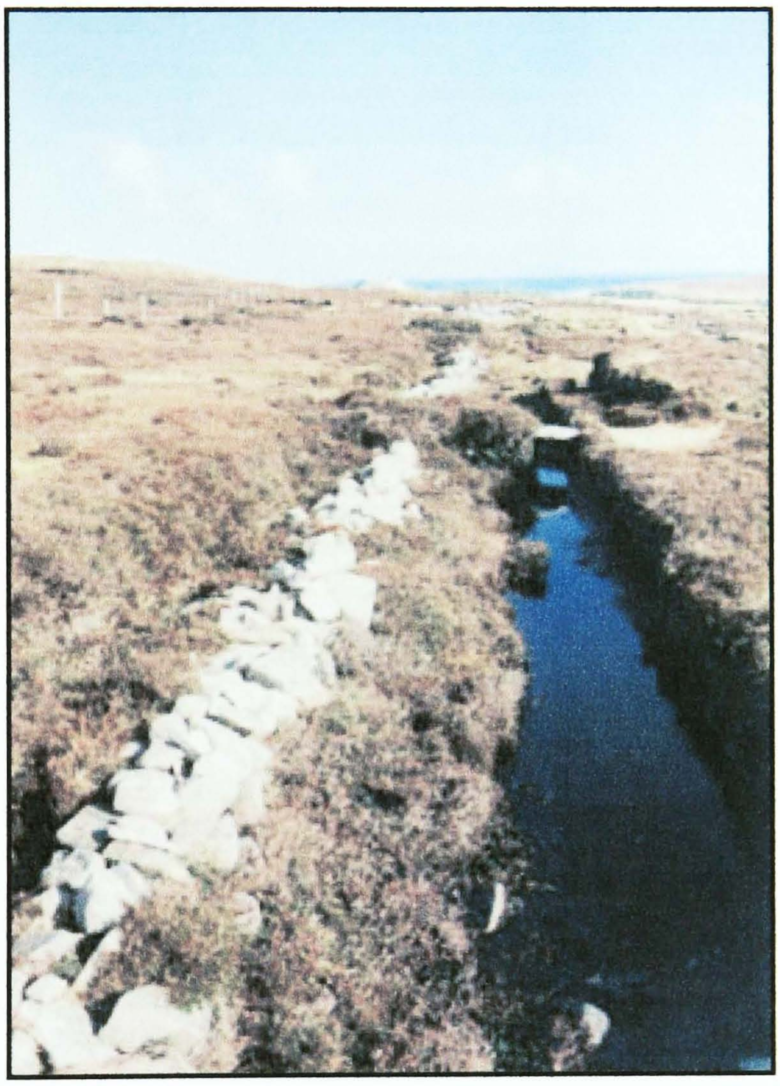
Later prehistoric environmental marginality in western Ireland: multi-proxy investigations.

Lucy Verrill



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"Belderg"

'They just kept turning up
And were thought of as foreign'-
One-eyed and benign
They lie about his house,
Quernstones out of a bog.

To lift the lid of the peat
And find this pupil dreaming
Of neolithic wheat!
When he stripped off blanket bog
The soft-piles centuries

Fell open like a glib:
There were the first plough-marks,
The stone age fields, the tomb
Corbelled, turfed and chambered,
Floored with dry turf-coomb.

A landscape fossilized,
Its stone wall patterning
Repeated before our eyes
In the stone walls of Mayo
Before I turn to go

He talked about persistence,
A congruence of lives,
How, stubbed and cleared of stones,
His home accrued growth rings
Of iron, flint and bronze.

So I talked of Mossbawn,
A bogland name. 'But *moss*?'
He crossed my old home's music
With older strains of Norse.
I'd told how its foundation

Was mutable as sound
And how I could derive
A forked root from that ground
And make bawn an English fort,
A planter's walled-in mound

Or else find sanctuary
And think of it as Irish,
Persistent if outworn.
'But the Norse ring on your tree?'
I passed through the eye of the quern,

Grist to an ancient mill,
And in my mind's eye saw
A world-tree of balanced stones,
Querns piled like vertebrae,
The marrow crushed to grounds.

Seamus Heaney 1975

Certification of originality

This is to certify that this thesis has been composed by the author and that the work is the authors own. The work has not been submitted for any other degree or professional qualification.

Signed:

Lucy Verrill

Abstract

This thesis assesses the environmental marginality of a site at the Atlantic fringe of the British Isles, occupied at various points throughout prehistory. Palaeoclimatic proxy records from the North Atlantic show that climatic fluctuations have occurred in the mid- and late-Holocene, at amplitudes likely to be perceptible to human communities. Coincident environmental changes occurred to affect the development of landscapes via vegetation change and pedogenesis. The degree to which prehistoric agricultural economies were vulnerable to these external fluctuations is tested in this thesis.

The archaeological complex at Belderg Beg, Co. Mayo, Ireland, consists of a sub-peat stone-built field system of the sixth millennium cal. BP, a Middle Bronze Age roundhouse and adjacent areas of ridge-and-furrow cultivation. By the time of Bronze Age occupation, blanket bog already covered a significant proportion of the landscape. A combination of on- and off-site investigation strategies included AMS ^{14}C dated sediment stratigraphic analyses, palynology, soil micromorphology, peat humification and geochemistry. Results show that peat initiation occurred during Neolithic agricultural occupation, at c. 5465 cal. BP. The initial woodland assemblage was a combination of typical upland and lowland tree types, and had been subjected to disturbance. The economy was primarily pastoral but with an arable component. Abandonment occurred at c. 5375 cal. BP, and woodland regenerated rapidly. Neolithic abandonment occurred several centuries prior to the spread of blanket peat over the fields. Peat spread upslope at an average rate of c. 0.385m/cal. yr. The Bronze Age archaeological remains probably represent several discrete phases of occupation, associated with intensive arable agriculture which included soil amendment strategies, and ceasing in the mid-second millennium cal. BP. Geochemical analysis failed to support previous hypotheses that a vein of copper ore 2km distant was exploited during the Bronze Age. The results from this investigation add to a growing corpus from western Ireland suggesting a clear pattern of Early and Middle Neolithic sedentism and mixed agriculture, followed by abandonment until reoccupation in the Early Bronze Age.

As the Neolithic field system at Belderg Beg was apparently smaller and less regular than that at nearby Céide Fields, it may represent an economically marginal site in terms of core-periphery relationships. Abandonment occurred during a phase of relative climatic aridity and it is concluded that soil deterioration and erosion was probably a factor in the demise of agriculture. The Bronze Age occupation is more difficult to characterise in terms of economy, but the gradual contraction of intensive agriculture suggests that again, soil quality rather than direct climatic shifts was the limiting factor and that the location eventually became environmentally marginal for an economy including significant cereal production.

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Chapter 1

Questioning marginality in prehistory

1.1 Aims and approach

1.1.1 Aims

This thesis addresses the issues of environmental marginality and climatic vulnerability in the context of a case study. A study area in western Ireland was sought due to its location in proximity to the Atlantic seaboard of Europe, where climatic changes resulting from Northern Atlantic coupled ocean-atmosphere system variations may have been recorded in terrestrial proxy indicators. A field system at Belderg Beg, North Mayo, was selected because it was known to have been occupied in the Neolithic and the Bronze Age and was at some time buried by blanket peat. This investigation aims to reconstruct, through the use of multiple palaeoenvironmental techniques, the climatic, pedological and environmental conditions throughout the period of occupation and abandonment, and how landscape evolution has impacted on the nature and effects of human activities.

1.1.2 Quotation of radiocarbon dates

All radiocarbon assays quoted from the literature have been calibrated with OxCal v3.9 (Bronk Ramsey 2003) using atmospheric data from Stuiver *et al* (1998). In the text dates are quoted in calibrated years BP (midpoint of 2σ range) with 2σ error. Full details of original assays and sources are presented in Appendix A.

Radiocarbon assays are presented in the published literature in different forms. Most archaeological literature, and an increasing proportion of the palaeoenvironmental literature, quotes calibrated ages in text, due to the calendrical significance and the extended and refined calibration curves available. Presentation methods may differ. The Irish Radiocarbon Date Database website (Milliken 2002) quoted raw (uncalibrated) dates only, whilst the web-based database of Scottish archaeological radiocarbon dates (Historic Scotland Radiocarbon Dating Search) quotes the calibrated range at 2σ error in addition to the raw measurement. Whilst uncalibrated ages are commonly presented with a 1σ error range, the 2σ range is most commonly used for calendar ages.

The problems associated with many archaeological (and indeed palaeoecological) radiocarbon assays must be addressed. It is vital to state at the outset of this thesis that not all published assays are uncritically accepted as a true estimate of the age of the event they are assumed to represent. As this investigation is concerned with human settlement over time, a synthesis of the archaeological background to the area in question is required. Many of the sites referred to were excavated before the era of AMS radiocarbon dating, and materials selected to date such sites were necessarily composed of mixed bulk charcoal samples. Due to the potential old wood effect and the possibility of a bulk sample containing a mixture of contemporary and residual material, Ashmore (1999) has counselled against the acceptance of bulk charcoal radiocarbon dates, instead proposing that single entity samples only should be used for archaeological dating purposes. There are related and additional complicating problems associated with the dating of organic samples, and these are discussed further in Section 4.4.7.2 in the context of methodological aspects of the present study.

Ashmore (2002, 784; 2004, 125) has also argued that radiocarbon assays measured many years ago should be rejected or used cautiously. Elsewhere, on the basis of the findings from the International Study Group (1982) the early- to mid-1980s have been suggested as a cut-off point, with errors of assays measured before these years being larger in fact than those quoted by a factor of between 1.8 and 4 (Ashmore *et al* 2000, 45-46).

It is therefore proposed that in discussion of sites dated by bulk charcoal samples, and/or by dates measured before 1982, caution should be taken in acceptance of the dates presented. Attempts have been made to avoid basing theories or arguments upon such sites.

1.1.3 Structure of the thesis

The opening chapter introduces the issue of marginality in archaeology and palaeoecology. The various types of marginality are discussed. Chapter Two is a literature review which assesses research and current thinking regarding the archaeology and palaeoenvironment of Ireland, focusing on the west of the island. The nearby sub-peat field system at Céide Fields is also described in detail as results from investigations there are extremely pertinent to this research. From previous work at Belderg, the sites are known to have been occupied at roughly the same time, and blanket bog spread also occurred at similar times. Other archaeological sites and published pollen profiles in the North Mayo area are discussed.

North Atlantic Holocene palaeoclimatic records are evaluated in order to locate the points in time at which environmental stress may have been an issue for societies of the British Atlantic fringe. Chapter Three provides an introduction to the study area. The site is described in its local environmental and archaeological contexts, and a summary of previous and ongoing research is provided. Chapter Four outlines the research questions which this investigation seeks to address, the research strategies employed and the methodologies involved. Both off-site and on-site studies are employed, the former consisting of sediment stratigraphic analysis of the valley-side and multi-proxy analysis of a long peat core taken from a basin outwith the area of archaeological remains. This long core provides the palaeoenvironmental history of the site. More specific on-site methods, pollen and soil micromorphological analysis of formerly cultivated Old Land Surfaces, are employed to specifically address the nature of prehistoric agriculture. Chapter Five presents the results and interpretations of the off-site palaeoenvironmental investigations. Chapter Six presents the results and interpretations of the on-site investigations. Chapter Seven integrates the results and interpretations and develops a wider assessment, forming a multi-tiered appreciation of the site with respect to its local, regional and wider significance and presents opportunities for further research. Chapter Eight summarises the conclusions of this study.

1.2 Introduction to Chapter One

This thesis is concerned with the environmental marginality of prehistoric societies. This is in most cases considered as climatically driven (Young & Simmonds 1999), however other environmental stresses such as soil degradation and resource depletion exist in this category. Holocene climate change is discussed and the different proxies are assessed to pinpoint the most clearly indicated climatic shifts. There is not complete agreement between the different forms of proxy climate evidence. However, as analytical and dating techniques become more sophisticated, some trends are consistently apparent in different records.

The effects of environmental marginality are not limited to humans. Chapter Two explores the 6000 cal. BP *Ulmus* decline and the 4500 cal. BP *Pinus* decline, pan-regional phenomena which are arguably the consequence of crossing environmental thresholds pertaining to one particular species. These examples, and other instances of recognised environmental marginalisation of non-human biota, may be significant to the study of human societies in that they help to pinpoint periods of climatic or ecological change and can aid quantification of flux in particular climatic parameters.

1.3 Marginality in archaeology

1.3.1 Defining marginality

The perception of marginality in prehistory largely rests upon the identification of core/periphery patterns. So-called marginal societies are those deemed to be 'living on the edge' (Coles & Mills 1998, vii). Marginality may perhaps be described as the vulnerability of a society or community to change. The degree of favourability for occupation or use of the landscape is almost always invoked, hence the term 'marginal environment'. There are currently three (overlapping) types of marginality recognised in archaeology, corresponding to the categories defined by Blaikie & Brookfield (1987): environmental, economic and social/political marginality.

1.3.1.1 Environmental marginality

Common causal factors of environmental marginality are climate, soils, biota and disease. These factors may be linked and work in tandem, compounding the stresses involved. Human activity can compound or cause marginalisation, for instance land management practices could cause soil deterioration.

Assessment of the environment as a limiting factor to the success of a society, measured in terms of maintenance of a viable population, rests upon ecological principles of adaptation, tolerance and critical environmental variables - whatever is in shortest supply (Coles & Mills 1998, viii; Dean 2000, 96). Marginality may advance through two routes; firstly, due to the short supply of a critical environmental variable (e.g. water, good quality soils), or alternatively, due to a change in a critical environmental threshold (most often climate). Adaptations and adoptions of new technologies may overcome environmental constraints. However if a change occurs which puts a particular variable beyond the operating threshold applicable to the society, failure or collapse is inevitable (Barber 1998, 152; Coles & Mills 1998, viii; Dean 2000, 96). The classic early studies of environmental marginality were those by Parry (1975; 1978; 1985) and these are discussed below (Section 1.3.2.2).

In prehistoric archaeology, environmental marginality is usually invoked in relation to societies perceived as having practised largely subsistence agriculture. A society becoming increasingly prone to diminishing returns under ecological stress will be less buffered against the effects of short term environmental changes and thence more susceptible to agricultural failure, with the eventual result being famine and population collapse, settlement abandonment or economic reorganisation (see Parry 1978; Baillie 1998; Grattan 1998). Assumptions of isolation and reliance on subsistence agriculture have arguably been over-estimated (see e.g. Tipping 1998). The existence of trading networks to redistribute commodities such as cereal products would mean that the suitability of land for arable agriculture was not a prime consideration in settlement location, and that a population inhabiting an area considered climatically or pedologically marginal for arable agriculture was able to prosper.

1.3.1.2 Economic marginality

The economic structure of a society may be marginal if there is a disparity between a community's food requirements and the relative economic potential of their environment to provide sufficient yields (Young & Simmonds 1999, 200). Marginal economies are typified by low rates of return for effort invested, or high inherent risk of potential crop failure, and are generally associated with systems in which labour inputs are high (ibid.). Put simply, it may be described as a periphery that cannot compete or trade with a core.

1.3.1.3 Social/political marginality

Political, social or cultural isolation of communities within the wider social or political system may stem from geographic remoteness, social status, or religious, linguistic or ethnic factors (see Coles & Mills 1998, ix). For instance, the Western Isles of Scotland were commonly considered 'marginal' during the 18th and 19th centuries AD (ibid.). However during the late Norse period (pre-14th century AD when the Isles were incorporated into the Kingdom of Scotland), the area formed the core of the Norse Kingdom of the Isles, suggesting that geographic location only influenced the move towards marginality once the larger polity developed, leading to the marginalisation of the areas on the periphery of the enlarged political unity (Armit 1998).

1.3.2 Archaeological recognition of marginality

1.3.2.1 General considerations

Recognising the marginal status of a prehistoric society can be difficult, because evidence varies depending upon the form of marginality. Identification of environmental or climatic change coincident with a change of some sort in the archaeological record is usually the starting point, as the change is seen as indicative of adaptive response to external pressure. The most commonly asserted examples probably relate to settlement expansion/contraction in relation to climate change and involve an element of arable agricultural decline (i.e. environmental marginality). The development of thought associated with this phenomenon is discussed below in Section 1.3.2.2. Additionally, or perhaps alternatively, the adoption of new subsistence methods or new technologies may well signal an adaptive response to environmental or economic marginality. Examples could be the introduction or evolution of manuring techniques (e.g. Simpson & Bryant 1998; Simpson *et al* 1998a; Simpson *et al* 1998b). Economic or social innovations to combat increasing marginality are closely related (see Coles & Mills 1998, xi). Increasing development of specialisation and trading (usually of cereal crops to communities in locations unfavourable for arable agriculture, but also of luxury goods) has been postulated (e.g. Tipping & McCullagh 1998). The emergence of social hierarchies has in part been linked to the development of redistribution networks, and repeated short-term episodes of marginality may have been a trigger in this (Halstead & O'Shea 1982) although it is equally possible that trade routes and networks were constructed for the purpose of distributing prestige or exotic items. Of course the two models are not mutually incompatible.

1.3.2.2 Marginality and agricultural settlement

The research of Martin Parry in the 1970s and early 1980s was instrumental in defining environmental marginality, and has explicitly influenced all subsequent research into the phenomenon of marginality in the British Isles. Essentially, Parry attempted to trace the effects of the Little Ice Age (LIA; c. 600-200 cal. BP) on agricultural settlement. Whilst Parry's original work was concerned with early modern agriculture in southern Scotland, its value as a case study ensured that the hypotheses contained therein have been discussed and/or tested in relation to other periods and regions.

The basis of Parry's (1975, 1978) original hypothesis was that cereal harvest yields and the probability of harvest failures are to a large degree influenced by climatic conditions, i.e. weather. By concluding that summer temperature is the most important influence on crop yield and therefore success/failure of a harvest, utilising the accumulated temperature (day-degree) measure of summer warmth he was able to calculate theoretical altitudinal isopleths of accumulated temperature, and thereby construct rational limits to cereal cultivation. By reference to instrumental records of temperature (Lamb 1977; Manley 1953) and documented records of harvest yields, crop prices, harvest failure and farm abandonment, he was able to construct a link between runs of years of poor yields or crop failures, and retreat from the agricultural margin, i.e. progressive abandonment of agricultural land at the upper altitudinal limit of arable cultivation during times of climatic deterioration.

Parry (1978, 62-65) recognised the increasing knowledge of Holocene climatic fluctuations - largely the work of H.H. Lamb; see Lamb *et al* (1966) - and postulated that from the fifth and fourth millennia BP there was a northern European trend towards cooler and drier conditions, possibly occurring in rapid shifts between phases of relative stability. This was followed in the first millennium BP with a cyclonic north Atlantic circulation pattern bringing a maritime climate of mild winters and cool damp summers to the British Isles and northern Europe. This phenomenon has been linked here and elsewhere to the recurrence of surfaces of renewed or accelerated mire growth in north west Europe (Parry 1978, 65). Parry (ibid., 119) also commented upon the potential significance of (principally Bronze Age) sub-peat archaeological sites in Ireland and Scotland as indicators of agricultural retreat from less favourable land during periods of climatic stress.

