery with *Eriophorum.*
UNIT H (PHS)	56.46m	102-118cm	PHS (H1), very loose.

CORE 3:7	OD (m)	Depth (cm)	Description
FIELD SURFACE - UNIT H (PHS)	57.47m	0-26cm	PHS with *Calluna*, minor variations within horizons.
UNIT G (MHS)	57.21m	26-48cm	MHS (H5).
		48-52cm	PHS (H2), very yellow.
		52-57cm	MHS (H6), fibrous.
UNIT J	56.90m	57-88cm	HHS, muddy, practically amorphous with *Calluna* at 57-58cm and 66-67cm.
UNIT G (MHS)	56.80m	88-115cm	MHS with *Calluna* (H4-H5).
UNIT H (PHS)	56.32m	115-125cm	Loose PHS (H3).
UNIT G/UNIT F		125-134cm	HHS (H8) with *Calluna* and *Eriophorum* from 125-128cm.
		134-154cm	MHS with *Calluna* (H5), loose with pockets of PHS.
		154-171cm	HHS with *Eriophorum* and *Calluna*.
		171-182cm	MHS (H4), loose.
UNIT F (HHS)	55.65m	182-215cm	HHS (H7-H8), loose.
		215-219cm	PHS, almost fresh.
		219-255cm	HHS with *Calluna* and *Eriophorum*.
UNIT C (FEN)	54.92m	255-275cm	Wood horizon.
		275-281cm	Black loose peat with wood, reed at 281cm.
		281-308cm	No record.
		308-403cm	Well decomposed, small wood remains and reed.
		403-525cm	Compact yellow-black sedge peat with reed, well decayed and decomposed. Decayed wood at 441cm.
		525-568cm	Wood peat with decayed wood and reed.
		568-610cm	Yellow fibrous fen, minor wood, well decomposed fen, well developed, bog bean at 610cm.
		610-621cm	Blue/yellow fen peat.
UNIT B (MINERAL SUBSTRATE)	51.27m	621-664cm	Sharp transition to sticky blue clay.

Drain Face 3:8	OD (m)	Depth (cm)	Description
	57.40m	n/a	No record made, water too deep in the drain. Water table at 68cm.

CORE 3:9	OD (m)	Depth (cm)	Description
FIELD SURFACE	57.30m	0-5cm	HHS, soil-like.
UNIT H (PHS)	57.25m	0-13cm	PHS (H3).
		13-16cm	MHS.
		16-21cm	PHS (H2).
		21-23cm	MHS (H6), dark.
		23-26cm	*Eriophorum.*
		26-29cm	MHS (H4).
	56.86m	29-44cm	PHS, almost fresh.
		44-49cm	*Sphagnum cuspidatum.*
		49-83cm	PHS (H2) with *Eriophorum* and *Calluna.*
		83-100cm	PHS (H3), very loose.
		100-108cm	No record.
		108-117cm	PHS (H3+).
UNIT G (MHS)		117-130cm	MHS with *Calluna* (H5).
		130-131cm	*Sphagnum cuspidatum.*
		131-138cm	MHS (H4).
		138-144cm	PHS (H3).
		144-157cm	MHS with *Calluna* (H6+).
		157-164cm	PHS (H3), loose, very wet.
		164-217cm	MHS with *Calluna* (H4), loose.
		217-229cm	HHS with *Sphagnum cuspidatum*, PHS and *Calluna.*
Sphagnum cuspidatum	54.92m	229-275cm	*Sphagnum cuspidatum* with PHS.
UNIT F (HHS)		275-310cm	HHS (H7) with *Calluna* and *Eriophorum.*
		310-313cm	Very soft, structureless, amorphous HHS.
UNIT C (FEN)	54.17m	313-318cm	Transition horizon with reed.
		318-323cm	Short plant fibres, laminated layers of other mosses.
		323-331cm	Well decomposed with bog bean, laminated, minor wood and sedge.
		331-375cm	Wood fen peat, well decomposed, decayed wood, little sedge, no reed.
		at 360cm	Wood lessens.
		375-388cm	More sedge.
		388-400cm	No record. Pushed through to 584m but nothing retained in chamber, felt like bottom but deposit too wet to be retained.
		400-440cm	Mix of *in situ* deposits and pushdown within blacker fen peat, bog bean and reed.
		440-538cm	Well decomposed fen with sedge and reed and decayed wood and *Menyanthes trifoliata* at 519cm.
		538-584cm	No record. Pushed through to 584m but nothing retained in chamber, felt like bottom.

Drain Face 3:10	OD (m)	Depth (cm)	Description
UNIT H (PHS)	57.56m	0-5cm	Almost fresh *Sphagnum.*
		5-12cm	MHS
		12-16cm	PHS.
		16-19cm	MHS.
		19-45cm	PHS (H1).
UNIT G (MHS)	57.11m	45-59cm	MHS (H5).
		59-60cm	*Sphagnum cuspidatum*, not muddy.
		60-65cm	*Eriophorum*?
		65-81cm	MHS (H4-5), red brown, soft and smelly.
		81-99cm	PHS (H1).

CORE 3:11	OD (m)	Depth (cm)	Description
FIELD SURFACE	57.80m	0-9cm	*Sphagnum cuspidatum*, laminated.
		9-14cm	*Sphagnum cuspidatum*, more decomposed.
UNIT H (PHS)	57.55m	14-25cm	PHS (H1).
		25-28cm	MHS.
		28-50cm	Loose PHS with *Calluna*.
UNIT G (MHS)	57.30m	50-53cm	*Eriophorum* with loose PHS.
		53-63cm	MHS (H4).
		63-80cm	MHS (H5) with *Calluna*.
		80-82cm	PHS.
		82-113cm	MHS (H6).
		113-123cm	*Sphagnum cuspidatum* with *Calluna* at 118cm.
		123-128cm	PHS (H2).
		128-142cm	MHS (H5).
		142-150cm	HHS (H8).
		150-158cm	MHS (H6).
		158-163cm	MHS (H4).
		163-165cm	PHS.
UNIT F (HHS)	56.11m	165-169cm	HHS.
		169-170cm	PHS.
		170-203cm	No record.
		203-207cm	*Eriophorum*.
		207-223cm	HHS, red-brown with *Calluna*.
		223-227cm	MHS (H6).
		227-244cm	HHS, internal variations (H8).
		244-247cm	*Eriophorum*.
		247-249cm	Amorphous.
		249-250cm	*Calluna*.
		250-293cm	HHS, mushy.
UNIT C (FEN)	54.87m	293-300cm	Yellow reed peat.
		300-310cm	No record.
		310-327cm	HHS bands, red-brown.
		313-314cm, 321-322cm	*Sphagnum cuspidatum*, extremely soft.
		327-353cm	Yellow-black fen peat, vertical roots, short plant fibres, some sedge.
		353-355cm	Very decayed wood.
		353-420cm	More compact, increased reed and sedge, well developed fen with wood at 407cm, 410cm, 418cm, 427-429cm.
		420-452cm	Less reed and sedge.
UNIT B (MINERAL SUBSTRATE)	53.28m	452-460cm	Mineral substrate, transition unclear as deposit not retained in chamber.

Drain Face 3:12	OD (m)	Depth (cm)	Description
FIELD SURFACE - UNIT H (PHS)	58.48m	0-11cm	Almost fresh *Sphagnum*.
UNIT J	58.37m	11-14cm	*Calluna*.
		14-18cm	Black HHS (H7).
		18-22cm	PHS.
		22-26cm	MHS.
UNIT H (PHS)/UNIT G (MHS)	58.22m	26-28cm	PHS.
		28-35cm	Mix of MHS and PHS.
		35-40cm	PHS (H2), dark brown.
		40-45cm	MHS (H6) with *Calluna*.
		45-55cm	PHS (H2), dark brown.
		55-59cm	MHS (H6).
		59-67cm	PHS (H2).
UNIT F (HHS)	57.81m	67-76cm	HHS with *Eriophorum* (H7).
		76-83cm	MHS (H6).
		83-94cm	PHS (H3) with *Calluna*.
		94-102cm	HHS.
Sphagnum cuspidatum	57.46m	102-103cm	Pool mud.
		103-108cm	*Sphagnum cuspidatum*.
		108-109cm	Pool mud.
UNIT F (HHS)	57.26m	109-122cm	HHS (H7), with *Eriophorum* and *Calluna*.

CORE 3:13	OD (m)	Depth (cm)	Description
UNIT J	58.96m	0-5cm	HHS (H7), yellow.
		5-14cm	HHS (H7), dark brown.
		14-16cm	*Calluna*.
		16-20cm	MHS.
		20-22cm	PHS.
		22-38cm	HHS (H7), oxidised black.
		38-50cm	HHS, red-brown, not oxidised.
		50-53cm	PHS (H3).
UNIT F (HHS)	58.20m	53-76cm	HHS.
		76-82cm	Mix of PHS and HHS.
		82-96cm	HHS with *Calluna*.
	58.00m	96-118cm	MHS, loose.
		118-121cm	*Eriophorum*.
		121-148cm	Moderately to HHS.
		148-152cm	PHS.
		152-153cm	*Sphagnum cuspidatum*.
	57.41m	153-203cm	HHS with *Eriophorum* and *Calluna*.
UNIT C (FEN)	56.93m	203-209cm	Yellow reed peat.
		209-212cm	Well decomposed fen with wood and reed.
		212-215cm	Yellow reed peat.
		215-245cm	Mix of reed and wood peat.
		245-258cm	Yellow fen, short plant fibres with reed and wood.
		258-300cm	More compact mostly yellow fen peat with sedge and reed, no wood, short plant fibres.
UNIT B (MINERAL SUBSTRATE)	55.96m	300-306cm	Mineral substrate.

CORE 3:14	OD (m)	Depth (cm)	Description
UNIT J	59.96m	0-13cm	HHS (H7) with *Calluna*, black-brown, oxidises to black.
		13-14cm	*Eriophorum*.
		14-25cm	HHS (H7) with *Calluna*, black-brown, oxidises to black.
		25-34cm	MHS (H5).
		34-38cm	HHS.
		38-45cm	MHS.
		45-47cm	HHS, layers all oxidised.
UNIT H (PHS)	59.32m	47-54cm	MHS, orange.
		54-65cm	PHS (H3).
		65-74cm	MHS.
		74-76cm	*Sphagnum cuspidatum*.
		76-118cm	PHS with *Eriophorum* at 80cm.
UNIT F (HHS)	58.66m	118-120cm	HHS.
		120-121cm	MHS (H5).
		121-124cm	*Eriophorum*.
		124-128cm	*Sphagnum cuspidatum*, slightly laminated.
		128-131cm	HHS (H7) with *Eriophorum*.
		131-143cm	HHS (H8) with *Calluna*, short plant fibres, some reed.
UNIT D (FBT)	58.43m	143-145cm	Transitional *Sphagnum cuspidatum*, laminated red-brown.
UNIT C (FEN)		145-188cm	Highly decomposed mix of wood and reed fragments.
		149-154cm	*Calluna*.
		188-203cm	Increased yellow sedge and reed peat with wood.
		203-210cm	Sedge and reed peat.
		210-211cm	*Sphagnum cuspidatum*-like.
		211-216cm	Wood.
UNIT B (MINERAL SUBSTRATE)	57.70m	216-219cm	Yellow sticky clay with organic inclusions.
		219-235cm	Sticky blue clay.

Drain Face 3:15	OD (m)	Depth (cm)	Description
FIELD SURFACE - UNIT H (PHS)	59.73m	0-20cm	Mostly PHS (H1) with lenses of MHS.
UNIT J	59.53m	20-36cm	Mostly HHS, black (standstill?) with *Eriophorum* and *Calluna* at 30cm.
		36-59cm	Mostly MHS (H6/7) with lenses of PHS. Difficult to distinguish bands.
		59-62cm	*Sphagnum cuspidatum*.
UNIT H (HHS)	59.11m	62-74cm	MHS (H5).
		74-76cm	*Eriophorum*.
		76-78cm	Pool mud?
		78-90cm	MHS (H6).
	58.93m	90-101cm	PHS (H1).