The main criticisms of Parry's theories are twofold. The first centres upon the processual view of human societies; that they ignore the buffering capability of exchange networks and the social and political factors that existed at any time (e.g. Tipping 1998; Young & Simmonds 1999, 199-200). The second is the focus on cereal agriculture to the near-exclusion of any other economic strategy (Young & Simmonds 1995, 11; 1999, 199) and a disregard for the actual farm organisation with respect to altitude during the time period concerned (Tipping 1998, 8). A further criticism is that Parry's evidence was wholly documentary, and based of absences of evidence. Direct evidence from radiocarbon-dated palynological investigations in a neighbouring area, the Cheviot Hills, recorded persistent cereal cultivation throughout the LIA (Tipping 1998).

Alternative theories regarding human action in the face of environmental or other marginality have been proposed that more or less oppose the 'agricultural retreat' hypothesis. These centre upon adaptation principles. Archaeological detection of settlement expansion and contraction has been suggested for the Strath of Kildonan, Scotland (Cowley 1998). Whether this is related to extensification of agricultural land as a response to ecological stress or climatic deterioration is unknown due to the poor chronological control on upland hut circle sites, and the problems associated with correlation of palaeoenvironmental records taken at some distance from archaeological sites (Cowley 1998, 170-171; Coles & Mills 1998, x). Edwards & Whittington (1998) suggested that 'regeneration' phases recognised in palynological profiles may reflect the marginalisation of land for agriculture – whatever the causal factors behind this shift. They argued that partial regeneration, especially in conjunction with increasing representation of acid grassland and heath taxa, may signal less intensive utilisation of land, conceivably due to marginalisation (ibid., 63).

1.3.2.3 Problems with the archaeological recognition of marginality

The most problematic aspect of the archaeological study of responses to marginality is proving cause and effect. This is compounded by the often imprecise dating of archaeological sites and certain palaeoecological records. In the case of settlement archaeology, a marked regional trend can support the case for settlement shift, but as described above and below, precisely dating each individual site can be difficult, and the identification of a climatic shift from peat stratigraphies can be problematic due to dating precision and the recognition of a definitive palaeoclimatic indicator (i.e. avoiding the problem of equifinality).

The wide age-ranges commonly provided by calibration of radiocarbon assays have been highlighted as often inadequate for correlation with historical events (Dumayne *et al* 1995). The related problems of sucking-in of events known to have occurred within a particular date-range into a radiocarbon chronology with a wide age-range, and of wide age-ranges smearing events across extended time periods, have been described by Baillie (1991) with respect to the insertion of calendrical tree-ring dates into radiocarbon-based chronologies. By extension, these problems are compounded when correlating events from the prehistoric archaeological record (which at best relies on radiocarbon dating of single events within a site's history) with an independent palaeoenvironmental chronology.

The need to consider more than just one part of the economic sphere of a prehistoric community is vital. Bearing in mind the criticism of Parry's study of the Lammermuir Hills in the LIA, a considered judgement of the relevant economic and agricultural systems in place (including buffering mechanisms such as trade) must be made, to avoid simple value judgements equating the economic success of a community with the sustainability of a cereal crop.

Chapter 2

Background literature review

2.1 Introduction to Chapter 2

Discussion of Irish archaeology and economy commences at the Mesolithic-Neolithic transition, as this period is important in setting the scene for a thorough understanding of the Neolithic, in social, economic, cultural and settlement terms. The apparently rapid and marked changes in economy between the two archaeological phases coincide with climatic and environmental changes, and causal links have been suggested.

2.2 The prehistoric archaeology of Ireland – settlement and economy

2.2.1 The Mesolithic-Neolithic transition

2.2.1.1 The transition in Ireland: continuity and contemporaneity?

Departing from the traditional view that Irish Mesolithic and Neolithic societies were dissimilar and separate from one another (e.g. Woodman 1976), discoveries in the 1990s proposed links between Later Mesolithic and Neolithic societies. Overlapping site distributions and greater continuity between lithic industries were postulated (Green & Zvelebil 1990, 83-84; Peterson 1990, 94-98 Woodman & Andersen 1990, 378). Contemporaneity between Later Mesolithic artefacts and animal domesticates was implied by occasional discoveries of domesticated animal bones in Mesolithic contexts (e.g. Woodman 1976), inviting suggestions of an 'availability phase' (Green & Zvelebil 1990, 85; cf. Zvelebil & Rowley-Conwy 1984; 1986). The Quaternary Fauna project (QFP) of the mid-1990s resulted in the undermining of many of these assumptions. AMS dating of mammalian bones from the late Pleistocene and Early Holocene was employed in an attempt to elucidate the chronology of a range of species in Ireland (Woodman *et al* 1997). Bones identified as domesticate (usually cattle) from several sites, which had been dated by context, were established as being in fact intrusive, for instance at Dalkey Island, Co. Dublin (McAuley & Watts 1961; Liversage 1968; Woodman 1976) and Moynaugh Lough (Bradley 1991). Details are presented in Appendix A. An early date for a *Bos taurus* (domesticated cattle) bone at Sutton, Co. Dublin, in a Later Mesolithic shell midden, may either be a brown bear or possibly a red deer bone, or that it represents a chance incursion of an aurochs (*Bos primigenius*) from Wales (Woodman *et al* 1997, 155).

Ferriter's Cove, Co. Kerry, provided a further incidence of cattle bones within a platform of mostly Later Mesolithic occupation sites (Woodman & O'Brien, 1993). These were originally assumed to be intrusive, but AMS dating proved the bones were roughly contemporary with the human remains and to ^{14}C-assayed charcoal samples from the 1992 excavations (see Appendix A; Woodman *et al* 1997, 139). The δ^{13}C value of the cattle bone indicates the animal consumed a partially marine diet. The recent assay of a further cattle bone from Ferriter's Cove to c. 6620 cal. BP (not fully published; see Woodman 2000, 259) has indicated significantly earlier knowledge of domestication than was previously assumed, even considering the pre-existing cattle bone dates from that site.

The beginnings of cereal cultivation are also problematic. As the principal definitive evidence of cereal cultivation – archaeobotanical assemblages – were rare and limited until the 1990s, the *Ulmus* decline was traditionally taken as the palynological indication of the start of the Neolithic (e.g. Herity & Eogan 1977). However, some potential cereal-type grains were recorded in pre-*Ulmus* decline levels in a small number of palynological investigations in the British Isles (e.g. Edwards & Hirons 1984), including between 2 and 11 instances in Ireland (Groenman van Waateringe 1983). A very early pioneer Neolithic, or 'substitution' phase (cf. Zvelebil & Rowley-Conwy 1984; 1986) before the earliest dated archaeological contexts was proposed (see Woodman 2000, 224). When the problems associated with distinguishing cereal from wild grass pollen (Section 4.4.2.3) were considered, most of these were discounted as cereal grains (O'Connell 1987, 218). It has become accepted that palynological inference of Neolithic agricultural activity is strongest when the pollen assemblage contains increased representation of agricultural indicator taxa (notably *Plantago lanceolata*) as well as the presence of cereal-type grains. Most western Irish profiles record an interval of between one and three centuries between the *Ulmus* decline and the palynologically recognisable onset of Neolithic agriculture (O'Connell & Molloy 2001).

2.2.1.2 Climatic change at the transition to agriculture

With the inferred increasingly continental climate of c. 6100 – 5000 cal. BP in northwest Europe, came changes in weather patterns that may have affected the lives of human societies. The main phase of the mid-Holocene IRD event (Section 2.3.4.1) was between c. 6000 and c. 5600 cal. BP (Bond *et al* 2001; see Tipping & Tisdall 2004, 74-75). Terrestrial records from northern Britain and Ireland, being of generally high resolution, show a complex sequence of frequent change from c. 6300 cal. BP until c. 6000 cal. BP; where wetness from c. 6300-6100 was abruptly terminated and followed by a very dry period at around 6100 cal. BP, which continued until c. 5200 cal. BP (Barber *et al* 1994; Tipping 1995; Anderson *et al* 1998; Hughes *et al* 2000; Barber *et al* 2003; Tipping & Tisdall 2004). By decoupling the often-assumed correlative relationship between temperature and precipitation, there is no necessity for an increase in warmth to have accompanied this brief dry spell (Tipping & Tisdall 2004, 75; *contra* Bonsall *et al* 2002b).

Agriculture was established along the channel coast of France and on the North European Plain between c. 7400 and c. 6800 cal. BP, but was not adopted widely in the Atlantic fringe, (Britain, Ireland, Denmark and Southern Sweden) until c. 6100 to 5700 cal. BP; a delay primarily accounted for thus far by emphasising the success of indigenous hunter-fisher-gatherers (e.g. Zvelebil & Rowley-Conwy 1986). Recent reinterpretations of the delayed transition in Atlantic Europe have focussed on the concurrent environmental changes (Bonsall *et al* 2002a; 2002b; Tipping & Tisdall 2004).

2.2.1.3 The *Ulmus* decline

Early suggestions as to the cause of the mid-Holocene *Ulmus* decline centred upon climatic change as the dominant factor, with climatic deterioration causing a contraction of the range limits of the already marginalised genus (Iversen 1941; 1960; Faegri 1944; Nilsson 1948; 1961; Frenzel 1966; Smith 1981). Paradigm shifts have occurred, bringing alternative theories to the fore: principally those of human activity (Troels-Smith 1960) and species-specific disease (Pilcher *et al* 1971; Girling & Greig 1985; Molloy & O'Connell 1987). By the late 1990s the hypothesis of disease, most likely aided by anthropogenic woodland clearance, was the most favoured. The spatial patterns displayed by the *Ulmus* decline across Europe suggest that the decline was a synchronous wave, generally coincidental with the adoption of agriculture, occurring in any particular region as the transition from a hunter-gatherer Mesolithic to a Neolithic agricultural economy occurred (Parker *et al* 2002, 26).

Reanalysis of the *Ulmus* decline has been advantaged by increasingly precise dating and larger datasets, and whilst disease as a key cause remains undisputed, climatic change is re-emerging as a contributory factor (Parker *et al* 2002). The proposed mechanisms were twofold. Firstly, the direct effect of colder winters might have damaged an environmentally marginalised biota. Colder winters, the increasing likelihood of spring frosts, and the effects of drier soils – *Ulmus* is vulnerable to drought (Rackham 1980) – have all been postulated as causal factors (Iversen 1941; 1944; Godwin 1975, 247; Tipping & Milburn 2000, 191).

Furthermore, climate could indirectly affect the spread of *Ulmus* disease if climate change partially determined the timing of the adoption of agriculture in certain locations (see below), and this transition facilitated the disease spread (Parker *et al* 2002, 27).

2.2.1.4 Subsistence economies of Atlantic Britain

Bone stable isotope analysis, hitherto relatively new to archaeology, is furthering knowledge in the field of palaeodietary research. This technique has been applied to skeletal remains from the Late Mesolithic and Early Neolithic of various locations within the north European Atlantic fringe, and studies so far have indicated that an abrupt shift in diet composition occurred at the transition to the Neolithic. Taken in consideration of the above evidence for climatic and environmental change, this has important implications for current theories as to the nature and mechanisms of the Neolithisation of Britain and Ireland.

The relative values of stable isotopes of carbon ($\delta^{13}C$) and nitrogen ($\delta^{15}N$) in bone indicate the long-term (5-10 year) protein component of the individual's diet. The $\delta^{13}C$ ratio reflects the balance of terrestrial versus marine dietary components, with more negative values representing increasing terrestrial-based resources. For nitrogen isotopic ratios, higher $\delta^{15}N$ values represent increasing trophic levels, indicating whether an individual had a mainly herbivorous, omnivorous or carnivorous diet (Schulting 1998).

Stable isotope data from northwest European archaeological human and faunal bone samples have been collated to reconstruct how dietary shifts characterising the Mesolithic-Neolithic boundary varied temporally and spatially. Samples from Scandinavia, western Scotland and Brittany (Schulting 1998) have comprised the main corpus of data, with some examples existing from Wales (Schulting & Richards 2002b) and England (Richards & Hedges 1999; Schulting 2000). Most studies have focused on $\delta^{13}C$ with additional information sometimes supplied by sulphur isotopes, which reflect the food source location, rather than the diet (Richards 2004, 87). These datasets display a distinct, rapid dietary change between the Late Mesolithic (characterised by marine-based economies) and Early Neolithic (characterised by terrestrial economies) individuals, regardless of inland or coastal location (see Richards 2004 for summary). In Britain this disjuncture occurred at c. 5950 cal. BP, at the point when Neolithic material culture began to appear (Richards 2004, 87). The $\delta^{15}N$ data are sparser (Richards 2000; Schulting & Richards 2002a; 2002b) but it appears that no further generalisation of a British Neolithic diet can be made (Richards 2004, 88).

Mesolithic human bones have been found at three sites in Ireland (see Appendix A): Ferriter's Cove, Co. Kerry (Woodman & O'Brien 1993; Woodman *et al* 1999), Rockmarshall shell midden, Co. Louth (Hedges *et al* 1997), and Stoney Island, Co. Galway (Hedges *et al* 1993). At Ferriter's Cove, $\delta^{13}C$ values indicate a marine-based diet. Although the $\delta^{13}C$ value for the Rockmarshall bone is still higher than those of most prehistoric Irish human bones sampled to date (Woodman *et al* 1997, 143), including the Stoney Island bog bodies, it suggests that the Rockmarshall inhabitants did not exclusively rely on marine resources. The small number of Mesolithic human bones from the British Isles makes generalisation difficult, but artefactual evidence undoubtedly supports theories of marine-based diets (Richards 2004, 87).

This apparent rapid shift from marine to terrestrial economies, which occurred even in coastally-based societies, coincident with the arrival of Neolithic pottery, has re-opened the discussion of a Neolithic package, which for many years had been out of favour in preference to a more gradual model of adoption. Identification of the reasons behind such a rapid, complete shift has largely focussed on the coincident environmental changes, although cultural change with sweeping reforms has also been considered (Richards 2003).

Arguments for an environmental trigger to the transition to farming along the northwest European Atlantic fringe largely rest upon the shift to a more continental climate, specifically the lowered precipitation levels which were apparently at their most extreme c. 6100 cal. BP (see Section 1.4.3.2; Bonsall *et al* 2002a; 2002b; Tipping & Tisdall 2004). By this model, drier soils have been argued to be the critical factor in the facilitation of the adoption of agriculture (Bonsall *et al* 2002b). This view implicitly assumes a crucial role for cereals in early Neolithic economies, indeed by extrapolation in the Neolithic package (see Section 2.2.2.1). The concept of a predominantly pastoral economy persists, with arable agriculture often considered to have been integral, yet lesser in terms of dietary contribution (e.g. Monk 2000; O'Connell & Molloy 2001). The significance of drier soils as the major variable allowing the adoption of cereal agriculture is enhanced by the above discussion of soil dryness as a contributory factor in the *Ulmus* decline.

In short, this somewhat environmentally deterministic model accounting for the near-millennial delay in adoption of agriculture along the northwest European Atlantic fringe describes an availability phase during which agriculture may have been known about, or even attempted to some degree; however until the c. 6100 cal. BP climatic shift towards increasingly continental conditions, further expansion was not feasible (Bonsall *et al* 2002b). The adoption of agriculture therefore commenced when environmental conditions were appropriate. The remaining question as to why the marine dietary component was apparently abandoned so rapidly, rather than a mixed diet prevailing, or coexistence of neighbouring communities with different economies, remains (Bonsall *et al* 2002b). The chief argument for wholesale adoption is that cereals provide an important storable food source for humans and animals and that straw is important for winter bedding for cattle (ibid., 6). The model of Rowley-Conwy (1984) which attributed the collapse of Mesolithic maritime systems in the Baltic to climate change *via* a reduction in marine foods caused by salinity changes, never gained wide popularity, and an environmentally deterministic model for the near-total abandonment of marine resources on a regional scale is unlikely to win support (Bonsall *et al* 2002b, 11; Schulting 1998, 214). Nevertheless, some element of declining marine productivity in the mid-Holocene has been postulated in connection with falling sea-levels, thereby contributing to the necessary total switch of resource-base (Schulting 1998, 214).

2.2.2 The Neolithic

2.2.2.1 The Irish Neolithic

Chronology

In this thesis, terminology conforms to generally accepted schemes (see e.g. Waddell 1998; Cooney & Grogan 1999) and the Neolithic chronology is subdivided into Early (c. 6000 – c. 5500 cal. BP), Middle (c. 5500 – 4800 cal. BP), and Late (c. 4800 – 4300) cal. BP) horizons.

Settlement

Theories have recently emerged regarding the nature of Neolithic settlement of Britain and Ireland which tend to characterise the period by transitory seasonal mobility (e.g. Thomas 1996; 1999; Whittle 1996; Bradley 1997, Edmonds 1999; Pollard 1999). This has partly resulted from the paucity of Neolithic domestic sites in southern mainland Britain in comparison to continental Europe. The large number of ceremonial monuments dating to the Neolithic is taken as evidence of migratory populations staking claims to the land, and utilising these constructions for seasonal congregational purposes (Thomas 1999, 23-29; Cooney 2000, 32-34). In the Scottish islands, some structures interpreted as having a domestic function have been dated to the Neolithic and occupation of some multi-period structures or sites appears to have included at least some Neolithic activity, such as the houses with associated fields at Scord of Brouster, Shetland (Whittle *et al* 1986; *contra* Whittle 1999), and the Outer Hebridean islet settlements Eilan Domhnuill and Eilan an Tighe, North Uist, and Northton, Harris (Armit 1996). These have been often considered as atypical;

adaptations to particular environmental settings (e.g. Thomas 1996; Pollard 1999). Primarily non-domestic functions have been postulated (Thomas 1996, 9-10), with comparisons drawn to structures such as the long timber-built, probably roofed structures at Balbridie (Fairweather & Ralston 1993) and Claish (Barclay *et al* 2002), both in Scotland, which are generally considered too large to represent domestic dwellings (ibid.).