CORE 3:16	OD (m)	Depth (cm)	Description
FIELD SURFACE	59.93m	0-9cm	HHS (H7).
		9-15cm	PHS (H2).
UNIT J	59.78m	15-27cm	MHS with *Calluna*.
		27-32cm	HHS (H7).
		32-36cm	MHS with *Calluna*.
		36-43cm	PHS (H3).
		43-44cm	*Eriophorum*.
		44-50cm	PHS (H3).
		50-83cm	HHS (H7/8), soft, yellow vertical roots, *Calluna* fragments, relatively homogenous.
UNIT G (MHS)	59.10m	83-92cm	MHS (H4).
		92-100cm	No record.
		100-119cm	MHS (H6), loose.
UNIT H (HHS)	58.70m	119-123cm	HHS (H7).
		123-124cm	*Sphagnum cuspidatum*? Or amorphous.
		124-131cm	HHS with occasional PHS.
		131-136cm	MHS, very soft (H4/5).
		136-141cm	*Sphagnum cuspidatum*.
		141-145cm	MHS with *Sphagnum cuspidatum* and PHS inclusions.
		145-150cm	*Sphagnum cuspidatum*, not laminated.
		150-154cm	PHS.
		154-163cm	Loose mix of highly and PHS, orange and *Eriophorum*-type plant.
		163-171cm	*Sphagnum cuspidatum* some lamination.
		171-174cm	*Sphagnum cuspidatum* with PHS.
		174-178cm	PHS (H2).
		178-182cm	*Sphagnum cuspidatum*.
		182-186cm	PHS.
		186-209cm	No record.
		209-211cm	PHS.
		211-218cm	*Sphagnum cuspidatum*.
UNIT F (HHS)	57.76m	218-235cm	HHS, soft and loose (H7/8), varies.
		235-242cm	*Eriophorum*.
		242-300cm	HHS, loose, red-brown with *Calluna*.
UNIT C (FEN)	56.93m	300-310cm	Sedge fen peat, yellow with reed and bog bean.
		310-340cm	Less coherent, mushy.
		340-365cm	Fibrous fen peat oxidises black-yellow.
		365-452cm	More structure with reed and wood.
		452-510cm	More structure, short dark fibres, occasionally reed and decayed wood, black-yellow as above.
UNIT B (MINERAL SUBSTRATE)	54.83m	510-511cm	Sharp transition zone.
		511-552cm	Top of sticky blue clay.

Drain Face 3:17	OD (m)	Depth (cm)	Description
FIELD SURFACE - UNIT H (PHS)	59.81m	0-20cm	Mostly bands of MHS with thin lenses of PHS, weathered yellow and fluffy.
		20-26cm	PHS (H1).
		26-28cm	*Sphagnum cuspidatum*, relatively fresh.
		28-29cm	Pool base algae.
		29-30cm	*Eriophorum*.
UNIT J	59.51m	30-47cm	Soft, very dark HHS, (H7) internal variations difficult to discern but weathered profile shows lenses of less well humified *Sphagnum*.
		47-57cm	MHS (H4).
		57-61cm	HHS (H7).
		61-63cm	*Eriophorum*.
		63-76cm	HHS (H8) red/brown soft, somewhat fibrous.
UNIT H (PHS)	59.05m	76-82cm	PHS (H2).
		82-88cm	Soft butter-like MHS (H6).
		88-99cm	PHS (H2).

CORE 3:18	OD (m)	Depth (cm)	Description
FIELD SURFACE	59.77m	0-5cm	Yellow MHS (H4).
		5-8cm	HHS (H7).
		8-9cm	PHS.
UNIT J	59.68m	9-14cm	Black MHS (H6).
		14-19cm	MHS, black-brown (H6).
		19-26cm	PHS (H2), dark brown.
		26-31cm	HHS (H7), soft.
		31-39cm	PHS, dark brown (H2).
		39-44cm	MHS, (H4).
		44-53cm	Laminated well decomposed HHS with occasional lenses of PHS (H7).
UNIT H (PHS) /UNIT F (HHS)	59.24m	53-68cm	PHS.
		68-86cm	HHS (H8), red-brown, soft minor vertical roots with *Calluna* and PHS (H1).
		86-116cm	HHS, yellow-red with *Calluna* and *Eriophorum.*
		116-132cm	PHS, loose broken plants, (H3) some *Calluna.*
		132-136cm	HHS.
UNIT G (MHS)	58.41m	136-142cm	MHS (H4).
		142-144cm	*Calluna* with loose peat.
		144-155cm	MHS with *Calluna* and lenses of PHS.
		155-182cm	Loose generally H3 with some H4 layers.
		182-200cm	No record.
		200-222cm	MHS (H4), very loose.
UNIT F (HHS)	57.54m	222-224cm	HHS (H7).
		224-229cm	MHS (H4), somewhat laminated.
		229-231cm	Laminated *Sphagnum cuspidatum.*
		231-238cm	HHS, structureless (H8).
		238-240cm	HHS, loose with *Calluna.*
		240-246cm	Fibrous HHS with *Sphagnum cuspidatum.*
		246-280cm	HHS mixed horizons with *Calluna* (H8).
		280-294cm	More fibrous, MHS (H6/7).
		294-305cm	No record.
		305-306cm	*Calluna.*
UNIT C (FEN)	56.70m	306-311cm	Dense reed.
		308-309cm	*Sphagnum cuspidatum.*
		311-325cm	Reed in well decomposed peat, less compacted towards 325cm.
		325-345cm	Mix of sedge, reed and other moss, very loose and uncompacted and wet.
		345-355cm	Loose uncompacted fen peat, well decomposed.
		355-374cm	More compact yellow-brown oxidises rapidly to black, short plant fibres, decayed wood, no reed.
		374-381cm	Wood.
		381-388cm	Reed.
		388-390cm	More compact yellow-brown oxidises rapidly to black, short plant fibres, decayed wood, no reed.
		390-436cm	No record.
		436-498cm	Very wet, very well decomposed, loose yellow-green short plant fibres, some sedge, very loose, structureless, with reed and wood.
UNIT B (MINERAL SUBSTRATE)	54.78m	498-500cm	Sticky blue clay.