A rapidly increasing number of house structures dating to the Neolithic have been excavated in Ireland, largely precipitated by developer-funded archaeology (Armit *et al* 2003, 146), with around 100 excavated at the time of writing (Grogan 2004, 103-105). Added to these as evidence of permanent settlement are fossilised agricultural landscapes such as the field systems buried beneath blanket peat at Céide Fields and elsewhere in North Mayo (Section 2.2.2.2). Sub-peat and other field boundaries dating to the Late Neolithic and the Bronze Age have also been found on Valencia Island, County Kerry (Mitchell 1989) and at Roughan Hill on the Burren in County Clare (Jones 1998). This evidence has arguably been overlooked in its European context by the prevalence of models stressing the prominence of mobility in Neolithic societies, which have been broadly based on evidence from southern Britain (see Cooney 1997; 2000; 2003). This interpretation and its tacit argument that the southern British Neolithic settlement model should not uncritically be applied elsewhere, support theories of a more regionalised British and Irish Neolithic than has hitherto been accepted (Armit & Finlayson 1992; Barclay 2000). Figure 2.1 shows the distribution of Neolithic houses and settlement sites at the time of writing.

Assessing the evidence from house sites in Ireland in terms of Neolithic settlement patterns, social structures and economies, Grogan (2004, 103) and Armit *et al* (2003, 147) have commented that the recent focus on house structures and the limited areas excavated in developer-funded archaeology have added to understanding of the period yet masked the importance of landscape- and regional-scale research and the frequency and extent of occupation evidence on sites with no identified structural evidence. Contextual frameworks may be provided by general surveys of the Neolithic, although greater attention at local and regional level is needed to fully appreciate these new data (Grogan 2004, 103).

Taken uncritically, the evidence from the known Neolithic house sites in Ireland can be seen to support some generalisations. At first, in his appraisal of Irish Neolithic houses, Grogan's (2004) chronological distinction between the Early Neolithic, characterised by rectangular timber houses (see Armit *et al* 2003, 148), and the Middle and Late Neolithic, when circular or oval houses dominate, appears sound. However dating evidence is omitted, for instance the

Belderg Beg roundhouse is listed as Neolithic, although a timber presumed to be structural was assayed to the Bronze Age (Appendix A; Section 3.2.2.1).

Using Grogan's (2004, 107) interpretation criteria, the majority (<90%) of the Early Neolithic rectangular houses were estimated to be capable of housing groups of between 5 and 12 people. One to three rooms are represented in each case, and sites occasionally contained structural indications of possible upper floors. Internal fires were frequent, but few formal hearths have been found. These dwellings were generally considered indicative of family unit groupings, with complex social relationships suggested by internal differentiations (ibid., 109). A further level of interpretation exists in the clustering of houses, although the spatial limitations of many excavations might infer caution in accepting uncritically the occurrences of isolated single farmsteads (ibid.). There is more substantial evidence for clustering (ibid.; Moore 2003), although contemporaneity on more than a broad level is difficult to prove due to the nature of radiocarbon dating and other evidence. Continuous or successive occupation is indicated in some sites by evidence of substantial rebuilding and/or structural repair (Grogan 2004, 109; Moore 2003). These factors, taken with the general similarity in ground plans exhibited by many agglomerated houses, can suggest long-term occupation by kin groups (Grogan 2004, 110). Nevertheless, permanent, year-round occupation is still difficult to establish. Environmental analysis at one site suggested short-lived occupation (Dunne 2003, 168). Furthermore, Grogan's automatic use of the term 'house' for a structure can also be criticised. Non-domestic functions for some structures in his critique have been proposed, such as feasting (Cross 2003) or mortuary locations (Dunne 2003). Without fully integrated investigations assessing such structures in their landscapes, the position of the Irish Early Neolithic on a spectrum between mobility and sedentism is still unclear, and of course unified settlement practice across the island did not necessarily occur.

Transition to circular ground plans in the Middle Neolithic is in evidence at both Lough Gur (Ó'Ríordáin 1954; Grogan & Eogan 1987) and Knowth (Eogan & Roche 1997; 1998) where both house types are present, distinguished stratigraphically. The majority of the known circular Middle/Late Neolithic houses are at three sites; Knowth, Newgrange and Townleyhall 2, suggesting that agglomeration continued to dominate over isolated settlement (Grogan 2004, 111-112). However, a pattern of longer occupation sequences by smaller groups has been proposed at some sites (Cooney & Grogan 1999), suggesting a gradual movement of the focus of domestic sites over subsequent generations, and a drift in settlement as houses were replaced metres or tens of metres away from the abandoned sites (Grogan 2004, 112). With imprecise site stratigraphies, inter-site sequences and site-specific radiocarbon chronologies, these theories remain difficult to confirm. That a change in architecture from rectangular to circular involved a decrease in internal area to an average of $25m^2$ has been taken to imply a reduction in inhabitants to generally five to seven (ibid.). Taken further, this consequence of a change in house shape may indicate more substantial developments in social organisation and the structure of residential groups, and perhaps a reduction in the range of activities which occurred in the house. Changing non-residential functions may reflect alterations in the perceived roles of domestic dwellings and perhaps a reduction in the status and social importance of the buildings themselves (ibid., 103 & 112). Perhaps dwelling places or buildings had lost their status or necessity as a claim to land in the Middle and Late Neolithic. This chronological disjuncture is also important in land-use and economic terms.

Economies

Following the numerous recent discoveries of settlement remains, the Irish Neolithic economy can now be considered independently, rather than extrapolated from (arguably already biased) southern mainland British excavations and assemblages (Legge 1989; Monk 2000; see also Robinson 2000). Some plant macrofossil assemblages contain high concentrations of cereal grains, e.g. Tankardstown, Co. Limerick (Gowen 1987; Monk 1988). The general evidence from these assemblages (see Appendix A for details of selected radiocarbon dated cereal remains) points to an Early Neolithic of c. 5700 – 5550 cal. BP characterised by a diverse mixed food base with a substantial cereal grain component (Monk 1993; 2000). The main cereal species was apparently emmer wheat (*Triticum dicoccum*), with barley (*Hordeum* sp.) less common. Einkorn (*Triticum monococcum*) was possibly represented at some sites (Gowen 1987; Simpson 1995; Monk 2000, 79). The principal gathered plants were hazelnuts (*Corylus avellana*) and wild/crab apple (*Malus sylvestris*) (Monk 1993, 45; 2000, 79).

A contraction in human activity in the Late Neolithic has been suggested on the basis of palaeobotanical evidence (e.g. the higher incidence of wild plants) from the British mainland as well as Ireland (Monk 2000, 82). Wild plants bearing edible fruit and nuts tend to be ecologically characteristic of secondary woodland, and their archaeological increase in the Late Neolithic may reflect the exploitation of re-wooded formerly cultivated areas (ibid.). Suggested causal factors of this change are population expansion, relocation, or environmental changes (ibid.), and the coincident changes in house and settlement characteristics may well be associated. In an overview of palynological evidence of Irish Neolithic agricultural dynamics, O'Connell & Molloy (2001) concluded that Neolithic agriculture was concentrated in the Early Neolithic in much of the west of Ireland, particularly North Mayo, and the Late Neolithic was characterised by less intensive agriculture and substantial woodland regeneration. Cereals were an integral, though minor, part of the Earlier Neolithic economy, and the lesser representation of cereal-type pollen in Late Neolithic levels is in agreement with the conclusions of Monk (2000; see above). Evidence is therefore increasingly suggesting the Middle Neolithic (c. 5500 - 4800 cal. BP) was a pivotal stage in the early prehistoric economy and settlement of much of Ireland, including the west.

Despite being a focus of ritual activity rather than domestic settlement, Newgrange, Co. Meath, has been one of the most informative sources of zooarchaeological evidence for the meat component of Irish Neolithic and Beaker diets. The lateral and vertical distribution of species was variable, but age-at-death patterns suggested a beef cattle economy rather than a significant dairying component (van Wijngaarden-Bakker 1986; McCormick 1987). Pig bones formed 35% of the assemblage but the MNI index indicated that they were nearly twice as numerous as cattle (van Wijngaarden-Bakker 1986; McCormick 1987). At Lough Gur, cattle bones comprised 95-99% of the assemblage (Ó'Ríordáin 1954), although this may be unreliable as smaller bones from other species may not have been retained by excavation methods of the time (Woodman 1985, 261).

2.2.2.2 The North Mayo evidence I: Céide Fields

Discovery and excavation

Following the discovery of pre-bog walls by peat-cutting and survey by M. Herity and S. Caulfield, survey and excavation in the Behy and Glenulra townlands revealed the widespread conjoined field systems now known as Céide Fields. From early in the investigations, it was noted that at least one court tomb was located within the areas enclosed by the walls (Caulfield 1978, 138) and more were later discovered, all constructed on mineral soil beneath the peat (Molloy & O'Connell 1995, 191-193). Probing demonstrated and defined the presence and dimensions of the stone walls (now buried by up to 4m of blanket peat) and, consequently, the areas they enclosed. The vast extent of Céide Fields, the relatively intensive investigations conducted therein, and the relative proximity of the site to Belderg Beg (7km) necessitate the detailed examination of this site. It is undoubtedly of vital importance in aiding the interpretation of the results from this investigation at Belderg Beg, particularly in regional terms.

Form and function

The regularity and unity of the field system patterning has been interpreted to indicate that the Céide Fields were constructed as a single operation, presumably by a sizable population (Caulfield 1978, 138; 1983, 197). Subsequent surveys established that two systems (in Behy and Glenulra townlands) were conjoined (see Figure 2.2). On present evidence there is no proof that the entirety of the system was in use contemporaneously, and the diachronous nature of blanket peat spread (see below) may account for some temporal differences in the fields; perhaps spread of peat forced abandonment of certain areas of the system, and extension of settlement into new areas. The two conjoined co-axial field systems appear to follow the lie of the land in their principal axes and cover over 1000ha. Walls run for up to 2km along their long axis and are spaced 150-200m apart, with the areas thus delimited being divided by offset cross-walls. Many of the walled fields contained stone-built oval or sub-rounded enclosures within them (see Figure 2.2).

Using calculations based on the size of the walls and individual fields, Caulfield (1983) concluded that the function of the field system was to organise land into individual family farms, with the primary agricultural system being one of grass-grazed beef production. The height of the walls (both in original condition as excavated and also when rebuilt from tumble) indicated that they were functional barriers capable of retaining cattle but not sheep (Caulfield 1983, 200). A dairying economy was considered unlikely due to the relatively small number of people who could be supported by this in such a large area (ibid.); however this can be criticised as a circular argument based on the presumption of a large population. By comparing the Neolithic cattle bones from Newgrange and Lough Gur with modern cattle, the Aberdeen Angus was selected as an analogue, and a stocking rate of one livestock unit per hectare proposed for the Céide Fields, calculated to maintain four or five families per square kilometre (Caulfield 1983, 203-205). A viable family farm was therefore estimated as occupying c. 25ha.

In the early excavations, archaeological evidence for cereal cultivation at Céide Fields was rather limited; a polished stone interpreted as the tip of an ard was recovered within the Glenulra enclosure (see Figure 2.2; S. Caulfield pers. comm.; see also Molloy & O'Connell 1995, 218). An unresolved question regarding a cattle economy concerns the availability of water. Only a few streams today run through the Céide Fields area, and at present no geo-prospecting techniques to identify sub-peat former watercourses have been employed. No artefactual evidence of troughs was discovered in the (relatively small-scale) excavations (S. Caulfield, pers. comm.).

Charcoal from the Glenulra enclosure assayed to c. 5300 cal. BP (Caulfield 1978, 141; see Appendix A) is questionable evidence of occupation within that date range due to the potential inherent age of the timber that produced it, and its standard error is too large for any practical purpose. Also recovered from the Glenulra enclosure were Neolithic pottery, scrapers, stone axes and a leaf-shaped arrowhead, which, with the above assay and three assays from a peat monolith by the Behy tomb (see Appendix A) were used to argue a Neolithic date for the whole Behy/Glenulra field system (Caulfield 1978, 141). A Neolithic date for agricultural activity was later verified palynologically by the investigations of Molloy & O'Connell (1995), although the same investigation discovered that occupation had occurred in the Bronze and Iron Ages also. Numerous assays from sub-peat pine stumps within the field system were also used to argue for a Neolithic date of peat initiation and therefore utilisation of the mineral soil (Caulfield *et al* 1998).

Palaeoenvironmental analyses

Palaeoenvironmental investigations were undertaken by Molloy & O'Connell (1995), based upon palynological analysis and radiocarbon dating of a core from a small deep peat basin within the Céide Fields, and of shorter monoliths from elsewhere within the fields (see Figure 2.2). The long pollen profile from the peat basin is actually a combination of two cores, with GLU IV being the main core analysed: spectra from GLU IIa completed the basal part of the profile (Molloy & O'Connell 1995, 201). Percentage pollen diagrams from GLU IV are reproduced in Figure 2.3. Only the relevant parts of the profile (post-*Ulmus* decline) are discussed here.

Mid-Holocene

An hiatus in the early to mid-Holocene period following the *Corylus* maximum (at 534cm depth) is suggested by the absence of *Alnus*, and supported by the radiocarbon assays (Molloy & O'Connell 1995, 199). The charcoal-rich nature of the peat at this depth and the high frequency of sand and silt inclusions in corresponding deposits in other cores suggests that severe firing of the peat surface occurred and fires in the wider catchment caused substantial erosion (ibid., 202). By extrapolation the *Ulmus* decline was dated to c. 5850 cal. BP (ibid., 198).

Neolithic land use

The first indications of (limited) anthropogenic clearance occurred after the *Ulmus* decline when a decline in arboreal pollen (AP; especially marked in *Pinus*) and increase in non-arboreal pollen (NAP) indicate opening of the canopy. Despite the reduction in local (mire-growing) *Pinus* being one considerable factor in the increased NAP representation, a typical Landnám sequence including *Plantago lanceolata*, indicates that open conditions replaced woodland more widely (Molloy & O'Connell 1995, 203). An increase in *Sphagnum* representation, indicating an increasingly wet local mire surface, was ascribed to increased runoff following deforestation (ibid.).

The pollen profiles suggest that the most intensive Neolithic activity occurred between 5660 – 5170 cal. BP (interpolated: Molloy & O'Connell 1995, 203). Maxima were reached in pastoral indicator curves: *Plantago lanceolata*, Poaceae and *Pteridium aquilinum*, with increases also in *Ranunculus*, *Rumex*, Lactuceae and *Trifolium repens* (ibid.). Only a single cereal pollen grain (probably attributable to *Triticum*-type) was recorded in the Neolithic levels of GLU IV, although four *Triticum*-type pollen grains were encountered in preliminary scanning of GLU IIa within the main Neolithic Landnám phase. Low representation of cereal pollen supported Caulfield's (1983) hypothesis that pastoral farming was the dominant mode of subsistence, although there was obviously a minor yet significant arable component, with the most likely crop being wheat (Molloy & O'Connell 1995, 202-218). Phases of cultivation may have been missed by non-contiguous sampling, and cultivation may have occurred undetected at some distance from the sampling site (ibid., 218). This latter point is particularly pertinent considering the location of the core sample within a small-diameter peat basin where cultivation in the near proximity would presumably have been unlikely.

Recognition of land abandonment from pollen profiles is notoriously problematical (Buckland & Edwards 1984). Rapid abandonment at c. 5170 cal. BP (interpolated: the LPAZ GLU IV-5/6 boundary) was suggested by the abrupt decline of NAP (Molloy & O'Connell 1995, 203). Scrub regeneration was indicated in LPAZ GLU IV-5c by increases in *Corylus* and *Alnus*, although these latter phenomena could have been a regional development, not necessarily indicative of local land abandonment (ibid., 219).

On the basis of trends in the curves for macrofossils, pollen and palynofacies, Molloy & O'Connell argued (1995, 203-204 & 219; O'Connell & Molloy 2001, 108) that the abandonment of the Neolithic farming phase occurred during a phase when the bog surface was relatively dry, indicating a shift towards relative climatic dryness. This contradicts suggestions that increased climatic wetness in an environment already somewhat marginal for agriculture was the primary causal factor in land abandonment. Further the available chronology of the basal peat overlying mineral soil in the short monoliths indicates an absence of evidence for general blanket peat growth prior to c. 4500 cal. BP (Molloy & O'Connell 1995, 219). Abandonment occurred significantly earlier, at c. 5170 cal. BP, evidently not in the context of widespread blanket peat initiation (ibid.).

2.2.2.3 The North Mayo evidence II: Rathlackan

Excavations at Rathlackan, approximately 11km west of Céide Fields, revealed a prehistoric landscape consisting of sub-peat stone built features (Byrne 1990; 1992; 1993). This megalithic landscape complex consists of seventeen enclosures (described as 'house sites' without implying a specific function) of various shapes and sizes, and eleven megalithic tombs, scattered throughout a sub-peat stone-walled field system in an area of four square miles (Byrne 1990; see Figure 2.4 for a plan of the archaeological complex). Excavation focussed on a 20m diameter D-shaped enclosure, abutting the court tomb M(vi) and enclosing house site H10 (see Figure 2.4). Excavations established that the enclosure was constructed after the tomb, but probably whilst the tomb was in use (Byrne 1990). Although there was a hearth within the house structure, the artefact assemblage consisted of only a few chert flakes. The paucity of artefacts, together with its small size, contributed to the interpretation of the house structure as fulfilling a ritual function associated with the tomb rather than a domestic dwelling (ibid.). Radiocarbon dates from the excavations are presented in Appendix A. Notwithstanding the uncertainty associated with unreliable charcoal dates (see section 1.1.2) the age can be placed within the brackets of the Middle and Late Neolithic, with secondary use evident in the Early Bronze Age. The radiocarbon evidence supports the age inferred from the artefact assemblage (Byrne 1993).

2.2.2.4 The significance of Neolithic field systems in north-west Europe

The earliest known fields in northwest Europe are those of the Atlantic fringe, such as Céide Fields and Belderg Beg, North Mayo (Caulfield 1978; 1983; Molloy & O'Connell 1995; Caulfield *et al* 1998; O'Connell & Molloy 2001). Scord of Brouster, Shetland (Whittle *et al* 1986; but *contra* Whittle 1999), and Machrie Moor, Isle of Arran (Barber 1998, 80-83). Less substantial clearance features of similar dates are known in Cornwall (Mercer 1978). That these are all sub-peat features raises the question of whether their distribution is in fact representative or is biased by coincidence with areas of blanket peat spread; i.e. the archaeological survival of early fields has depended upon their location in peat-covered areas.

whilst in locations of better soil, such features would be archaeologically invisible due to reworking and/or superimposition. Johnston (2000) has argued that the distinctive Atlantic distribution of Neolithic field systems should be viewed as tangible evidence of changing social relationships between people and the land they occupied, rather than in purely economic or technological frameworks.

The idea that changing relationships between humans and landscape in prehistory have been expressed (and can therefore be traced) by changing traditions in the form and nature of upstanding settlements and constructions is, of course, not new. Arguably revisiting the domus ideology of Hodder (1990; 1998), Fokkens (1999) has linked the evolving traditions of longhouse typology in the late Neolithic and Early Bronze Age of the Netherlands to the increasing economic or status value of cattle and to the issue of land ownership, in conjunction with the phenomenon of burial monuments in close proximity to the settlements. That stone field boundaries were not necessarily present in this area does not detract from the relevance of the pattern to the current study. The location of megalithic tombs within the field boundaries at Céide Fields and Belderg Mór in North Mayo (see Figures 2.5 and 2.6) can be considered in a similar context.

Caution has been prescribed against over-emphasising the significance of the British and Irish Neolithic field systems and permanent settlements, with suggestions made that they are unrepresentative of British Neolithic settlement as a whole (Thomas 1999, 10). Molloy & O'Connell (1995, 222) considered the extensive Céide Fields to have been initiated by a desire to clear the land of stones. Such permanent settlements have also been argued as adaptations in response to impositions of island location or environmental conditions (Pollard 1999, 85). This is a somewhat environmentally deterministic theory, and arguably recalls the idea that the adoption of permanent settlement reflected a particular view of the relationship between self and environment on the part of the communities who inhabited them.

The abandonment of field systems is, like the wider issue of archaeological settlement abandonment, complex. As the known Neolithic systems were buried by blanket peat, it was perhaps inevitable that the question of environmental deterioration would be raised. It is extremely difficult to pinpoint with sufficient precision and accuracy the date of abandonment, and burial by peat may be diachronic across single sites (e.g. the Céide Fields: Molloy & O'Connell 1995). Furthermore, even if two events are proven to have occurred at the same time, causality is difficult to establish.

2.2.3 The Bronze Age

2.2.3.1 The Irish Bronze Age

Chronology

This thesis uses a scheme subdividing the Irish Bronze Age into Early (c. 4300 – 3700 cal. BP), Middle (c. 3700 – 3200 cal. BP) and Late (c. 3200 – 2550 cal. BP) phases (Cooney & Grogan 1999). The transition between the Late Neolithic and Early Bronze Age of Ireland is archaeologically recognised by a chronology constructed according to the appearance of metallurgy. The trends of increasing emphasis on the individual, settlement expansion and population increase, and developing regional identities, are all perceptible in the final phases of the Neolithic (ibid., 93-94).

Settlement

The Irish Bronze Age is much better known for its metalwork and burials than for its settlement practices (Doody 1993a, 93; Waddell 1998, 205) and even less is known about its agricultural regimes and the relative importance of cereals and pastoralism (Mitchell & Ryan 2001, 219). As with the Neolithic, however, more house sites have been discovered in recent years as construction has necessitated archaeological monitoring, and more landscape surveys have occurred. General conclusions regarding settlement can be made from the sites available, although economic information rests largely on palynological analyses and a small number of archaeobotanical and faunal assemblages.

The Bronze Age settlement of Ireland is typified by isolated, frequently enclosed, settlements. Whilst circular/oval houses continued to be constructed in the Bronze Age, rectilinear dwellings are known also. Occupation at Lough Gur continued into the Early Bronze Age in both rectangular and round houses. Rectangular turf-walled houses at Coney Island, Co. Armagh contained bowl pottery dated by context to the mid-fourth millennium cal. BP (see Appendix A; Smith *et al* 1971). Bronze Age round houses are known at Belderg Beg (Section 3.2.2.1); Carrownaglogh, Co. Mayo (Section 2.2.3.3) and Downpatrick, Co. Down (Smith *et al* 1973a, 213; see Appendix A). Carrigillihy, Co. Cork and at Chancellorsland, Co. Tipperary (both dated to around the early fourth millennium cal. BP; see Appendix A) consist of oval house structures within oval enclosures of stone and earth respectively. At Ballyveelish, Co. Tipperary, a truncated sub-rectangular ditched enclosure contained sufficient artefactual and economic evidence for general interpretation (Appendix A; Doody 1987a). A more extensive

Late Bronze Age settlement at Curraghatoor, Co. Tipperary, had circular and rectangular huts, refuse/storage pits, fence-lines and animal enclosures (see below & Appendix A; Doody 1987b; 1990).

Some wetland settlement occurred. Domestic settlement at Cullyhanna Lough, Co. Armagh, consisted of an oval house enclosed by a wooden stockade (Hodges 1958). An inter-tidal peat at Carrigdirty, Co. Limerick, contained an arc of vertical alder posts with axe-marks, and a cattle jawbone was found inside the arc (O'Sullivan 1996). This has been interpreted as a seasonal cowherd shelter (Mitchell & Ryan 2001, 220). Both sites date to c. 3500 cal. BP (see Appendix A).

The final part of the Irish Bronze Age, the Dowris Phase (c. 2850-2450 cal. BP) is archaeologically recognised by its artefact typologies and numerous metal hoards, characterising an aristocratic warrior society (Waddell 1998, 225). Settlement evidence is sparser but shows the same general landscape distribution pattern and range of sites, i.e. wetland and hilltop locations (ibid., 264). A multi-phase crannog at Lough Eskragh, Co. Tyrone, included Bronze Age, Dowris and Iron Age levels (Appendix A; Williams 1978). Lakeside settlements have been documented at Ballinderry, Co. Offaly, and Knockalappa, Co. Clare (Waddell 1998, 264-268). Enclosures of various sizes occurred, from the relatively small such as that at Aughinish, Co. Limerick, to the large hillfort at Mooghaun, Co. Clare. At Aughinish, in the Shannon estuary, two enclosures comparable to the Carrigillihy site were discovered; one contained a circular house and both included shell-filled pits and coarse pottery (Kelly 1974).

Mooghaun was constructed with three (probably contemporary) ramparts utilising a natural slope in a prominent landscape position, with only limited evidence for domestic settlement discovered inside its boundaries (Grogan 1995; 1999). Material sealed by the outer rampart was dated to c. 3040 cal. BP (Appendix A). Pollen analysis from the small Mooghaun Lough, 750m from the hillfort, recorded low-level human impact from c. 4835 cal. BP, cereal cultivation associated with increasing agricultural activity from c. 4190 cal. BP, and the main Landnám at c. 3050 cal. BP, which is in agreement with the *terminus post quem* date for rampart construction (O'Connell *et al* 2001). Cereal pollen was relatively well-represented, dominated by *Triticum* type (*sensu* Beug 1961: O'Connell *et al* 2001, 172). Agriculture was at its most intensive until c. 2755 cal. BP, but continued at reduced levels until c. 1930 cal. BP.

A range of Bronze Age settlement types can thus be seen, from isolated enclosed houses and enclosed agglomerated houses to larger-scale sites such as Haughey's Fort and the early phases of settlement at Dun Aonghasa, Inis Mór, Co. Galway. An emerging settlement hierarchy has been envisaged in parallel with the importance of bronze and gold and symbolic weaponry (Waddell 1998, 221). The poorer preservation of cattle bones prevents full assessment of the possibilities of cattle as status items, and whilst coarse pottery was the norm, there was an apparent scarcity of finer wares even at high-status sites (ibid.).

Fulachta fiadh (burnt mounds), almost invariably dating to the Bronze Age (Brindley *et al* 1990, 28), are the most common prehistoric monument type in Ireland. Vastly more numerous in the landscape than known Bronze Age settlements (more than 4500 are recorded), they have been used to interpret part of the settlement record (Waddell 1998, 174; Cooney & Grogan 1999, 102; Mitchell & Ryan 2001, 220). Distribution is skewed to the south-west (Doody 1993a, 96; Waddell 1998, 174; Mitchell & Ryan 2001, 220). They are usually kidney-shaped or circular grassy mounds, close to water or in marshy ground, consisting of hearth/fire traces and a wooden or stone-lined trough surrounded by burnt stones which had been used to heat water, then discarded (Waddell 1998, 174-177; Mitchell & Ryan 2001, 220-221). Evidence from excavated and radiocarbon-dated sites suggests that they were typically used repeatedly over long periods of time, resulting in mound accumulation (Waddell 1998, 177). As they rarely contain artefactual or environmental evidence, the idea that they represent seasonal or temporary hunting camps (Doody 1993a, 96) has fallen out of favour, and suggested functions include ritual feasting with thorough cleaning (Ó Drisceoil 1988, 675), or bathing (Barfield & Hodder 1987). Their distribution in the landscape varies regionally, perhaps indicating differences in purpose or even settlement patterns.

Economies

Until the late 1980s all knowledge of crop husbandry in Bronze Age Ireland came from pottery impressions; the majority of these being of naked barley (*Hordeum polystichum* var. *nudum*), with occasional imprints of hulled barley (*Hordeum vulgare*), flax (*Linum usitatissimum*) and probable bread wheat (*Triticum aestivum*) (Monk 1986; cf. Jessen & Helbaek 1944). The increasing corpus of plant macrofossil evidence is slowly furthering knowledge of arable agriculture. The main sites to produce such evidence are Ballyveelish and Curraghatoor, Co. Tipperary, Haughey's Fort, Co. Armagh, and two shell middens (False Bay and Mannin 2) at Ballyconneely, Co. Galway (Monk 1986; 1987a; 1987b; Weir & Conway 1988; McCormick *et al* 1996; Weir 1996a; 1996b). The principal cereal crop appears to be barley, with 6-row (*Hordeum polystichum*), naked (*H. vulgare* var. *nudum*), and hulled

(*H. vulgare*) varieties all represented. Emmer (*Triticum dicoccum*) and spelt (*Triticum* cf. *spelta*) wheats were also present at Curraghatoor. Oat (*Avena strigosa*) was well-represented at Mannin 2 (Weir 1996b, 81-82). Although oat is represented in the Late Bronze Age in England and in the Scottish pre-Roman Iron Age (Boyd 1988, Greig 1991), it was previously thought to be introduced to Ireland in the later first millennium AD; however its presence in such high frequencies here suggest cultivation rather than that it was occurring as a weed species (Weir 1996b, 81). Nevertheless, the processing stages represented by the assemblage are uncertain, inhibiting interpretation. Weed flora assemblages included Chenopodiaceae, Cyperaceae, *Plantago lanceolata,* Poaceae, *Polygonum aviculare, Rumex* and *Sinapsis.*

There are a number of zooarchaeological assemblages dating to the Bronze Age in Ireland, although few date to the Late Bronze Age. The assemblage at Haughey's Fort, Co. Armagh was too small to provide useful information pertaining to the livestock economy or the dietary importance of the individual species, but cattle, horse, sheep/goat, pigs and dog were represented (McCormick 1988, 25). A few sheep/goat and possibly cattle bones were present at the Mannin 2 midden (McCormick *et al* 1996, 81). Ballyveelish, Co. Tipperary, contained a larger zooarchaeological assemblage, primarily of food refuse. Cattle was the dominant species represented, with pig secondary, and sheep tertiary, and occasional remains of horse, red deer and dog (McCormick 1987, 26).

2.2.3.2 The North Mayo later prehistoric fields I: Céide Fields

Blanket bog initiation and spread

Radiocarbon assays from the short monoliths confirmed that peat initiation was diachronous across the Céide Fields area (Molloy & O'Connell 1995; O'Connell & Molloy 2001). Relevant dates are reproduced in Appendix A. Whilst in some locations peat growth commenced early enough to record the *Pinus* expansion (see below), in the area near the tomb (BHY IV and BHY V), peat accumulation began a few centuries later, when *Pinus* had declined and was of minor importance in the pollen rain and consequently the landscape (Figures 2.7 and 2.8; O'Connell & Molloy 2001, 101).

The Pinus *expansion and decline*

Blanket peat initiation at Céide Fields occurred early enough in many locations, for instance west of the Behy court tomb (profiles BHY III and IV: Figures 2.2, 2.3 & 2.7-2.11), to record (by macro- and micro-fossils) an expansion of *Pinus* trees at c. 5300 cal. BP, and the regionally significant decline of the taxon at c. 4500 cal. BP (Caulfield *et al* 1998; see Section 2.2.3.4). Successful colonisation of *Pinus* onto blanket bog suggests the mire surface was then relatively dry. A two-phase climatic sequence was proposed; drier, less windy conditions allowing the *Pinus* expansion in the early sixth millennium cal. BP; with the mid-fifth millennium cal. BP *Pinus* decline and renewed or accelerated blanket bog growth caused by the shift to a wetter, windier climate (Caulfield *et al* 1998, 636-637). The synchroneity of the *Pinus* decline is highlighted by the tight bracket of radiocarbon dates cataloguing the deaths of these stumps (Caulfield *et al* 1998; see Section 2.2.3.4).

Later land use

Between c. 3540 and 1865 cal. BP, farming in the locality of the sampling area is indicated. *Plantago lanceolata* is well-represented, and its peak at the lower zone boundary is accompanied by minor peaks in Lactuceae, *Trifolium repens* and *Urtica* (LPAZ GLU IV-9a and 9b, see Figure 2.3; Molloy & O'Connell 1995, 204-205). Occasional cereal pollen grains are recorded (see Figure 2.3). The knoll to the east of the Glenulra basin (see Figure 2.2) was suggested as the likely location of such agricultural activity as it was probably the only land in the vicinity of the sampling site not to have been covered by blanket peat at this time, (ibid.). A drier bog surface was indicated in 9b (c. 2880 - 1930 cal. BP) than 9a (c. 3490 - 2880 cal. BP) by pollen and palynofacies indicators and the higher frequency of microscopic charcoal particles in the former, indicating frequent firing (see Figure 2.3; Molloy & O'Connell 1995, 205).

The BHY monoliths also contain evidence of Bronze Age mixed agriculture. In BHY IV, high Poaceae values around c. 3095 cal. BP (zone 3) are accompanied by strong *Plantago lanceolata* representation along with Cereal-type pollen, *Trifolium*, *Rumex* and Lactuceae. Similar phenomena are recorded in BHY V after c. 3685 cal. BP and in BHY VI at some time after c. 3830 cal. BP (Molloy & O'Connell 1995; Figures 2.7, 2.8 and 2.9). The CF Ib profile contains high representation of cereal pollen, with indications of a grass and herb dominated landscape at c. 3000 cal. BP, continuing after c. 2245cal. BP (ibid. 221; & Figure 2.10). This profile was taken from just outside a short length of wall which is part of a network of smaller walls appearing to form a later addition to the Neolithic field system (Molloy & O'Connell 1995, 213 & 221). Plough- or ard-marks were recorded 55m from the CF Ib sampling site prior to construction of the visitors' centre (ibid., 195 & 221). Infill material from these contained cereal-type pollen, however, similarly to CF Ib, arable weed taxa are poorly represented (see Figure 2.11; ibid., 214). In the course of that excavation, a lynchet, some undiagnostic pottery and an ard share were discovered (ibid., 193; Byrne 1991), although these, like the plough-marks, do not necessarily date to the Neolithic occupation (Molloy & O'Connell 1995, 218). Agriculture ceased at c. 1865 cal. BP, during the Late Iron Age, typical for western Ireland (see Section 2.4.2.1).

2.2.3.3 The North Mayo later prehistoric fields II: Carrownaglogh

Site location, investigation and form

Excavations at Carrownaglogh, Co. Mayo, by M. Herity revealed a sub-peat stone wall enclosure, an extensive, well-formed ridge system and a circular structure interpreted as a house (Herity 1981). Palaeoenvironmental investigations were undertaken by O'Connell (1986) and results further discussed in O'Connell (1990b). The site lies on drift deposits on the lower western slopes of the Ox Mountains, between two regions rich in megalithic monuments; the northwest coastal area of North Mayo west of Killala Bay, and the passage tomb cemeteries of Carrowmore and Carrowkeel, Co. Sligo to the east (see Figure 2.12; O'Connell 1986, 118-120). The four common tomb typologies (Neolithic court tombs, passage graves and portal tombs, and the mainly Early Bronze Age wedge tombs) are represented in the immediate area (ibid., Herity & Eogan 1977).

A plan of the site is reproduced in Figure 2.13. Ridges were spaced around 1.5m apart, with a height of 10-15cm from hollow to ridge (O'Connell 1986, 119). They assume numerous orientations with the main group contouring the hillside, suggesting drainage was not problematic in the coarse sandy loam soil at this locality (ibid.). Stone features, apart from the main enclosure, were two robbed out walls with evident lynchet formation; several stone clearance heaps; and the circular house structure with a central hearth (ibid., 119-120).

Palaeoenvironmental analyses

A 2m long monolith from a peat basin c. 250m south of the enclosure wall was palynologically analysed (see Figure 2.14). Radiocarbon dates are reproduced in Appendix A. The extremely wide error margins associated with all assays reduce the certainty of the chronology. Peat initiation was dated to c. 4000 cal. BP (O'Connell 1986). Typical western Irish woodland prevailed (see Section 2.4.2.1) until clearance at c. 2855 cal. BP for mixed agriculture, estimated to have lasted for c. 250 years. Slow woodland recovery followed, with a second phase of clearance and agricultural activity (probably of a lesser magnitude) dated to c. 1850 – 1500 cal. BP (O'Connell 1986, 165-167).

Short monoliths from podzolised soil including the ridges were also taken for pollen analysis and overlying peat layers radiocarbon-dated (Appendix A & Figure 2.15; O'Connell 1986, 123-127). Comparison with the long monolith chronology suggests that peat began to accumulate over the lower slopes of the knoll containing the archaeological site, and that its spread upslope was fairly rapid (ibid., 172). Activity within the enclosure was therefore firmly correlated with the first agricultural phase (c. 2855 - c. 2600 cal. BP) and the ridges assigned to late stages of this occupation. *Triticum*- and *Hordeum*-type pollen grains were recorded in spectra from the short monoliths. Rotation was implied by the depth-dependent dominance of one cereal type over another, and fallowing inferred by high values of *Pteridium* (ibid., 162-163). The presence of occasional *Avena* type pollen grains in lower spectra may indicate pre-Iron Age cultivation of oat (ibid., 163; *contra* Jessen & Helbaek 1944).

2.2.3.4 Environmental marginality? – the 4500 cal. BP *Pinus* decline

Wood macrofossils (principally stumps) preserved in peat have been recognised in the British Isles since at least the 19th century (e.g. Moss 1904; Lewis 1905; 1906; 1907; 1911; Praeger 1937). Although *Pinus* was rejected in favour of *Quercus* for Irish dendrochronological research (Smith *et al* 1972: Pilcher *et al* 1995) investigations into the possible climatic significance of subfossil *Pinus* stumps continued (Birks 1975; Tallis & Switsur 1983; Bennett 1984; Wilkins 1984; Dubois & Ferguson 1985; Gear & Huntley 1991). Radiocarbon dating of subfossil *Pinus* stumps in Ireland and the north of Scotland identified a phase of widespread expansion of *Pinus* onto peat between c. 5200 and 4500 cal. BP, immediately followed by the decline and virtual disappearance of the species from the sedimentary record as a macrofossil (Bennett 1984; Bradshaw & Browne 1987, 243-244).