Drain Face 3:19	OD (m)	Depth (cm)	Description
FIELD SURFACE - UNIT H (PHS)	59.63m	0-8cm	PHS.
UNIT J	59.55m	8-19cm	MHS with lenses of PHS, dark yellow weathered band, 17-19cm black.
		19-25cm	PHS, almost fresh.
		25-29cm	PHS (H2).
		29-33cm	HHS (H7).
		33-39cm	Mostly PHS with lenses of MHS.
		39-51cm	Weathered cracked band at this level, HHS, very dark (H8), *c.*100cm wide, no cracking on either side.
		51-55cm	PHS (H2).
UNIT H (PHS)	59.08m	55-65cm	MHS (H6) with *Eriophorum* and *Calluna* at 63-65cm.
		65-90cm	Mixed MHS-PHS, no clear boundaries.
		90-100cm	Possibly PHS.

CORE 3:20	OD (m)	Depth (cm)	Description
FIELD SURFACE - UNIT H (PHS)	59.64m	0-6cm	PHS.
		6-8cm	MHS.
		8-14cm	PHS, very loose.
UNIT J	59.50m	14-15cm	*Eriophorum.*
		15-21cm	Black/brown HHS (H7).
		21-32cm	Dark brown PHS (H3) to MHS (H4) with black and yellow stems.
		32-38cm	HHS with *Calluna* (H7).
UNIT H (PHS)	59.26m	38-41cm	PHS (H3), dark brown.
		41-44cm	Poorly developed *Sphagnum cuspidatum.*
		44-50cm	MHS (H4).
		50-52cm	PHS.
		52-55cm	*Sphagnum cuspidatum,* poorly developed, not laminated.
UNIT G (MHS)	59.09m	55-63cm	MHS with *Calluna.*
		63-77cm	HHS (H7/8).
		77-89cm	MHS with *Calluna* (H4/5).
		89-100cm	No record.
		100-120cm	MHS (H4) with *Calluna.*
UNIT H (PHS)	58.44m	120-128cm	PHS (H2).
		128-135cm	MHS (H4).
		135-139cm	PHS (H2).
		139-140cm	*Sphagnum cuspidatum.*
		140-175cm	PHS, loose (H1).
		175-200cm	No record.
		200-214cm	MHS (H6).
UNIT F (HHS)	57.50m	214-250cm	HHS/possibly fen?, decayed *Eriophorum.*
		250-300cm	No record.
		300-308cm	HHS (H8), no structure although plant fibres and *Calluna.*
UNIT C (FEN)	56.55m	308-315cm	Yellow horizon, *Sphagnum cuspidatum* with reed.
		315-325cm	Yellow fen, sedge, vertical roots and reed.
		325-338cm	Laminated sedge peat with decomposed small wood fragments.
		338-345cm	Less laminated, darker, oxidises black.
		345-404cm	Sedge, wood and reed peat.
		404-459cm	Compact sedge fen peat, previously oxidised.
		431-484cm	Wood and reed, decayed wood through out, many vertical roots, well decayed.
	54.68m	495cm	Deepest point. Could not push corer deeper, hit wood/tree

Drain Face 3:21	OD (m)	Depth (cm)	Description
FIELD SURFACE - UNIT H (PHS)	59.44m	0-11cm	PHS (H1).
UNIT J	59.33m	11-14cm	MHS.
		14-15cm	*Eriophorum.*
		15-20cm	HHS (H7).
		20-23cm	PHS (H3).
		23-27cm	HHS (H7), dark.
		27-31cm	PHS.
		31-35cm	HHS, black with *Calluna.*
		35-37cm	*Eriophorum* tussock.
UNIT H	58.92m	37-42cm	PHS (H2).
		42-52cm	HHS with *Calluna.*
		52-61cm	PHS (H2-3) with *Calluna.*
		61-65cm	MHS (H4).
		65-69cm	PHS.
		69-112cm	MHS to PHS, difficult to distinguish boundaries (H2-4).
		112-136cm	PHS (H2).

CORE 3:22	OD (m)	Depth (cm)	Description
UNIT H (PHS)	59.14m	0-4cm	MHS (H6).
		4-6cm	PHS (almost fresh).
		6-10cm	MHS (H6).
		10-12cm	PHS (H1).
		12-18cm	HHS (H7).
		18-19cm	PHS (H1).
		19-21cm	HHS (H7).
		21-41cm	PHS (H3) with *Calluna* at 29cm.
		41-53cm	MHS (H4).
		53-55cm	PHS.
		55-58cm	MHS with *Calluna*.
		58-69cm	PHS.
		69-100cm	No record, nothing held in chamber.
		100-111cm	PHS (H2).
		111-116cm	*Sphagnum cuspidatum*, laminated with *Eriophorum* at 114cm.
		116-118cm	PHS, almost fresh.
		118-125cm	Mix of *Sphagnum cuspidatum* and PHS.
		125-150cm	Loose PHS (H3).
		150-191cm	PHS with *Eriophorum*.
UNIT F (HHS)	57.23m	191-212cm	No record.
		213-230cm	HHS, red-brown with *Eriophorum*.
		230-270cm	MHS.
		272-276cm	*Calluna* and *Eriophorum*.
		270-283cm	HHS.
		283-288cm	PHS.
UNIT I	56.14m	300-400cm	Peat held in chamber, very loose, all raised bog peat, lots of water, possible not *in situ*.
UNIT C (FEN)		400-455cm	Very soft mushy fen, small wood remains and reed, no compaction.
		458-478cm	Red-brown to black fen, sedge, occasional reed, decayed wood, short fibres.
		478-488cm	Mix of yellow-red fen, well decomposed sedge peat with wood at 487cm and non-Sphagnum mosses at 488-502cm.
		502-521cm	Mix yellow-red-brown bands, laminated, sedge, wood fragments, brown bands = other mosses, reed.
		521-535cm	Yellow-red-brown fen, well decomposed with reed and some wood remains
		535-537cm	More mud-like with reed, yellow-brown.
UNIT B (MINERAL SUBSTRATE)	53.77m	537-539cm	Transition horizon, organic silt.
		539-541cm	Sticky blue clay.
		541-543cm	Coarse sand.
		543-558cm	Sticky blue clay.