Due to the combined problems of abundant pollen production (Andersen 1970) and the long-distance transport of wind-dispersed pollen grains, *Pinus* can be overrepresented in palynological records (ibid., Bennett 1984, 137). Presence in a pollen diagram is not always interpreted as an indicator of local or even regional presence of the species, with various cut-off points suggested to distinguish a local population from the long-distance component (e.g. 20% in Bennett 1984, 137). Nevertheless, a distinct decline in *Pinus* at around 4500 cal. BP has been noted in many pollen diagrams from the British Isles, particularly in the north and west where it was most strongly represented. This is now a well-recognised chronostratigraphic marker in Holocene palynology. That the decline was synchronous and most marked in those regions where the tree was nearest its range limits (the northern Atlantic fringe of the British Isles) suggests the species was environmentally marginal and some climatic parameter crossed the threshold beyond which pine growth was near-impossible (Blackford *et al* 1992).

Many pine stumps dating to the expansion and subsequent decline occur in North Mayo, including the Belderg Beg vicinity. A dating programme was undertaken to establish the c. 5200-4500 cal. BP *Pinus* expansion as a *terminus ante quem* for the initiation of blanket bog and the abandonment of the Belderrig Valley and Céide field systems (Caulfield *et al* 1998). Excluding five outliers, the mean age of the main cluster (N=39) of the North Mayo sub-peat pines was c. 4850 ± 120 cal. BP (Figure 2.16). The onset and demise of the North Mayo pine cluster was shown to coincide with the dates of pine expansion onto peat and decline in northern Scotland collected by Gear & Huntley (1991) (Figure 2.17). The mean age of the northern Scottish pines (N=31) was c. 4745 ± 225 cal. BP, indistinguishable from the North Mayo pines (Caulfield *et al* 1998, 636-7). Caution may be advised in over-emphasising the importance of the apparently definitive onset of the chronological clustering of bog pines. Caulfield *et al* (1998, 636-7) purport that before the starting point of c. 5200 cal. BP there were very few pine trees, and that this suggests the cause of this pine expansion was quite dramatic. The apparent expansion of pines may, however, be due to their circumstance of preservation, i.e. the widespread growth of blanket bog (cf. Dubois & Ferguson 1985, 68). Assays from macrofossils inevitably record periods of tree growth rather than decline and rarely occur in sufficient concentration to indicate changes in abundance through a stratified sequence (Bennett 1984, 135). Comparing pollen diagrams from several sites in Counties Mayo and Galway, O'Connell & Molloy (2001) record pine colonisation onto peat (recognised by elevated *Pinus* pollen values) occurring between c. 4750-4400 cal. BP.

Interpretation of the cause of the *Pinus* decline and apparent associated widespread initiation and/or acceleration of blanket bog growth has to be approached carefully due to the multiple factors which could possibly have interlinked to produce such a phenomenon. Similarly to the *Ulmus* decline, a widespread death of pine trees could result from climatic change, pathogenic activity, human activity or pedogenesis, none of which need be mutually exclusive (Bennett 1984, 146).

Theories linking the *Pinus* decline in Ireland to human activity (Baillie 1995b) and the Hekla-4 eruption of 4260 ± 20 cal. BP (Blackford *et al* 1992) have been criticised due to low human populations and methodological errors respectively (Hall *et al* 1994; 1996; Edwards *et al* 1996; Dwyer & Mitchell 1997). Association between the *Pinus* decline and blanket bog spread has favoured climate change leading to increased bog-surface wetness as an explanation (Birks 1975; Bennett 1984; Dubois & Ferguson 1985; Bradshaw & Browne 1987;

Bridge *et al* 1990; Gear & Huntley 1991). This was supported by the recognition that the decline was apparently more severe in the Atlantic north and west of the British Isles, i.e. in the region of harshest climatic conditions, based on the theory that the most environmentally marginal populations would suffer the greatest effect of any climatic deterioration (Gear & Huntley 1991; Blackford *et al* 1992; Lageard *et al* 1999). Southward shift of the range-limits of *Pinus* was also seen at c. 4500 cal. BP in Fennoscandia (Eronen 1979; Eronen & Huttunen 1987; Kullman 1989; Eronen & Zetterberg 1996).

O'Connell & Molloy (2001, 102) suggested that although peat was common in North Mayo before the *Pinus* expansion (some stumps are rooted on up to 90cm of peat) it may have been too wet to facilitate germination of *Pinus* seedlings, and that the window of opportunity for colonisation of bog at c. 4600 cal. BP existed because the peat provided a suitable habitat for *Pinus*. This supports the hypothesis that two periods of climate change are represented: one towards a drier climate, attributed to higher summer temperatures an/or decreased precipitation, slowing blanket peat growth and allowing *Pinus* to colonise its surface, then a second change towards wetter conditions, leading to renewed bog growth and the death of *Pinus* trees (Caulfield *et al* 1998, 636-7).

Gear & Huntley (1991, 546) also proposed a two-stage hypothesis of climate change which is in broad agreement with that of Caulfield *et al* (1998). Firstly, it stated that the expansion of *Pinus* onto peat in northern Scotland resulted from drying of blanket peat and the northwards movement of range limits in Fennoscandia resulted from higher summer temperatures around c. 5000 cal. BP, and that these changes are consistent with a north or north-east expansion or shift of the Azores high and consequent north shift of the jet stream. Subsequently, at c. 4500 cal. BP, a reversal of these circulation trends occurred, resulting in the extinction of *Pinus* on blanket bog and the southwards shift of its range limit in Fennoscandia.

Investigations into δD records in subfossil *Pinus* stumps from the Cairngorms by Dubois & Ferguson (1985) can be seen to support arguments for a two-phase climatic oscillation. The period between c. 6650-4800 cal. BP was marked by δD values indicating relative climatic dryness (cf. Section 2.3.3.2). At c. 4800 cal. BP a rapid shift to increasingly wet conditions was signalled.

2.2.3.5 Later prehistoric upland settlement in the British Isles

Drawing on the work of Parry (1975; 1978; 1985) a settlement concept was constructed for later prehistoric northern Britain, based on studies from Northumberland and the Scottish

Borders, which hypothesised large-scale abandonment of upland settlement as a response to climatic deterioration (Burgess 1984; 1985; 1989; 1992). The change from a continental climate with warmer summers in the first half of the fourth millennium BP to a cooler, wetter, stormier regime at around 3400-3200 cal. BP (Lamb 1981, 53-55) was interpreted as causing a restriction of crop growing seasons and reducing altitudinal limits to ripening and thus cereal cultivation (Burgess 1985, 200). During the climatically mild majority of the fourth millennium BP, Burgess (1985, 202-203) reported a settlement and agricultural expansion onto marginal land in most of upland, and indeed lowland, Britain, citing the development of (principally sub-peat) field systems as evidence. A concurrent rise of population was suggested. He noted an hiatus between hillforts dating to the late fourth and mid-third millennia BP, proposing that the gap or discontinuity in the hilltop settlement record corresponded to the phase of climatic deterioration and that population decline must have been involved (ibid, 204-205; Burgess 1992, 25-26). Burgess (1989) subsequently correlated this supposed event of environmental marginalisation of upland Britain with (Icelandic) volcanicity (principally the H3 eruption) based on the research of Baillie (1989a; 1989b).

This settlement retreat and its explicit assumption of environmental marginality in the uplands have subsequently been questioned. Edaphic effects of volcanic aerosols have been questioned, and H3 tephra is apparently absent from Scotland; hence the potential of volcanicity to cause such climatic deterioration is dubious. Alternative reasons for land abandonment may be applicable to the supposed later prehistoric settlement retreat; the most frequent suggestion is pedogenesis. Changes in soil hydrological regimes (Piggott 1972) and waterlogging (Turner 1981) have been suggested as causal factors in later prehistoric land reorganisation, and these theories have recently been developed by Barber (1998, 137-144), who linked accelerated soil acidification (podzolisation) combined with waterlogging to crop failure and the abandonment of agricultural land to blanket peat in later prehistoric Arran.

Furthermore, doubts have been cast upon the widespread land abandonment in Late Bronze Age upland Britain. The supposed 300-year upland settlement dislocation between unenclosed ring-bank and ring-ditch structures in the fourth millennium BP and the enclosed (palisaded or hillfort) sites dating from c. 2750 cal. BP (Burgess 1985, 208-212) has been largely discredited as a result of incremented excavation and radiocarbon dates (Gates 1983; Jobey 1985; Young & Simmonds 1995). Although the problem has been recognised that the bulk of available radiocarbon evidence rests on charcoal assays, sites have also been dated by cereal macrofossils (van der Veen 1992; Young & Simmonds 1995, 10).

More precisely dated examples of settlement studies are known of in northwest Europe, though on smaller spatial scales. Wiggle-match dating of climate changes and extensive dating of settlements in West Friesland, the Netherlands, has enabled a direct mechanism by which climatically-driven environmental change was linked to abandonment of marginal settlements. Coastal ridges around a tidal inlet, occupied since c. 3500 cal. BP, were increasingly threatened by increasing water tables caused by impeded drainage and climatic deterioration from c. 2760 cal. BP, and the settlement areas were abandoned by around 2620 cal. BP (van Geel *et al* 1996, 453-454; 1998, 536-538). A shift of settlement focus at c. 2650 cal. BP to salt marshes newly exposed by a fall in sea-level was inferred, also based on multiple radiocarbon assays (van Geel *et al* 1996; 454-455; 1998; 540-541).

2.2.3.6 The significance of Bronze Age field systems in north-west Atlantic Europe

In his appraisal of the prehistoric field systems of Atlantic Europe, Johnston (2000) envisaged a northwest Atlantic European Bronze Age phenomenon of enclosed settlements and field systems, apparently chronologically distinct from the Neolithic field systems considered above (Section 2.2.2.4). He stressed that their distributions were related, as the later fourth millennium BP field systems (i.e. the earliest of the Bronze Age systems) are located throughout Britain. Without necessarily assuming a diffusionist perspective upon the geographical spread of such features, the field systems of western Europe (those of Scandinavia, the Netherlands, eastern France and the Rhineland), appear chronologically later, in the Later Bronze Age and Early Iron Age (ibid., 52).

In contrast to Neolithic field systems, later prehistoric fields are generally considered as commonplace rather than exceptional; central to the mechanics of upland cattle-based agriculture (Johnston 2001). Land tenure and delimitations have been the primary focus of such studies (ibid.). Land tenure, and by implication, field systems, are structured by, and also are responsible for structuring, agricultural practices; a recognition which has resulted largely from ethnography (ibid.). One further inference gleaned by examining the agendas pursued by those studying Neolithic and later prehistoric landscapes is a perceived transference of land occupation symbolism from communal burial monuments to enclosed settlements over these periods. This perception can be interpreted as supporting views that Neolithic fields and permanent settlements were exceptional and responses to particular circumstances (Thomas 1999; Pollard 1999).

The environmental context of later prehistoric field system construction and usage is complex and has never been satisfactorily addressed. Fleming (1987, 193) highlights the fact that many prehistoric field systems are situated in locations currently environmentally marginal for agriculture. This may unnecessarily influence interpretations of their function and agricultural capabilities. An interpretation of extensification rather than intensification of agriculture does not necessarily imply that a prehistoric community needed to use marginal land. Rather, population factors may be considered, such as the potential requirement for future expansion, which may have been primary considerations in land-use strategies (ibid.). Perhaps later prehistoric coaxial field systems were situated on land which was most capable of sustaining extensive agriculture.

Many studies have sought to portray a distinction between cairnfields, which are typically small and poorly defined, bounded by clearance heaps, and coaxial field systems. Conventional wisdom has portrayed an evolutionary development of later prehistoric field systems from small, irregular fields to the large coaxial field systems, perhaps with the repeated actions of stone clearance and agriculture causing the former to develop over time into the latter (cf. Fowler 1981, 37). In Britain, the major phase of cairnfield construction has been calibrated to the end of the fifth millennium BP and the first half of the fourth millennium BP, which, when the likelihood of long-term and intermittent occupation histories are taken into account, suggests that there was a discrete phase of cairn construction during the Bronze Age (Johnston 2000; 2001, 106). In the case of coaxial field systems, a distinct mid-fourth millennium BP phase of field system construction can be identified in Ireland, Britain and the Netherlands (Smith *et al* 1981; Yates 1999; see Johnston 2000 for summary), and whilst changes in agricultural technology and increased permanence of settlement have been associated with this phenomenon, the dating evidence is not always unequivocal (Johnston 2000, 50).

The typology of field systems may not be simply a function of chronology or evolution. Johnston (2001) draws a distinction between Bronze Age cairnfields and field systems based upon their social functions. Drawing upon examples of cairnfields from Northumbria and Cumbria where charred material (including human remains) were deliberately deposited and sealed beneath clearance cairns on agricultural land, he suggests that such depositions formed a link between the ancestral past and the agricultural present, acting to formally express pre-existing networks of tenure and belonging (Johnston 2001, 104-7). Field systems, especially when joined to houses, legitimated tenure differently, by linking the domestic and agricultural domains through the lives and wider network of relationships of the inhabitants (ibid.).

In conclusion, it becomes apparent that a simple evolution of agricultural enclosure from clearance cairns, *via* cairnfields, to coaxial field systems and those systems incorporating the domestic landscape, is no longer tenable. Whatever their roots, the field systems of later prehistoric Britain and Ireland are part of a distinct Atlantic European phenomenon showing variation in function, form and indeed symbolism.

2.3 Holocene climatic history of the North Atlantic, focussing on Ireland

2.3.1 Late-Quaternary chronology

The late-Quaternary Irish climatic and geological chronology as currently recognised is presented in Table 2.1. Correlation with Britain, mainland Europe and the marine oxygen isotope record is difficult (see Woodman *et al* 1997).

2.3.2 Sources of evidence

In order to identify the periods of time during which communities on the North Atlantic seaboard might have been particularly vulnerable to climatic change, it is necessary to consider evidence from a wide range of literature. Various proxy indicators often reveal different or contradictory suggestions as to the timing and nature of climatic shifts. An appraisal of the most common sources of evidence is considered most likely to identify the most commonly-discovered results.

2.3.2.1 Marine records

Deep sea sediments

Atlantic deep-sea sediment cores have been analysed for a variety of palaeoclimatic indicators. Methods have included sedimentation rates and grain size analysis to reconstruct flow rates of deep dense water, a component of thermohaline circulation (THC: see section 2.3.3.1) (Bianchi & McCave 1999); carbon isotope analysis of benthic foraminifera to reconstruct palaeoclimate (Oppo *et al* 2003) and analysis of lithic concentration, petrologic tracers, and species abundance and oxygen-isotope measurement of planktonic foraminifera (Bond *et al* 1997). Lithological analysis has identified episodic deposition of ice-rafted debris (IRD); discrete events during which angular rock fragments (probably derived from Arctic icebergs surviving to British latitudes) increased in proportion in north Atlantic deep-sea sediments (Bond *et al* 1997; 1999; 2001). IRD events (also called Heinrich events) occurred at various intervals during the Holocene with inferred cyclicity (see Section 2.3.3.1).

Ice-cores

Investigations in Greenland have focussed on the Greenland Ice Sheet Project (GISP2) core, which has been analysed for accumulation rate change (Meese *et al* 1994), glaciochemical composition (marine- versus terrestrially-derived elements) (O'Brien *et al* 1995) and oxygen isotope records (Grootes *et al* 1993). These proxies have been used to indicate, respectively, climatically-induced atmospheric snowfall delivery, atmospheric circulation patterns and palaeotemperatures (Alley 2000). Accumulation rates of the cosmogenic nuclide ^{10}Be have been used as an index of irradiance, aiding development of theories that Holocene climatic fluctuations are in part forced by solar activity (see below, section 2.3.3.1; Finkel & Nishiizumi 1997; Yiou *et al* 1997).

Different proxy indicators exhibit different amplitudes of climatic fluctuations. Oxygen isotope ratios, methane concentrations and snow accumulation rates in the GISP2 core indicate a relatively stable Holocene climate in comparison to glacial events, but the chemical impurity analysis showed significant climatic fluctuations, again with cyclical patterning (see section 2.3.3.1; O'Brien *et al* 1995).

2.3.2.2 Terrestrial records

Tree-rings

As dendrochronological records now cover the entire Holocene, ring-width and stable-isotope variations have been used as indices of growing conditions of sub-fossil trees and as palaeoclimatic proxies. *Pinus sylvestris* records now extend 7400 years in Swedish Lapland (Grudd *et al* 2002) and 7500 years in Finnish Lapland (Helama *et al* 2002). In temperate Europe, *Quercus* have been used to construct Holocene radiocarbon chronologies (Stuiver *et al* 1998; Bronk Ramsey 2003) and palaeoclimatic records (Leuschner *et al* 2002; Mayr *et al* 2003). Synchronous inter- and intra-site ring-width variations in trees indicate growing conditions, governed ultimately by regional climate factors as well as local environmental variables (Baillie 1995a; Leuschner *et al* 2002). Trees growing close to their thermal limits (in climatically marginal locations such as altitudinal or high-latitude tree-lines) react most palpably to climatic fluctuations, principally growing-season temperature (Tranquillini 1979; Leuschner *et al* 2002; Helama *et al* 2002; Grudd *et al* 2002).

Stable carbon and hydrogen isotope ratios of sub-fossil trees are used to reconstruct palaeoclimates. The stable hydrogen isotope δD (deuterium) value of tree rings indicates the isotopic composition of water taken up by the tree, which in turn generally reflects the isotopic composition of precipitation (Mayr *et al* 2003, 393). Deuterium levels within precipitation are governed by both temperature (Tang *et al* 2000) and humidity (White *et al* 1994). Low δD values in the Cairngorm subfossil pines were attributed to pluvial periods with very heavy rainfall, probably originating from more northern air masses than at present (Dubois & Ferguson 1985, 73). The deuterium record of *Pinus* trees has been investigated in the context of the mid-Holocene pine decline (Section 2.2.3.4). The carbon isotope $\delta^{13}C$ has been found to be closely correlated with climatic parameters such as temperature, relative humidity, light intensity and water availability; with the controlling variable dependent upon site conditions (McCarroll & Pawellek 2001). In marginal European conditions it is suggested that water availability is the most important factor controlling $\delta^{13}C$ ratios (Mayr *et al* 2003).

Mires

Peatlands are a source of palaeoclimatic evidence often applied to human timescales due to their rapid accumulation rates and high temporal resolution in comparison to deep-sea sediments. The most commonly utilised peatland palaeoclimatic proxies are the humification record (see Section 4.4.4), testate amoebae, and plant macrofossils. These are often used in combination to avoid confusion arriving from equifinality, as humification in particular can be affected by more than one environmental variable. Both raised and blanket mires are sources of palaeoclimatic information (Aaby & Tauber 1975; Aaby 1976; Chambers 1984; Rowell & Turner 1985; Blackford & Chambers 1991; Blackford & Chambers 1995; Chambers *et al* 1997, 391). The selection of potentially sensitive locations appears to be vital in gaining a meaningful record of humification changes in blanket mires, both locally (water-shedding sites are ideal) and regionally (with sites near the Atlantic Ocean showing most sensitivity: Haslam 1987). Comparison of mires displaying different microclimatic regimes, affected by topography, effective precipitation and thereby hydrological stability, has suggested that mires without potential summer water deficits show the greatest sensitivity to shifts towards climatic wetness, perhaps because conditions for *Sphagnum* growth are optimal at such sites (Mauquoy & Barber 2002). Like marine and ice-core proxies, some peat stratigraphies show evidence for cyclic environmental change, though generally on much reduced periodicities (Section 2.3.3.1).

Stable isotope ratio studies have been applied less frequently in mires than in other substrates, but $\delta^{18}0$ and $\delta^{13}C$ shifts have been correlated qualitatively to climatic shifts (Brenninkmeijer *et al* 1982). Glacial deposits and lake sediments have also been subjected to limited stable isotope analyses (Whittington *et al* 1996; O'Connell *et al* 1999; Ahlberg *et al* 2001).

Speleothems

Speleothems record palaeoclimates *via* variations in stable isotopes, extension-rates, textures and luminescence wavelengths. Luminescence wavelength has been related to mean annual rainfall *via* effects on properties of overlying sediments in Sutherland, Scotland (Baker *et al* 1998; Charman *et al* 2001). Speleothems from elsewhere in Europe have given different, indeed contradictory, palaeoclimatic signals. For instance, temperature appeared to govern speleothem $\delta^{18}0$, $\delta^{13}C$, textural and extension-rate variations at Crag Cave, Co. Kerry, Ireland (McDermott *et al* 1999, see Section 2.3.3.1). Such inter-site differences question the reliability of speleothems as indicators of regional palaeoclimates, prompting suggestions that speleothem proxy signals might more closely reflect local environments (e.g. McDermott *et al* 1999; Charman *et al* 2001, 232-233).

Lake levels

Former lake level changes are reconstructed by a variety of sedimentological and biological methods. Sedimentological or geological indicators include changes in sediment texture, lithology, and the relative frequency of biochemically-originated carbonate concretion morphotypes (Magny 1992; 2004; Magny *et al* 2003). Biological indicators include plant macrofossils, diatom and ostracod assemblages, and chemical or stable isotopic analysis of fossils (Gray 1988). Regional syntheses have emerged from central and northern European lake-level reconstructions (Digerfeldt 1988; Magny 1993; Magny *et al* 2003), furthering understanding of the mechanisms of North Atlantic atmospheric circulation patterns (e.g. Magny 1992; 2003; Yu & Harrison 1995). Lake levels indicate precipitation/evaporation ratios, forced by the climatic regime, and climatic variables can differentially affect precipitation and evaporation (e.g. Magny *et al* 2003, 268). Additionally, non-climatic factors such as tectonic activity can also affect lake levels (ibid., 270). Quantitative data models have correlated phases of higher lake levels with lower summer and winter temperatures, mean annual temperatures and growing day-degrees (see section 1.3.2.2), and higher annual precipitation, precipitation minus evaporation, and available moisture (Magny *et al* 2003, 270). A certain degree of synchronicity exists between Jura lake-level fluctuations and French alpine glacier advance/regression models (Magny 1992).

2.3.3 Towards a Holocene palaeoclimatic chronology

2.3.3.1 Mechanisms of Holocene climate change

The coupled ocean-atmosphere convective model

Ocean circulation (the oceanic conveyor-belt model) is at the forefront of research into Quaternary climate variability and a coupled ocean-atmosphere convective model has been developed (Broecker 1994; Broecker & Denton 1989; 1990). Thermohaline circulation (THC) is explained in Figure 2.18. Ocean-atmosphere coupling of the THC system is responsible for the current dominant westerly weather systems. The atmospheric constituent is governed by the North Atlantic Oscillation (NAO); the relative strengths of the Azores High and Icelandic Low pressure. This large-scale controlling factor of northern hemisphere climate determines the position and strength of poleward pressure gradients, directly influencing the position of westerly winds and storm tracks over Europe (Dunbar 2000, 64). Monthly NAO indices in Atlantic Britain (northern Scotland and western Ireland) have been analysed with reference to storm frequencies from historic records, and a positive correlation has been uncovered between low or negative NAO index values and storm frequency, effecting speculations that phases of stormy weather were influenced by southward displacement of polar atmospheric and oceanic fronts and therefore storm tracks (Dawson *et al* 2002).

Cyclicities, periodicities and solar activity

High-resolution investigation of deep-sea sediments and ice-cores have proved the Holocene has hosted events of abrupt, rapid shifts in northern hemisphere sea-surface temperatures (SSTs), direction of prevailing air currents, and thereby the climatic regimes of the North Atlantic (Bond *et al* 1997; 1999; Meese *et al* 1994; O'Brien *et al* 1995), such as had occurred more distinctly during the last glaciation (Bond *et al* 1993). Furthermore, these events were abrupt and cyclical, with quasi-millennial periodicities identified (O'Brien *et al* 1995; Bond *et al* 1997; Chapman & Shackleton 2000). Climatic cycles noted in deep-sea sediment and ice-core records exhibit varying periodicities (see Figure 2.19). The GISP2 glaciochemical index displayed trends indicating cooler climatic conditions at quasi-2600 year periodicities, with cooling events occurring at c. 0 to 600, 2400 to 3100, 5000 to 6100, 7800 to 8800, and >11300 BP (O'Brien *et al* 1995). Conversely, milder climatic regimes were indicated at c. 610 to 960, 1500 to 2700, 6300 to 7900, and 9300 to 10600 BP (ibid.). Deep-sea sediment cores have shown periodicity in cyclicity of palaeotemperature signals on different time-scales. IRD events, accompanied by shifts in foraminifera assemblages, in North Atlantic cores studied by Bond *et al* (1997) occurred on millennial scales, peaking at about 1400. 2800, 4200, 5900, 8100, 9400, 10300, and 11100 BP. This 1470-year cycle correlated well with the GISP2 record (see Figure 2.19), supporting theories of a coupling between oceanic and atmospheric circulation patterns of the North Atlantic governing short, millennial-scale climatic shifts (ibid., 1262-1263).

Correlation between the glacial and IRD evidence suggested that these episodes were triggered by iceberg discharges pushing south and persisting to lower latitudes (Bond *et al* 1997; 1999; 2001). One suggested mechanism allowing iceberg discharges from the Arctic is by reduction of North Atlantic Deep Water (NADW) formation, which could potentially weaken THC (e.g. Bond *et al* 1997; Bianchi & McCave 1999; Chapman & Shackleton 2000). There is some evidence for this in some of the Holocene climatic events: registered in $\delta^{13}C$ content of benthic foraminifera at 9300, 8000, 5000 and 2800 cal. BP (Oppo *et al* 2003); on 550-year and 1000-year periodicities (Chapman & Shackleton 2000); and in phase with the GISP2 record (Bianchi & McCave 1999). A positive feedback mechanism enhancing oceanic circulation fluctuations during periods of climate change has been identified, *via* increased freshwater from increased river discharge (related to precipitation levels) in the northernmost North Atlantic resulting in a dilution of high-latitude dense salty water weakening the pump mechanism (Dickson *et al* 2002; Prange & Lohmann 2003). Nevertheless, THC fluctuations are far from proven as the causal mechanism of iceberg discharge and thereby Holocene climate change. Marotzke (2000) has underlined the lack of current understanding regarding fundamental aspects of THC changes, whilst Keigwin & Boyle (2000) highlighted the ambiguity of evidence for Holocene deep ocean circulation change by comparison to that for the last glacial cycle. Arguably, the only Holocene climatic event with sufficient evidence for a cautious link with THC fluctuation is the Little Ice Age (Broecker 2000; Keigwin & Boyle 2000).

The driving force behind Holocene climate change is uncertain, although solar variability is currently a popular theory. Bianchi & McCave (1999) have suggested that solar forcing drives the 2500 year periodic cycle noted by O'Brien *et al* (1995), whilst internal climatic oscillation drives the 1500 year cycle noted by Bianchi & McCave (1999) and Bond *et al* (1997). Enhanced amplification of ocean surface forcing of deep water formation was suggested to increase the effects of solar fluctuations (Karlén & Kuylenstierna 1996; van Geel *et al* 1999; Bond *et al* 2001; Oppo *et al* 2003). Solar output fluctuations were also implied in the quasi-1500 year cycle (Bond *et al* 2001). Petrological tracers of IRD events were correlated with variations recognised in the accumulation rate records of cosmogenic nuclides: ^{10}Be flux in GRIP and GISP2 ice cores (Finkel & Nishiizumi 1997; Yiou *et al* 1997) and ^{14}C in tree rings

(Stuiver *et al* 1998). Higher production rates of cosmogenic nuclides are associated with weaker solar winds and reduced solar irradiance. Rapid, centennial scale cyclic shifts of 200-500 years in drift ice records closely matched shifts in production rates of cosmogenic nuclides. Several of these cosmogenic fluctuations were rapid (100-200 years) with large amplitudes, suggestive of a forcing beyond the capability of Holocene climate fluctuation alone (Bond *et al* 2001, 2133). The grouping of these centennial oscillations corresponds well to the 1500-year quasi-periodicity noted in earlier studies (ibid., Bond *et al* 1997; 1999).

Cyclical palaeoclimatic shifts have been recorded in peat-based investigations, with varying periodicities: c. 1100 and c. 600 years at Walton Moss, Cumbria (Hughes *et al* 2000); c. 1100 years at Temple Hill Moss, southeast Scotland (Langdon *et al* 2003); c. 800 years at Bolton Fell Moss, Cumbria (Barber *et al* 1994); c. 210 years at Talla Moss, Scottish Borders (Chambers *et al* 1997); and c. 260 years at Draved Mose, (Aaby 1976). The major difficulty in reconciling these datasets is the precision and accuracy of the dating methods applied (Chambers *et al* 1997, 396).

Solar activity fluctuations, causing variabilities in insolation, have been postulated at complex periodicities, traced by fluctuations in atmospheric ^{14}C in the INTCAL curve (Stuiver *et al* 1998) and correlated to palaeoclimatic signals in wiggle-match-dated terrestrial records in attempts to prove linkages between solar activity levels and Holocene climatic change. In investigations utilising plant macrofossils and humification data in British and Irish ombrotrophic mires as palaeoclimatic proxies, the onset points of the late third millennium cal. BP wet shift and the LIA were found to have occurred during rapid increases of atmospheric $\delta^{14}C$ flux (Blackford & Chambers 1995; Kilian *et al* 1995; Mauquoy & Barber 2002).

Short-term climatic fluctuations

Seasonal to centennial-scale fluctuations are currently the focus of much research into Holocene climate history, based on evidence that regionally-specific multidecadal temperature anomalies of c. 0.5-1°C characterised late Holocene variability, such as the MWP and the LIA (Bradley & Jones 1992; Hughes & Diaz 1994). Such fluctuations are best highlighted by fine-resolution terrestrial palaeoclimate records. Centennial-scale fluctuations in $\delta^{18}O$ were observed to dominate over lower-resolution periodicities in the late-Holocene section of the Crag Cave stalagmite (McDermott *et al* 2001). Various causal mechanisms have been debated for such rapid, low-frequency shifts: solar forcing, volcanism, internal variations within the coupled ocean-atmosphere system, oceanic variability, and trace gas variability (Crowley & Kim 1993; Rind & Overpeck 1993). Modelling has predicted that any of the above factors could be capable of causing regional temperature anomalies of 0.5-1°C (Rind & Overpeck 1993), however the evidence for volcanic influence has been argued as overstated (Crowley & Kim 1993). With reference to the aforementioned recent evidence for oceanic enhancement of solar fluctuations, it appears increasingly likely that this is a promising area of future research into short-term climate changes.

2.3.3.2 Evaluating the various palaeoenvironmental records

A problem with the reconstruction of palaeoclimates from terrestrial proxies from the mid-Holocene onwards is the complicating issue of human activity. If a proxy record itself has not been directly affected by humans, then anthropogenic alterations of ecosystems may well have caused environmental changes apparent in the record. Therefore palaeoenvironmental proxy records of the mid- and late-Holocene have often been interpreted as dominated by anthropogenic activity, whereas the early Holocene records are interpreted as climatically-driven (e.g. Selby *et al* 2005).

The most marked Holocene (post-Younger Dryas) cooling events are the 8200 cal. BP event and the LIA (O'Brien *et al* 1995; Alley 2000, 1333; Alley *et al* 1997, 483; Broecker 2000; Keigwin & Boyle 2000). The most noticeable events in the deep-sea sediment study by Oppo *et al* (2003) were those at c. 5000 BP and the LIA. The interval between 5000 and 6000 cal BP was marked as an especially prominent peak in cosmogenic nuclide production by Bond *et al* (2001).

Irish proxy records of Holocene climate change are summarised in Figure 2.20. Pollen, geochemical, magnetic and stable isotope ($\delta^{18}0$ and $\delta^{13}C$) investigations at Tory Hill, Co. Limerick, suggest that rapid climatic amelioration occurred subsequently to the Nahanagan (Younger Dryas) stadial, from c. 11450 – 11280 cal. BP (O'Connell *et al* 1999, 204). In the early Holocene, data is available from stable isotope records in speleothems and lake sediments. In the Crag Cave stalagmite rapid early-Holocene warming was evident, possibly in response to the melting Laurentide ice-sheet (McDermott *et al* 1999, 1033). Shifts in oxygen isotope ratios generally did not correspond to the quasi-1500-year ice-rafting episodes (ibid., 1330; see Bond *et al* 1997; 1999). Coupling of cold events in the Crag Cave and GISP2 records occurring in the early- to mid-Holocene (see Figures 2.20 & 2.21) were interpreted as centennial-scale manifestations of regional North Atlantic margin climate signals, rather than local effects (McDermott *et al* 2001, 1330). The inferred cause was THC fluctuations, as the impacts were better detected than those of lower-frequency IRD events, and mid-to late-Holocene ice-rafting failed to impact on $\delta^{18}0$ at this site (ibid.).

The Crag Cave stalagmite $\delta^{18}0$ record was interpreted as recording a cooling trend on the Atlantic seaboard between c. 7800 and 3500 cal. BP, followed by warming continuing until the present day (McDermott *et al* 1999). There is some agreement of the Sutherland speleothem and humification records with GISP2 records, but forcing mechanisms are complex, primarily because effects of temperature and precipitation are difficult to distinguish (Charman *et al* 2001, 232-233).

The major results and trends seen in long-term tree-ring records from various studies in northern Europe are presented in Figure 2.22. Ring-width studies have had variable success correlating with records from other regions and other proxies (Grudd *et al* 2002; Helama *et al* 2002), however most chronologies seem to indicate cooling with high variability in the late third millennium BP and a cold climate in the mid-late second millennium BP (Grudd *et al* 2002; Helama *et al* 2002). Reasonable correlation between Irish and continental (German and Dutch) ring-width chronologies was observed between c. 7500 and 4000 cal. BP, with either increased human influence or a shift in growing conditions in one or both regions effecting asynchronous growing dynamics after this point (Leuschner *et al* 2003). A common forcing factor has been interpreted causing the often contemporary germination, die-off and growth-depression events in the Irish ring-width records (ibid., 702).

Palaeoclimatic proxies from British and Irish ombrotrophic mires are presented in Figure 2.23, with the identified periods of wetter climate marked by shading. Atmospheric circulation has been reconstructed primarily by reference to lake-level reconstructions on a regional scale. Results from major European published studies are presented in Figure 2.22. A synthesis of northern European Holocene lake-level changes showed that from 11500 cal. BP in the band from southern British, southern Scandinavian to the eastern Baltic, climatic conditions became increasingly dry, whilst lake-levels in northern Britain were higher indicating a wetter climate (Yu & Harrison 1995). After c. 10200 cal. BP a more meridional circulation regime emerged, with the regions suffering wetter conditions confined to the extreme northwest of Europe. From 8900 cal. BP the band of lakes with regressed conditions spread northwards, and between 6800 and 4500 cal. BP most of northern Europe was drier than at present, with wetter conditions in the far north such as Iceland. By 3200 cal. BP wetter conditions prevailed in Britain, lasting until after 2000 cal. BP. These patterns were translated into a reconstruction of atmospheric circulation, whereby a more zonal circulation system caused the early Holocene contrast between wet conditions in northern Britain and northern

Scandinavia and drier conditions in southern Britain and southern Scandinavia. Westerlies would have been more strong and northerly than today. (ibid., 266-267).

An alternative hypothesis whereby the LIA was correlated with more enhanced meridional circulation patterns has been proposed by Lamb (1977). This has been given recent support; impurities in Greenland snow peak in the northern hemisphere winter when meridional flow is intensified, thereby indicating that the cooling periods observed by glaciochemical records in the GISP2 core correlate to meridional circulation (O'Brien *et al* 1995, 1962).

2.3.3.3 Correlating the various records

Correlation between climatic shifts registered in different proxy records is hampered by the differing resolutions, levels of sensitivity, and governing environmental constraints. In addition to the 8200 cal. BP event, analysis of the various terrestrial records confirmed the LIA as a major cold period and added additional detail regarding its progress, identifying various phases of extreme cooling within the overall period concerned. The 6100-5000 cal. BP cooling phase seen in the Greenland ice core and cosmogenic nuclide records is not especially well highlighted in many terrestrial records, although cooler or wetter episodes within it are present in some records, and indeed several of the peat stratigraphies under study were apparently initiated during this timespan. The most frequently recognised periods of climatic deterioration apparent in the terrestrial records described above occur at c. 4500-4000, c.2700-2300, c. 1400, c. 1000, c. 540 and c. 300-100 cal. BP; with cooling periods also noted (in multiple, but less frequent) records at c. 5300, c. 3500, c. 3200-2800, c. 1900, c. 1750 and c. 700 cal. BP. Peat stratigraphies have provided most of this evidence. It must be noted that due to the dating methods applied the correlations are often imprecise, with some smearing of the chronological boundaries of each identified climatic episode (cf. Baillie 1991).

Taking into account the problems of applying accurate, precise chronological boundaries in incremental records (especially peatlands) the aforementioned most frequently recognised periods of climatic deterioration on the British Atlantic seaboard can be summarised thus: c. 8200 cal. BP, c. 6100-5000 cal. BP, c. 4500-4000 cal. BP, c.3200-2300 cal. BP, various phases over the second millennium BP, and the LIA. These periods have been highlighted by shading in Figures 2.22 and 2.23. Only the periods directly relevant to this study are discussed in detail.

2.3.4 Timing and nature of Holocene climatic events

2.3.4.1 The period 6100 – 5000 cal. BP

Glaciochemical ice core evidence of atmospheric reorganisation at c. 6100 to 5000 cal. BP (O'Brien *et al* 1995) can be tentatively correlated to the c. 5900 cal. BP IRD event (Bond *et al* 1997) and several peat-based indications of wetter bog surfaces, taking into account the problems associated with correlating different proxy records. As increasing volumes of data are analysed, the period in question appears to be characterised by several discrete events. A complex series of rapidly fluctuating climatic parameters could have had implications for human responses. The ability to adapt to rapid changes in environmental conditions may have influenced the long-term success of human societies in vulnerable locations.