Drain Face 3:23	OD (m)	Depth (cm)	Description
FIELD SURFACE	59.48m	0-9cm	*Sphagnum cuspidatum* (H1).
UNIT G (MHS)	59.39m	9-18cm	MHS (H6) with *Calluna.*
UNIT J	59.30m	18-22cm	HHS (H7) with *Calluna.*
		22-24cm	PHS (H3).
		24-30cm	HHS (H7).
		30-31.5cm	MHS (H5).
		31.5-33cm	HHS (H7).
		33-38cm	MHS (H4), loose.
UNIT H (PHS)	59.10m	38-43cm	PHS.
		43-46cm	*Eriophorum.*
		46-72cm	PHS.
		72-88cm	*Sphagnum cuspidatum*, well laminated, appears to be uninterrupted.
		88-97cm	PHS.

CORE 3:24	OD (m)	Depth (cm)	Description
UNIT H (PHS)	58.98m	0-16cm	PHS, almost fresh.
		16-45cm	PHS and *Sphagnum cuspidatum.*
		45-100cm	No record.
		100-190cm	Loose PHS (H3), wet with *Eriophorum* levels.
		190-202cm	No record.
UNIT F (HHS)		202-210cm	MHS with *Eriophorum* and *Calluna* (H4).
		210-250cm	HHS with *Calluna.*
UNIT C (FEN)	56.48m	250-258cm	*Sphagnum cuspidatum* with wood and reed.
		258-278cm	Wood fen peat, wood through out, well decayed wood, highly decomposed peat.
		278-300cm	No record.
		300-304cm	PHS.
		304-328cm	HHS (H7) with *Eriophorum* and *Calluna.*
	55.67m	328-331cm	Decayed wood.
		331-400cm	Yellow fen peat, well decomposed, sedge, soft and homogenous with wood and reed levels.
		400-423cm	Fen, slightly darker, somewhat crumblier, less plant fibres and remains, no reed or wood.
		423-425cm	Very black, mud-like.
		428.5cm	Organic mud?
UNIT B (MINERAL SUBSTRATE)		428.5-438.5cm	Mineral substrate.

CORE 3:25	OD (m)	Depth (cm)	Description
FIELD SURFACE - UNIT H (PHS)	57.67m	0-7cm	PHS (H1)
UNIT J / UNIT F (HHS)	57.60m	7-24cm	HHS (H7) with *Calluna*, red-brown, and *Eriophorum*.
		24-33cm	PHS (H3)
		33-55cm	Dark HHS with Calluna (H7), almost black
		55-58cm	*Eriophorum.*
		58-65cm	Mix of HHS, red-brown and MHS
		65-70cm	*Eriophorum.*
UNIT D (FBT)	56.97m	70-75cm	Transition to fen, peat reasonably well decomposed with wood.
UNIT C (FEN)	56.92m	75-84cm	Laminated compact fen peat with lots of bog bean, reed, very well decomposed.
		84-103cm	Somewhat looser darker, crumblier, less compact sedge.
		103-190cm	Well decomposed fen peat with minor reed, few vertical roots, wood, well decomposed, compact.
		190-200cm	No record.
		200-251cm	Sedge fen, well developed, decayed wood, reed, red-brown.
	55.47m	220-221cm	Mineral soil inundation with wood and roots, red-brown fen with sedge, short yellow fibres.
		225-226cm, 230-231cm	Wood, fen peat more soil like, compact, dry.
UNIT B (MINERAL SUBSTRATE)	55.16m	251-252cm	Sharp transition, slightly organic top to mineral substrate.
		252-261cm	Sticky blue clay.
		261-260cm	Sand.

APPENDIX 3

ARCHAEOLOGICAL SITE RECORD SHEET

Location Code: 01	Date: / /01 Sheet of
Equivalent if any:	Classification:
Bog: Works: Lemanaghan	Preservation (DBS):
County: Offaly	NGR:
Townland:	OS:
	Ordnance Datum:
	Dimensions:
	Orientation:
	Photo: CP :

Description ARCHAEOLOGY ☐ PEAT ☐ BOTH ☐

Samples:

APPENDIX 4

DEMs of Kilnagarnagh: Phases of Mire Development

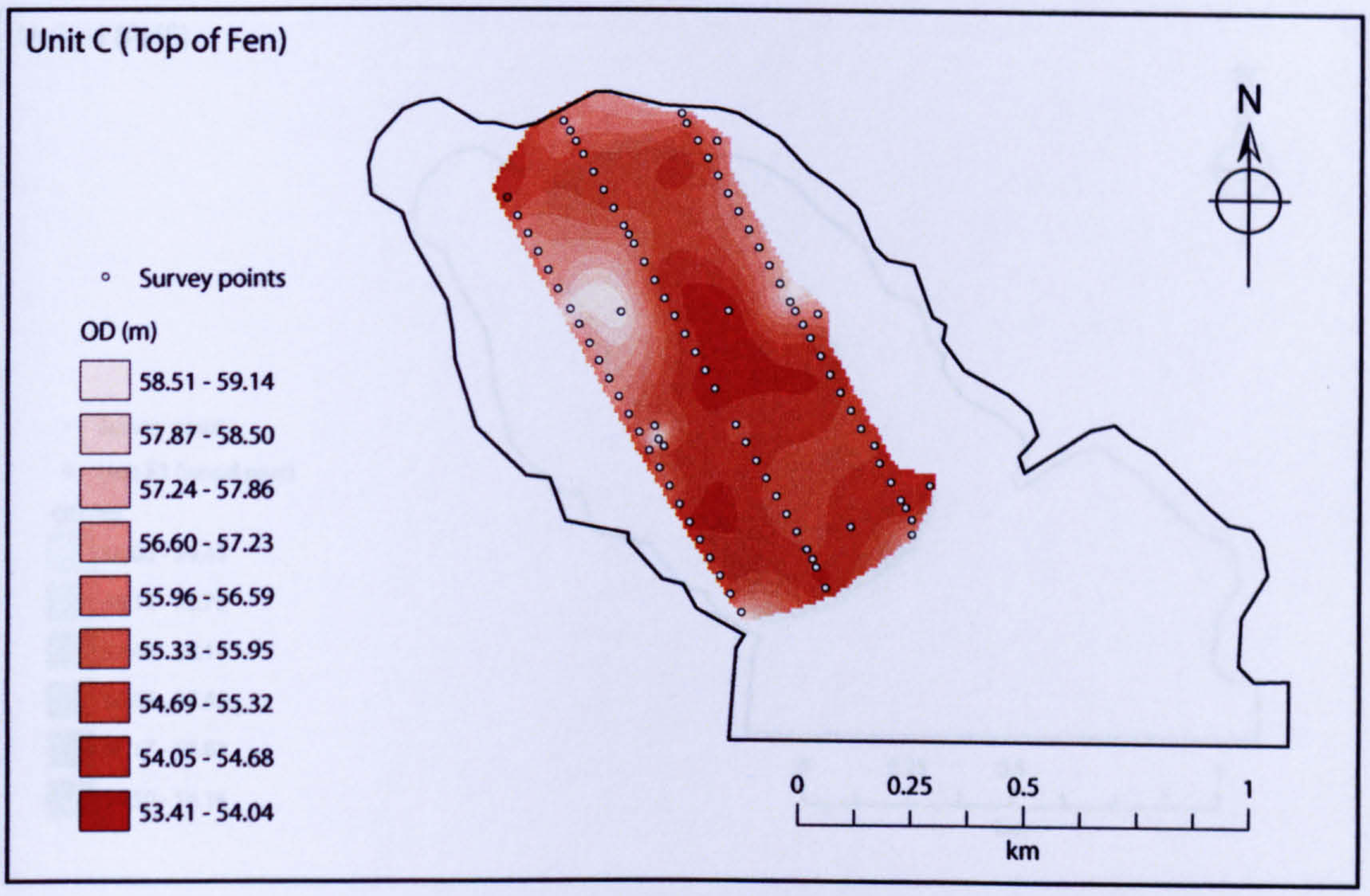

Fig. A4:2 Top of Unit C (Fen)