The c. 6100 cal. BP climatic shift has been interpreted as triggering an increasingly continental climate in northwest Europe, prompting exaggerated seasonal temperature differences (e.g. O'Brien *et al* 1995). Effects on vulnerable human communities and vegetation taxa are discussed in Sections 2.2.1.3 and 2.2.1.4.

A significant event of extreme storminess at c. 5200-5100 cal. BP has been inferred from a layer of silt preserved in blanket peat at Achill Island, Co. Mayo (Caseldine *et al* 2005). Whilst the period 5800 – 5200 cal. BP was apparently one of relative climatic dryness, extreme dry conditions just before c. 5200 cal. BP were evidenced in humification records (ibid., 172), similar to the inferences from Céide Fields (Molloy & O'Connell 1995, 219). At Achill Island, *Pinus* invaded the (presumably dry) peat surface in the period immediately post-dating the c. 5200 – 5100 cal. BP event, for a brief duration of a few generations. Occurring immediately prior to a shift to wetter climatic conditions (seen in decreasing humification and increasing peat accumulation rates), the storminess was interpreted as a manifestation of the regionally significant shift in North Atlantic climate dynamics. The storminess was tentatively correlated with the abandonment of Céide Fields. Similarly to Céide, Achill Island contains evidence of occupation in the Early to Middle Neolithic occupation (though in the form of megalithic tombs rather than definite agricultural systems), but not the Late Neolithic; a situation characteristic of Irish pollen profiles during the c. 5200 – 4500 cal. BP *Pinus* expansion (ibid., 175; Cooney 2000).

2.3.4.2 4500-4000 cal. BP

The later Holocene is typified by more frequent climatic excursions, arguably of lesser magnitude, and on a more regional basis, than the early- and mid-Holocene (Barber *et al* 1994; O'Brien *et al* 1995; Spurk *et al* 2002; Tipping & Tisdall 2004, 76). The interlude 4500 – 4000 cal. BP is characteristic of this; with modest peaks in North Atlantic IRD (Bond *et al* 1997; 2001), and evidence of climatic deterioration in British peat stratigraphies (Barber *et al* 1994; 2003; Anderson 1998; Anderson *et al* 1998). NAO weakening by a reduced Azores High and resulting contraction of the jet stream was inferred by Gear & Huntley (1991), bringing cooler, wetter summers to the Atlantic fringe of northern Europe.

It has therefore been proposed that an increase in variability of climate was of major significance during this period (Tipping & Tisdall 2004, 76). The *Pinus* decline is a probable example of a species reducing its range limits at its environmental margins during this period (see section 2.2.3.4). Human responses in the British Isles to climatic fluctuations have proved more difficult to gauge. Settlement expansion into upland areas after this period, at c. 4000 – 3500 cal. BP has been postulated (Burgess 1980; 1984; Cowley 1998; McCullagh & Tipping 1998; Tipping 2002), possibly indicating uptake of increased opportunities for pastoral agriculture provided by upland woodland collapse (Tipping & Tisdall 2004, 76-77).

2.3.4.3 c. 3200-2300 cal. BP

The chronological precision of a climatic shift at this period is poorly defined, but quasi-corresponding cooling events exist in the IRD record (Bond *et al* 1997), the GISP2 glaciochemical index (O'Brien *et al* 1995) and benthic foraminifera assemblages from subpolar Atlantic deep-sea sediments (Oppo *et al* 2003), with most of the peat-based proxy reconstructions showing similar trends (see Figure 2.23 and section 2.3.3.2). This millennial-scale cooling signal may in fact represent the combination of several discrete events. The IRD event and benthic foraminifera assemblage shift are well-dated to c. 2800 cal. BP and several peatland studies show cooler and/or wetter conditions prevailing from around this point (Mauquoy & Barber 1999a; Barber *et al* 2003; Langdon *et al* 2003). Similarly, a sudden, sharp rise in atmospheric ^{14}C at 2800-2710 cal. BP (coinciding with the IRD event) has been recorded and correlated with transitions in northwest European raised bogs from macrofossil assemblages signifying warm, dry conditions to those indicating humid, cold conditions, reflecting a shift to an increasingly oceanic climate (Kilian *et al* 1995). As more data emerge from Europe, the Americas and Asia, climatic teleconnections relating to a considerable abrupt climate change at c. 2800 cal. BP have been postulated (van Geel *et al* 1998). Alternatively, the more prolonged GISP2 event, though apparent, is less marked than other such increases in impurities (O'Brien *et al* 1995, 1962). Again, a generally more variable climate may well have characterised the period in question with a particularly marked climatic event at c. 2800 cal. BP.

This period and the LIA are the principal phases of Holocene climatic change which have been explored in detail by archaeologists and landscape historians with reference to human settlement (Tipping 2002, 15). Contraction of upland settlement in the British Isles has been proposed (see Section 2.2.3.5) and hitherto accepted as a generalisation (e.g. Armit & Ralston 1997, 188; Mitchell & Ryan 2001, 236). Due to the chronological resolution of the archaeological record and the complex societal factors in existence, such oversimplifications are increasingly being queried or revoked (Tipping 2002; Young & Simmonds 1995; Cooney & Grogan 1999, 141-142; see Section 2.2.3.5).

2.3.4.4 The second millennium cal. BP

A climatic cooling at c. 1400 cal. BP is registered in many peat-based records (e.g. Blackford & Chambers 1991) as well as by an IRD event (Bond *et al* 1997), though not in the GISP2 record (O'Brien *et al* 1995). There are some, but fewer, terrestrial indications of short-lived cold phases at c. 1900 and c. 1750 cal. BP (see section 1.4.2.2). The general picture is of an unstable climate in the early second millennium BP with a markedly cold phase at c. 1400 cal. BP. This event has only recently been defined (in contrast to the Late Bronze Age and LIA climatic downturns), and no human response to this event has been recorded or suggested in northern or upland Britain, supporting arguments that archaeological evidence of abandonment is only sought when evidence of climate change exists already (Tipping 2002, 15).

2.4 Irish Holocene environmental history

2.4.1 Pedogenesis

Pedogenesis is affected by climate, relief, time, parent material and biota. Holocene soil maturation in Ireland has been affected to varying degrees according to location (see Figure 2.24; Gardiner & Radford, 1980). Soil development from the C- (unaltered) horizon in the post-glacial landscape depended upon parent material, and as extensive drift deposits cover most of Ireland, solid geology is relatively unimportant (Curtis *et al* 1976, 147). Although full weathering of soil parent materials can take many millennia (Cruickshank 1970, 90), Dimbleby (1965, 355) estimated that most of Britain's soils would have been mature by the mid-Holocene.

Predominant downward water movement in Ireland resulted in surface leaching and therefore gradual acidification of soils and sediments (Mitchell & Ryan 2001, 103). In much of northern and central Ireland, clay-rich tills prevented soil horizon development and so luvisols and gleys (surface-water, ground-water and peaty gleys) are present (Cruickshank 1970, 92; Mitchell & Ryan 2001, 103-104). Brown earths developed in areas of coarser, better drained parent material (e.g. cambisols of the north-east), although no virgin brown earths remain today due to anthropogenic influences (Cruickshank 1970, 92). Acid brown earths, somewhat leached soils with developed B-horizons, formed where non-calcareous basal material predominated (e.g. cambisols of the south-east). In higher rainfall areas - the south-west - leaching is more intensive and podzolisation has occurred, giving rise to brown podzolic soils, and peaty podzols in upland areas where plant decomposition is delayed by lower temperatures and higher precipitation/evaporation ratios. Histosols – organic soils – in this case refer to peatlands; the lowlying Atlantic blanket mires, the upland blanket mires and the raised mires most common in the centre of the island.

Progressive acidification of soils in temperate climates, *via* leaching and podzolisation of (principally) brown earths, is accepted to be most noticeably manifested on base-poor soils (Iversen 1969; Dimbleby 1962; 1965; Simmons *et al* 1981, 98). Such acidification was conventionally believed to have occurred in late interglacial times, when soils were fully mature (e.g. Andersen 1961) though arguments have been made for earlier degradation (early- or mid-Flandrian) in certain fragile environments such as base-poor upland soils (e.g. Simmons 1964; Dimbleby 1962; 1965; Simmons *et al* 1981, 98). Evidence from Scotland is suggestive of significantly earlier acidification (Davidson & Carter 1997); podzolisation in areas of freely draining, coarse-textured parent materials (e.g. McCullagh 1993) and gleying in finer-textured parent materials (e.g. Pennington *et al* 1972) leading to peat development. Peat initiation therefore occurred on both fine- and coarse-textured parent materials. It has been argued that by the Neolithic, when the first widespread and long-term human impacts upon soils were initiated, the present-day pattern of soil distribution in Scotland was already established (Davidson & Carter 1997, 57). A similar sequence may have occurred in Ireland as its climate is similar to that of Scotland and its geology also largely covered by drift.

Pedogenesis from the mid-Holocene onwards is more complex to reconstruct because of increasing human influence. In the west of Ireland, the area under study, peat initiation and spread have been the most prominent and widespread modes of soil evolution. Histosols now cover a significant proportion of County Mayo (see Figure 2.24) and from the surveys of Herity and Caulfield undertaken in the 1970s (see Section 2.2.2.2) it is known that in many locations blanket peat is a superficial deposit overlying mineral soil (see Herity & Eogan 1977, 50; Caulfield 1978, 137; 1983, 196-7).

Raised bog development had begun in the early- to mid-Holocene from terrestrialisation of marshes and lakes (e.g. Bradshaw 1987), and was probably a natural process (Bradshaw 2001, 436). Outside of small basins, large-scale blanket bog spread was largely a post-*Ulmus* decline phenomenon, which has led to ongoing debate over its primary causal factors – climatic, pedological, or anthropogenic (see O'Connell 1990a). In some areas of Co. Donegal blanket bog initiation commenced earlier in the Holocene, in two main phases; from c. 10100 - 9150 cal. BP, concurrent with increasing woodland diversity and loss of canopy cover associated with tree invasions, and from 5700 and 5150 cal. BP as woodland declined (Fossitt 1994, 26). These developments, whilst atypical for Ireland, are useful in the study of more general later Holocene blanket peat spread. The early Holocene blanket bog spread was apparently a natural process in areas which were marginal for tree growth, with no associated soil deterioration or podzolisation (ibid.). The mid-Holocene peat initiation phase in Co. Donegal may have commenced naturally, however human activity probably contributed to its spread (ibid.), by suppressing tree growth and woodland regeneration. This situation has been compared to lowland Atlantic blanket bog expansion further south (O'Connell 1990a; Huang 2002).

Elsewhere, radiocarbon dates have been obtained from Irish blanket peat showing initiation dating from c. 8000 to less than 1000 cal. BP, with pollen and plant macrofossil evidence showing that woodland occurred under almost all areas now covered by blanket bog (Bradshaw 2001, 437). Occurrences of archaeological evidence for human settlement at various times underneath blanket peat have prompted theories that anthropogenic activity, especially forest clearance and agriculture, may have initiated blanket bog spread in some areas (e.g. O'Connell 1990a). This theory is similar to that which Moore (1975; 1986) developed in mainland Britain, whereby small raised bogs developed in natural topographic depressions and lakes, and acted as *foci* for further peat development. Increased run-off from human or natural canopy opening would enhance peat development, with more widespread waterlogging induced by extensive deforestation, burning and grazing. The crux of this model is that the more optimal the location for forest growth, the more necessary was human impact for initiating blanket peat growth (Bradshaw 2001, 437). Areas marginal for tree growth would therefore require less interference for blanket bog to initiate and spread.

At present, peat erosion is apparent in all mountainous areas of Ireland, manifested by gullying on slopes and deep channel incision on plateaus, culminating eventually in freestanding peat haggs (Bradshaw & McGee 1988). Peat erosion has been registered in Irish lake sediments for up to 3000 years (Bradshaw & McGee 1988; McGee & Bradshaw 1990, 117) and the factors governing sensitivity or susceptibility to erosion appear to have varied. Mechanisms to maintain stability appear to be incorporated in intact mire systems and erosion results when the stability threshold is crossed, which occurs under particular circumstances. Factors as climate change, human disturbance, overgrazing, atmospheric pollution and changes in the mechanical stability of peat masses over time have been suggested to cause passing of this threshold (Stevenson *et al* 1990; Bragg & Tallis 2001). Causal factors appear to vary according to location: some studies have suggested that susceptibility to anthropogenic interference is heightened during periods of climate change (Bragg & Tallis 2001; cf. Stevenson *et al* 1990). Similarly, Bradshaw (2001, 437; see also Bradshaw & McGee 1988) has argued that peat erosion is probably an autogenic process on sloping ground, and human activity may have accelerated its progress. In other ecosystems, however, long-term stability has been displayed and recent erosion has been correlated with the upland extension of grazing in the 18th and 19th centuries AD (Huang 2002, 163-164).

2.4.2 Vegetation history

2.4.2.1 General vegetation history

This section employs the classical Blytt-Sernander scheme subdividing the Holocene into pollen assemblage zones. The divisions have been applied *sensu* Mitchell (1956), delimited by palynological reference points rather than by radiocarbon dated horizons.

The primary cause of Ireland's reduced range of native flora and fauna in comparison to mainland Britain is the post-glacial severing of the land bridge. Various arguments regarding the presence of a land bridge have been advanced (Devoy 1985; Preece *et al* 1986) and new modelling suggests that the glacial forebulge would have exposed migrating sea-bed sand-ridges in the Early Holocene (Wingfield 1995).

The classic Irish postglacial pollen diagram was from Littleton Bog, Co. Tipperary, which gave its name to the term for the Irish postglacial; the Littletonian (Mitchell 1965). In addition to the complete or near-complete Holocene records from raised bogs in the Irish Midlands, lake sediments have been used for early Holocene vegetation reconstruction (e.g. O'Connell *et al* 1988; Fossitt 1994; Huang 2002; Molloy & O'Connell 2004; Selby *et al* 2005). Generalisations can be made from comparisons of such pollen profiles to form an outline scheme of vegetation successions.

An early postglacial flora of disturbed-ground herb taxa such as Poaceae, *Rumex* and *Filipendula*, with *Empetrum* heath, was rapidly colonised by the scrub taxa *Juniperus* from c. 12350 cal. BP, followed by *Betula* at c. 11500 cal. BP and then *Salix* (Fossitt 1994, 23; Huang 2002, 159; Molloy & O'Connell 2004, 51). *Betula pubescens* has been presumed to be the major taxa (O'Connell 1980, 313), though *B. nana* may have been a lateglacial survivor (Mitchell & Ryan 2001, 109). By c. 10800 cal. BP the *Salix/Juniperus* scrub had mostly been overtaken by *Betula*, and *Corylus* appeared. *Pinus*, the first canopy species to invade, appeared in western Ireland as the *Corylus* expansion commenced at around 10350 cal. BP (O'Connell *et al* 1988, 283; Molloy & O'Connell 2004, 51). Similar sequences occurred in midland and north-central Ireland, though *Pinus* apparently never reached such high proportions on base-rich lithology (Bradshaw & Browne 1987; Selby *et al* 2005, 158-160). The *Corylus* maximum is fairly well-dated in western Ireland to the centuries around 10100 cal. BP (see Section 2.4.3.1). *Pinus* peaked shortly after *Corylus*, and between c. 10000 and 9000 cal. BP *Quercus* and *Ulmus* became slowly established (Molloy & O'Connell 2004). Persistence of some open ground populated by herbs such as *Plantago* spp., *Rumex*, and *Helianthemum* is evident into the Boreal period in the extreme west, probably due to unfavourable edaphic conditions (e.g. the Aran islands: Molloy & O'Connell 2004). The *Alnus* rise, traditionally characteristic of the onset of the Atlantic period in northwest Europe, began asynchronously between c. 8000 - 7500 cal. BP (Fossitt 1994, 23), coincident with the spread of damp soils (e.g. Huang 2002, 159; Selby *et al* 2005, 160). As most Irish sites show a decline in *Pinus* percentages coincident with the *Alnus* rise, suggestions have been made that *Pinus* was replaced by *Alnus* in the lowlands, possibly in response to increased waterlogging, and by blanket peat in the uplands at a similar time (Bradshaw & Brown 1987, 214; Bennett 1984). As there are indications of peaks in microscopic charcoal frequencies before the *Alnus* rise in some Irish profiles, suggestions have been made that forests may have been deliberately opened to attract game and that *Alnus* capitalised on the clearances (Bradshaw 2001, 438).

The Atlantic woodlands (here considered to represent the time in between the *Alnus* expansion and the *Ulmus* decline) represent the vegetational response to the Holocene climatic optimum of c. 9000 – 6000 cal. BP, when temperatures have been estimated at 1-2°C higher than those of the present day (Bell & Walker 1992, 70-71), although this is a generalisation not accounting for the fluctuations outlined above. Composition of the Atlantic woodlands varied according to location, largely influenced by edaphic conditions (Bradshaw 2001). In western Ireland, many pollen diagrams indicate that the dominant taxa were *Quercus*, *Pinus* and *Corylus*, with *Ulmus* of lesser significance, although it is usually under-represented in the palynological record (Bradshaw 2001, 433; Molloy & O'Connell 2004). *Quercus* and *Ulmus* were commonly dominant in midland Ireland (e.g. Selby *et al* 2005, 160), with *Ulmus* frequently predominant in base-rich lithology (see O'Connell 1980, 309). *Alnus* was the principal taxa of wetter soils and lake margins, and in most upland areas *Pinus* and *Betula* dominated (ibid., Bradshaw 2001, 433; Huang 2002, 159; cf. Bradshaw & Browne 1987). Other well-represented taxa in lowland habitats included *Populus*, *Ilex*, *Hedera helix*, and woodland-edge taxa such as *Prunus* and *Sorbus* (Fossitt 1994, 23; Bradshaw 2001, 433; Huang 2002, 159). As woodland diversity increased, open areas became more frequent in western Ireland and NAP percentages (e.g. tall shrubs such as *Rhamnus cathartica* and *Viburnum opulus*, and Poaceae, Cyperaceae, *Calluna* and *Pteridium*) increased (Fossitt 1994, 23; Molloy & O'Connell 2004, 51). *Taxus* and *Fraxinus* were present, but better-represented in more open conditions (Fossitt 1994, 23; Molloy & O'Connell 2004, 52). Deciduous tree species native to mainland Britain that never became established in Ireland are *Tilia*, *Carpinus* and *Fagus*, with uncertainty remaining as to whether the Irish Sea or subtle temperature constraints acted as the barrier that prevented *Tilia* from spreading (Bradshaw 2001, 430).