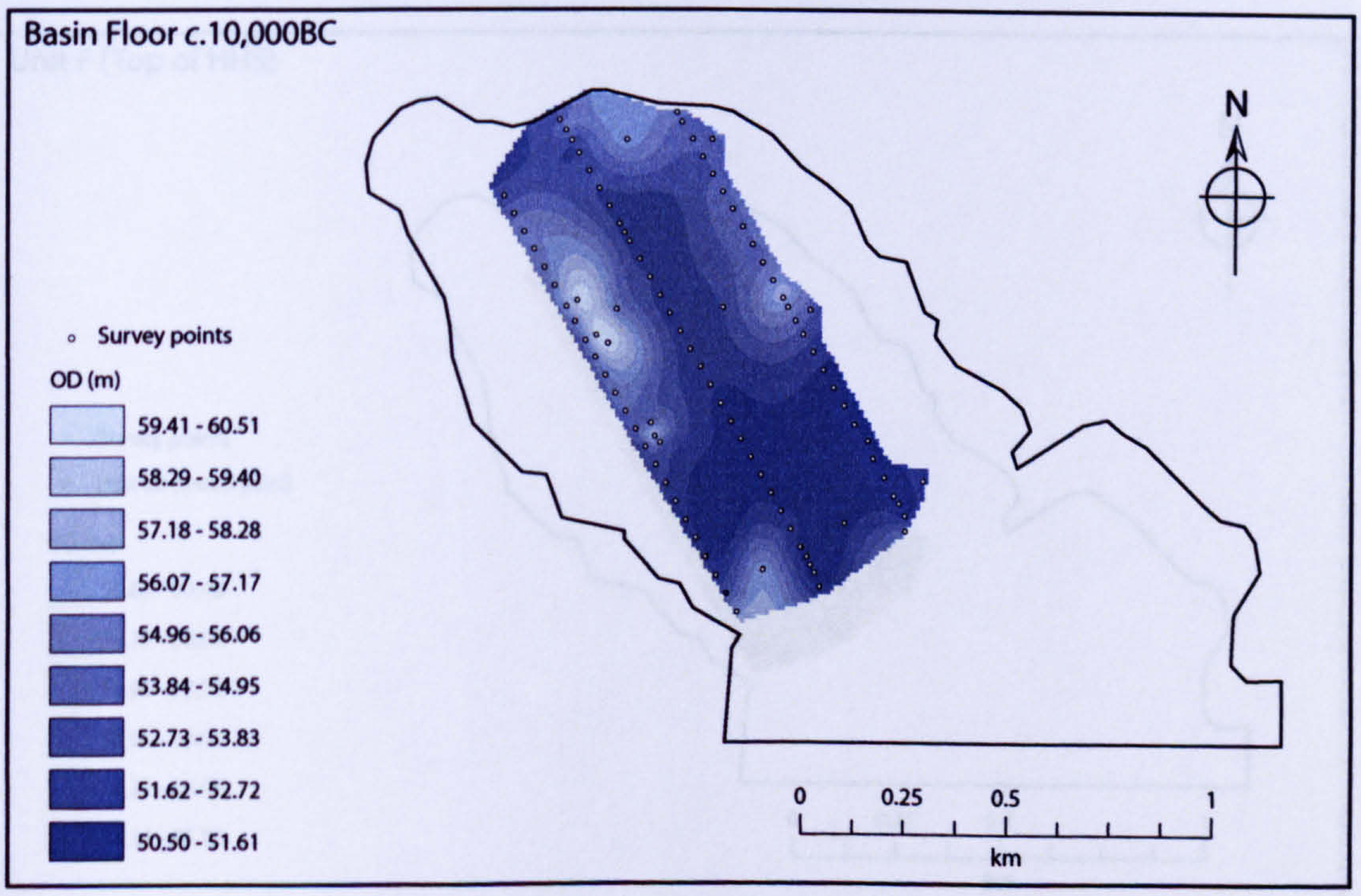

Fig. A4:1 Basin floor

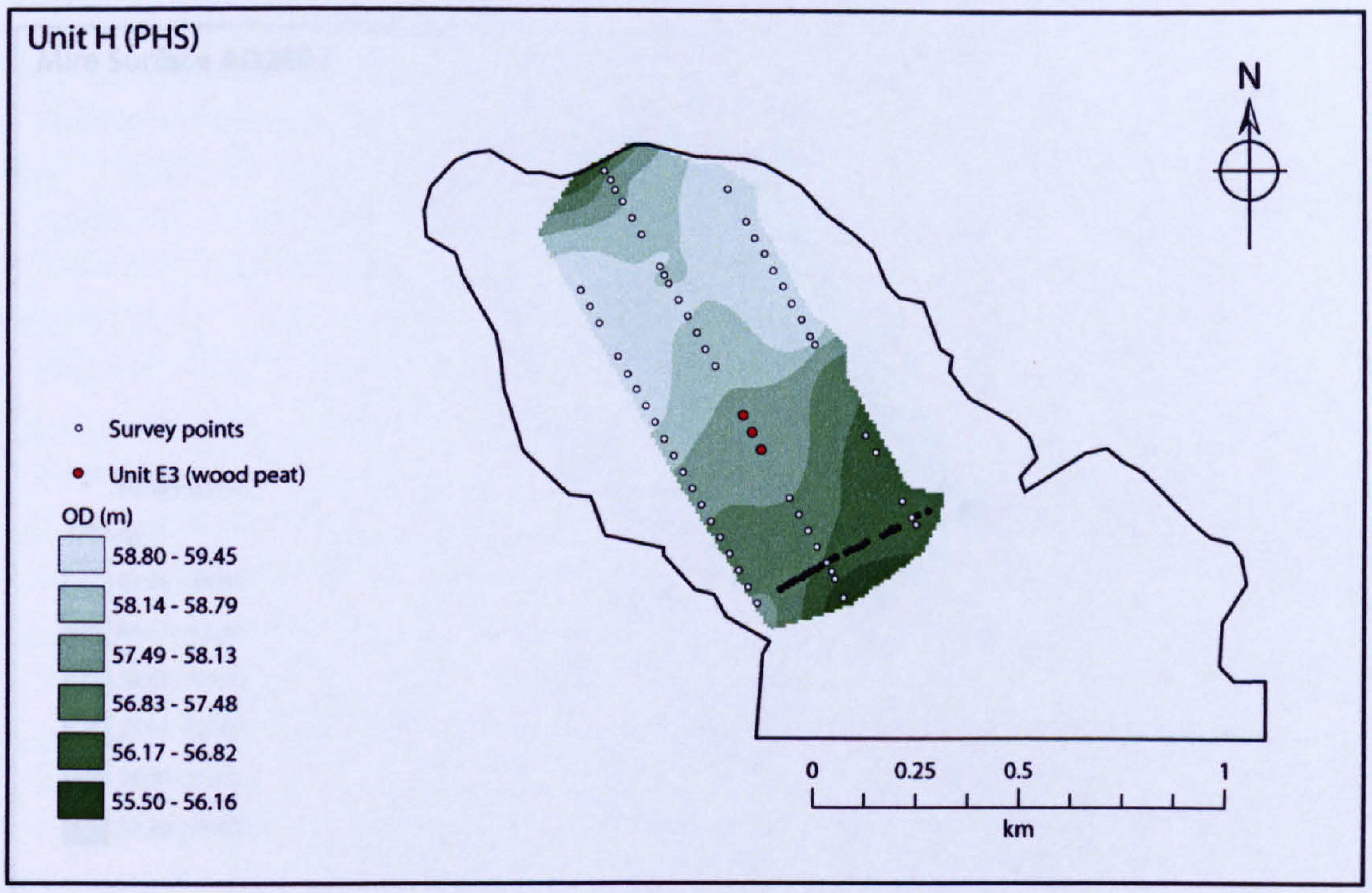

Fig. A4:4 Top of Unit H (PHS)

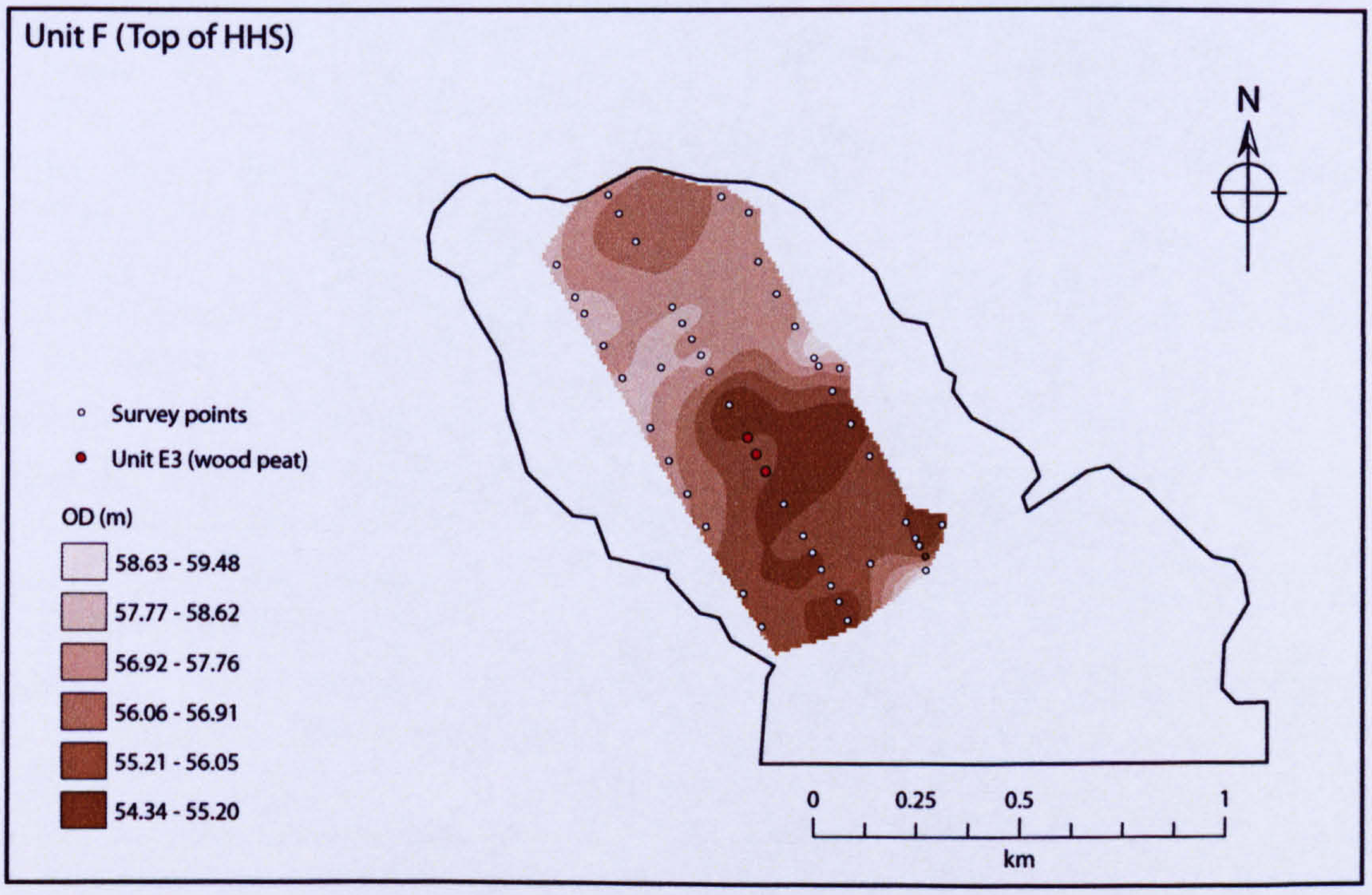

Fig. A4:3 Top of Unit F (HHS)

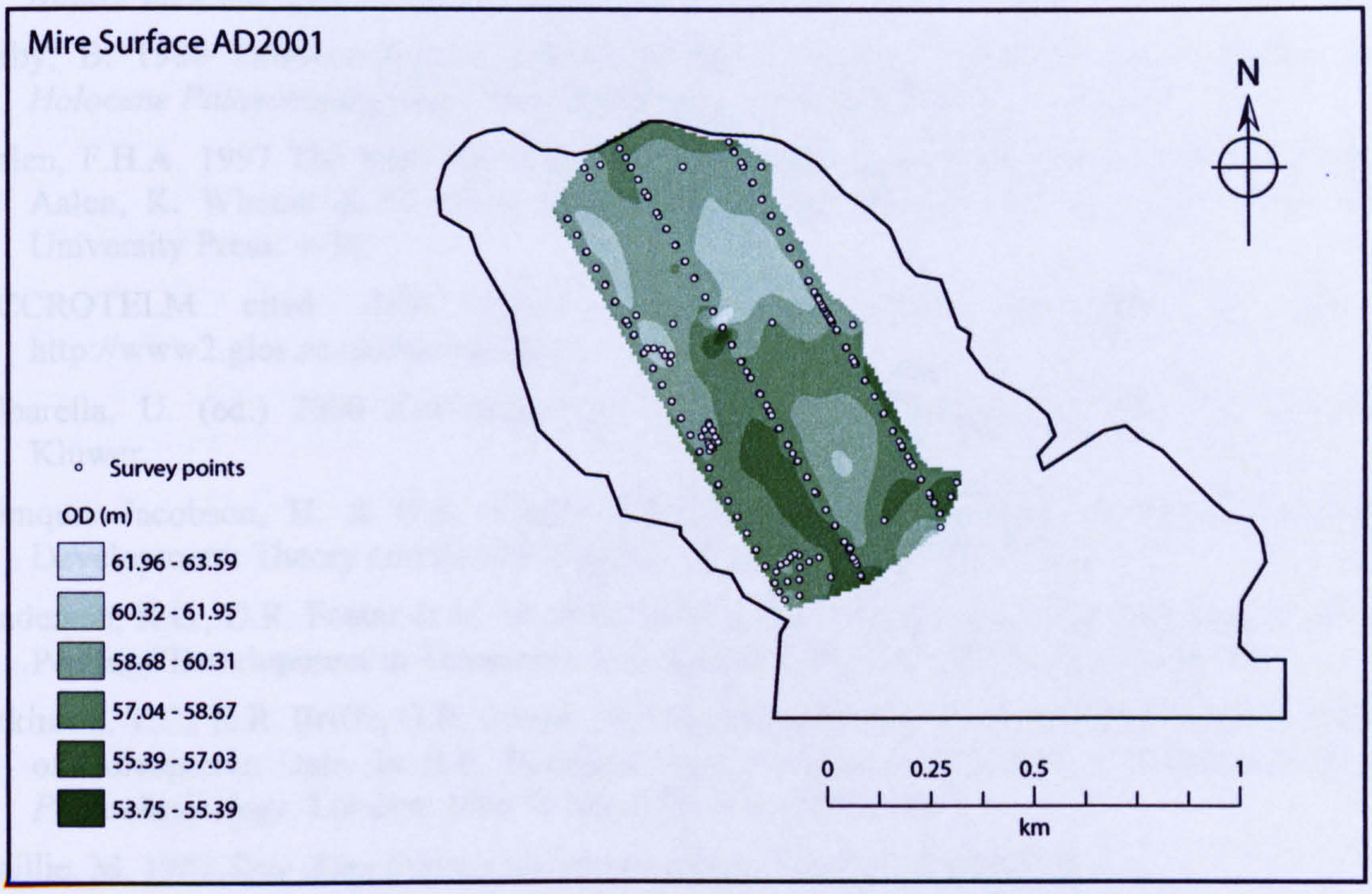

Fig. A4:5 Mire Surface AD2001

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