Some western Irish pollen diagrams show evidence of the pre-*Ulmus* decline presence of *Plantago lanceolata* (e.g. Huang 2002; Molloy & O'Connell 1987; 2004). Although *P. lanceolata* has been traditionally considered a strong indicator of agricultural activity (Behre 1981; Groenman van Waateringe 1986) such incidences are unlikely to represent farming activity in western Ireland, where pronounced Neolithic Landnám phases invariably occur after the *Ulmus* decline (Molloy & O'Connell 2004; see also O'Connell & Molloy 2001). The *Ulmus* decline is well-dated to c. 5900 cal. BP, although it is not a feature of all Irish pollen profiles, especially those in upland, wet locations where conditions were never favourable for the taxon or where woodland was already open (Fossitt 1994, 24). The arguments regarding causality of the *Ulmus* decline are summarised in Section 2.2.1.3; but in western Ireland there is little evidence for contemporaneous human activity, therefore early settlement may have been facilitated by increased openings and clearances provided by the demise of *Ulmus* (O'Connell *et al* 1988, 285; Fossitt 1994, 24; Molloy & O'Connell 2004, 58). Multiple or complex, protracted *Ulmus* declines are features of some Irish pollen diagrams (O'Connell 1980; Hirons & Edwards 1986, 147-148; Heery 1997; Selby *et al* 2005), and have been ascribed to the influence of anthropogenic activity (O'Connell 1980; Hirons & Edwards 1986; Selby *et al* 2005).

Due to the complicating factor of human influence, it is difficult to detect authigenic vegetational changes or those forced by alterations in climatic or edaphic conditions from the

Sub-boreal onwards. Landnáms evident in pollen diagrams in western Ireland are invariably post- *Ulmus* decline (O'Connell & Molloy 2001; Molloy & O'Connell 2004, 52) although, based on securely stratified cereal pollen grains, small-scale agriculture immediately prior to or during the *Ulmus* decline has been occasionally recorded (e.g. Molloy & O'Connell 1987; Huang 2002) and is assumed to have been practised upon the better soils such as brown earths (Huang 2002, 162). Landnáms were typified by decreases in AP and substantial increases in NAP, especially Poaceae and *Plantago lanceolata*, indicating extensive grassland creation at the expense of woodlands. Canopy openings following the *Ulmus* decline and Neolithic Landnáms favoured light-demanding tree taxa such as *Fraxinus* and *Taxus*, which are better represented in Sub-boreal than Atlantic period (e.g. Fossitt 1994, 24; Bradshaw 2001, 438; O'Connell et al 2001, 179-180; Selby *et al* 2005, 160). Whilst woodland regeneration often occurred in post-Landnám contexts, some upland landscapes were characterised by secondary woodland of a scrubby nature, as evidenced by increases in such taxa as *Juniperus* and *Ilex* which are grazing-tolerant and could represent the use of woodland for pasture (Huang 2002, 162). Elsewhere, an expansion of *Corylus* has been seen in secondary Neolithic woodland clearance phases, possibly due to inferred resistance to burning and grazing (Pilcher & Smith 1979, 360).

The expansion of *Pinus* between around 5700 and 5150 cal. BP and its subsequent decline at c. 4500 cal. BP have been discussed in detail in Section 2.2.3.4. Whilst the *Pinus* decline has been associated with blanket bog spread in the uplands (Bradshaw & Browne 1987), in Connemara a delay of c. 200 years between the decline of pine (and coincident expansion of *Taxus*) and the major blanket bog expansion has been noted, suggesting no causal connection (Huang 2002, 162). Blanket bog spread in western Ireland from c. 4500 cal. BP has been associated with maintenance of open ground (O'Connell 1990a) and the upsurge in farming activity at the beginning of the Bronze Age (Huang 2002). Referring to the model of blanket bog spread described by Moore (1986: see Section 2.4.1), the decline of *Pinus* (a tree of marginal edaphic conditions) due to environmental marginality would indicate heightened edaphic vulnerability to blanket peat spread. After the *Pinus* decline the species survived in low numbers (though not in significantly waterlogged upland locations), becoming more or less extinct by the third millennium BP, although occasional specimens may have survived until c. 1000 cal. BP (Bradshaw & Browne 1987, 246). Widespread replanting took place in the 17th and 18th centuries AD (ibid.).

Woodland instability and subsequent woodland decline in the Subboreal varied across Ireland, with the transition to a treeless blanket bog landscape occurring earliest in the north-west (Fossitt 1994, 27). Arguments that human agency was largely responsible for woodland decline in Ireland have been to some extent favoured by evidence of its asynchronicity, although the variability of ecosystems in different environmental locations to withstand externally-forced stress means that woodland regeneration would be more successful in some areas than in others (ibid.). In Connemara, considerable human impact from c. 3750 cal. BP (Late Bronze Age) has been linked to woodland decline and blanket bog spread, with fire important in effecting the transition (O'Connell *et al* 1988, 285).

In some areas of Ireland, human-induced landscape clearance did not take place until post-Neolithic times, such as Mooghaun, Co. Clare (see Section 2.2.3.1). The implications of increasing grazing pressure on Bronze Age landscapes, and consequent blanket peat spread, suggests pastorally-based agriculture dominated during much of this period in western Ireland (Molloy & O'Connell 2004, 53). Increased forest clearance in the early- and mid-Iron Age is seen frequently in Irish pollen profiles (O'Connell *et al* 2001; Molloy & O'Connell 2004). This often represented the final phase during which dense woodland occurred; for instance, in Co. Donegal, blanket peat dominated the landscape and woodland was scarce after c. 2400-1500 cal. BP (Fossitt 1994, 28).

The Late Iron Age, c. 1850 – 1450 cal. BP, has typically been seen as period of relative forest resurgence and reduced farming activity in Ireland, especially the western portion (Mitchell 1986; cf. Lynch 1981; Jeličić & O'Connell 1992; O'Connell 1994; O'Connell & Ní Ghráinne 1994; Molloy & O'Connell 1993; 1995; 2004, 54; O'Connell *et al* 2001, 173 & 180-181; Lomas-Clarke & Barber 2004). This is not, however, universal. Killarney Valley, Co. Kerry, has palynological evidence of disturbance and large-scale deforestation and mixed farming, implying a large population (Mitchell 1988). Dendrochronological evidence shows that the wooden trackways of midland Ireland were constructed and maintained at a constant rate during the Iron Age (Bradshaw 2001, 439). In Co. Louth, eastern Ireland, some sites record a late Iron Age forest regeneration whilst others show major clearance (Weir 1995). A Late Iron Age lull in farming activity cannot therefore be extended to the whole island.

The Early Medieval period, from c. 1400 to 1000 cal. BP, has been described as the final woodland demise in Connemara (O'Connell *et al* 1988, 286) and this extends to Ireland as a whole. Expansions of NAP indicating an upsurge in farming activity are characteristic of pollen profiles (Weir 1995; O'Connell *et al* 2001, 178; Lomas-Clarke & Barber 2004; Molloy & O'Connell 2004, 55). Mixed agriculture continued into the Anglo-Norman and early Modern periods, with increasing *Quercus* values and concurrent declines of other AP taxa, indicating that woodland management such as coppicing or pollarding may have occurred (Lomas-Clarke & Barber 2004). Recent high-resolution palaeoenvironmental investigations and comparisons with historical records have allowed more detailed reconstruction of vegetation dynamics during the last millennium. Tephrochronology has dated agricultural collapse in the lowlands to c. 20 years after the mid-14th century AD Black Death, indicating either a population decline or abandonment of less favourable agricultural land (Hall 2003, 15). General reductions or temporary cessations of cereal cultivation, with persistence of pastoralism, are evident in most Irish pollen records of the late Middle Ages (ibid.).

Major human impact on the western Irish landscape commenced in 17th century AD (Cole & Mitchell 2003; Lomas-Clarke & Barber 2004), as population pressure increased following land confiscation elsewhere (O'Connell *et al* 1986, 286). This culminated in the period of maximum population pressure during the early 19th Century AD, regarded as representing the greatest impact upon the landscape in terms of floral and faunal extent and diversity (Bradshaw 2001, 439). Management strategies in the past century have revived forest cover somewhat, with reduced diversity (ibid.).

2.4.2.2 Pollen profiles from North Mayo

Garrynagran

A blanket peat monolith from an area of sandstone bedrock in Garrynagran townland, 16km south of Céide Fields, was palynologically investigated by Jennings (1997) and results partially published in O'Connell & Molloy (2001). Site location is indicated in Figure 2.25. Two court tombs and adjacent pre-bog stone walls occur within 2km of the sampling site (ibid., 108). *Pinus* stumps are preserved within the blanket bog (ibid.). In common with many western Irish pollen profiles (see section 2.2.1.1) the *Ulmus* decline at c. 5950 cal. BP clearly occurred some two centuries earlier than the Neolithic Landnám, (see pollen profile in Figure 2.26; O'Connell & Molloy 2001, 110). Low microscopic charcoal values suggested that fire was not important in woodland clearance. NAP components indicated that substantial pastoral agriculture with a minor cereal component typified the Neolithic activity, within a wider landscape in which woodland was still important. This agricultural phase ceased or became drastically reduced by c. 5150 cal. BP. Re-emergence of agricultural activity occurred in the Late Neolithic / Early Bronze Age, at c. 4500 cal. BP (ibid.).

Lough Doo

This site, situated at the junction of the Ballina lowlands and the south western part of the Ox mountain range (see Figure 2.25), was investigated by O'Connell *et al* (1987) and further discussed in O'Connell (1990b). Probably lying on psammitic (metamorphosed sandstone) bedrock, the solid geology in the vicinity of the lake is covered by drift (O'Connell *et al* 1987, 150). The pollen and geochemical profiles are reproduced in Figures 2.27 and 2.28. The topmost two radiocarbon dates (see Appendix A) were considered inverted, resulting from recent severe inwash of older humic soil horizons (ibid., 156; O'Connell *et al* 1988). Similarly to Carrownaglogh, the wide error margins associated with the radiocarbon assays reduces the precision of interpretation, and to all practical purposes the radiocarbon chronology is useless. The zonation therefore defines chronology in this discussion.

Sedimentation began before the *Alnus* expansion, with some degree of openness in the woodland landscape evident. Soil erosion in the catchment during DOO-1 was indicated by low loss-on-ignition and relatively high levels of K, Mg and Na (see Figures 2.27 and 2.28). Before the upper zone boundary a peak in *Pinus* (see Figure 2.27) records its expansion onto the lake margin, facilitated by falling water table levels; a situation subsequently reversed by the upper boundary (the *Alnus* rise: O'Connell *et al* 1987, 159). The Atlantic woodland was typical of western Ireland (see section 2.4.2.1) and geochemistry indicated stable soils. At the *Ulmus* decline, marking the DOO-2/3 boundary (see Figure 2.27), slight relative increases in tree pollen, the appearance of NAP, falling organic content and rising K and Na flux indicated substantial canopy opening, interpreted as caused by *Ulmus*-specific disease, rather than anthropogenic clearance (ibid., 158).

The *Pinus* decline at c. 4540 cal. BP (interpolated; note large errors) was gradual with no indications of human interference (O'Connell *et al* 1987, 158). Geochemistry indicated some catchment erosion and reducing conditions in DOO-3; although rising *Betula* and *Quercus* percentages preclude widespread podzolisation, paludification and blanket bog spread. The precedence of *Betula* over *Corylus*-type might however be interpreted as edaphic deterioration (ibid.). In a landscape context, the palaeoenvironmental signals in this zone of the *Pinus* decline and blanket bog spread accord with those at other sites in the North Mayo region, e.g. the nearby Carrownaglogh site (see above). At Lough Doo, where agriculture was not practised until the Middle Bronze Age, the mid-fifth millennium cal. BP indications of blanket bog spread are much more muted than at sites of known Neolithic occupation (e.g. Céide Fields, Carrownaglogh, Belderg Beg).

The first widespread deforestation and agricultural activity occurred in DOO-4, from c. 3750 - 2600 cal. BP (interpolated; O'Connell *et al* 1987, 158 & 162), in the Middle and Late Bronze Age. The Landnám was typical of woodland clearance for mixed farming, with an expansion of *Betula* indicating its colonisation of open ground in edaphically unfavourable areas. Peaks in Na, K, Mg and Fe indicated increasing erosion, and the increasing Fe:Mn ratio and rising percentages of Cyperaceae and *Calluna* suggested progressively severe reducing conditions, perhaps as a result of waterlogging (ibid., 161). General woodland recovery, with *Taxus* initially important, followed. Woodland regeneration equating to the Late Iron Age lull in farming activity (see Section 2.4.2.1) occurred in DOO-4 (from c. 1800 cal. BP [interpolated]; see Figure 2.27 & Appendix A).

DOO-5 saw a major phase of deforestation and a renewal of mixed agriculture in the locality (O'Connell *et al* 1987, 161). The reversal in radiocarbon dates, plus rising Fe:Mn ratios but steady loss-on-ignition values, indicate anoxic conditions, probably organic inwash. Blanket peat erosion in the catchment was suggested (ibid.). This phase was dated to post- AD 400; archaeologically supported by the nearby presence of Early Medieval church sites (ibid., 161-162).

Bunnyconnellan East

A short section from an undulating sub-peat soil surface on a glacial ridge in the Ox Mountains some 4km south of Carrownaglogh (see Figure 2.25 for location) was investigated to determine whether the ridge features were natural or relics of previous cultivation (O'Connell 1990b, 270). A sub-peat oval cairn of stones was discovered 5m from the sampling location, although whether it was constructed prior to peat initiation was unclear (ibid.). The sub-peat profile was an organic-rich soil overlying a gleyed horizon and a well-developed iron pan over an iron-enriched B_2 horizon (ibid.). The pollen profile is presented in Figure 2.29.

Palynological analysis suggested that pollen was differentially preserved in the soil, and that *Pinus/Corylus* woodland probably existed prior to peat inception (O'Connell 1990b, 270). Subsequently, increasing *Calluna* values probably reflect the local mire taxa, whilst the regional component was dominated by *Quercus*, *Corylus*, *Ulmus* and *Alnus*. There were no indicators of agricultural activity in these lower spectra. In the upper zone (after c. 3740 cal. BP), the uppermost spectra contained cereal pollen grains, *Plantago lanceolata* and elevated Poaceae percentages, with generally lower AP levels. A short-lived agricultural function was therefore proposed.

Chapter 3

Introduction to the study area

3.1 Introduction to Chapter 3

This chapter describes the archaeological site which is used as a case study to test previously held assumptions concerning the responses of prehistoric human communities to climate change. The site in question, Belderg Beg, is located in close proximity to the Atlantic Ocean, on the extreme western fringe of Ireland and thereby of the British Isles. It is established that climatic changes have occurred throughout the Holocene, forced by alterations in an integrated atmospheric-oceanic convection system, and that the manifestations of such changes were of greatest amplitude nearest the north-west Atlantic fringe. In order to assess the potential of the Belderg Beg site to contribute to knowledge of Holocene environmental changes, their effects on ecosystems, and any responses or adaptations by the people that lived on and farmed the land, an appraisal of current understanding of the Holocene climatic, environmental, edaphic and vegetational history of Ireland is required. The site at Belderg Beg and its environs are then discussed. Finally, the opportunities at Belderg Beg to investigate Holocene climate and environmental change and adaptive or buffering responses of the human inhabitants are assessed.

3.2 Belderg Beg

3.2.1 Location and present environment

3.2.1.1 Location

The archaeological site at Belderg Beg (NG F983407, longitude 8 degrees 0 minutes 0.000 seconds W, latitude 53 degrees 21 minutes 24.654 seconds N), lies at c. 50m OD in the townland of Belderg Beg, Co. Mayo. The site is located on a gently sloping hill which has an east-facing aspect. Modern settlement and road construction means that its original extent is unknown. Figure 2.25 shows the North Mayo area with sites considered in the thesis marked. Figure 3.1 shows a detail of the Belderrig area. Figure 3.2 shows the location of the site in its landscape context.

3.2.1.2 Geology

The bedrock geology of the area is the Grampian subdivision of the Dalradian supergroup. metamorphosed sedimentary rocks, with subordinate volcanic and intrusive rocks and some metamorphosed glacial deposits (Long *et al* 1992, 13). The rocks around Belderg consist of quartzites and psammitic schists (metamorphosed sandstones), with intrusive veins of Caledonian igneous metadolerite around Belderg harbour. Copper mineralization occurs frequently in Grampian group rocks along the North Mayo coast between Broad Haven and Killala Bay. The best known example occurs at Horse Island, approximately 2km north of Belderg, where the mineralization, including green malachite coatings, formed along the contact between a quartz vein and a basic intrusive dyke which both cross-cut quartzites (ibid., 33). Figure 2.12 shows the solid geology of the North Mayo area.

Devensian landscape development of the area is poorly understood. It is believed that Belderg lay outside the limits of the British and Irish ice sheet as it is several kilometres west of the Ballycastle-Mulrany moraine and the immediate area contains few or no drift deposits (Coxon 1991, 7-9). However, localised shelly drift deposits at Belderg harbour have been offered as evidence for localised glaciation or a Late Midlandian ice advance (ibid.). Decalcification of upper layers of this drift has occurred. Today the site is within an extensive area of blanket peat, classified as lowland Atlantic blanket bog (see Section 2.4.1).

3.2.1.3 Climate

Present-day Irish climatic features (30-year average mean annual rainfall, mean annual wind speed and wind direction for the island of Ireland and annual temperature range at Valentia, Co. Kerry) are presented in Figure 3.3.

Local climatic statistics reflect 30-year averages from the nearest national weather station, situated at Belmullet, 35km west of Belderg. Mean maximum and minimum annual temperatures are 12.5°C and 6.7°C respectively. Mean January and July daily temperatures are 5.7 and 12.6°C respectively. Mean annual rainfall is 1142mm. The mean annual sunshine hours are 3.5 per day. Mean wind speed is 13.1 knots, with a prevailing south-westerly direction.

3.2.1.4 Vegetation and land-use

Belderg Beg is within the area of Atlantic blanket bog, the low-lying ombrotrophic vegetation system complexes which are generally confined to the western seaboard counties of Ireland and which covers 120, 000ha of County Mayo. Atlantic blanket bog is characterised not only by relief but on the basis of its distinctive floristic composition (Doyle 1990; O'Connell 1990a). Varying in depth from 1.5 to 7m, it is permanently waterlogged due to low drainage capacity and high precipitation in relation to evaporation (Doyle 1990, 77). Typical vegetation of the north west Mayo Atlantic blanket bog complexes has been described by Doyle (1982; 1990). The blanket bog in the area under study corresponds to the 'valleyside mire' subcategory as defined by Lindsay (1995): occurring on sloping ground, bounded by a watercourse at the base of the slope, with linear pools oriented along the slope's contours (see also Charman 2002, 10).

Today, the vegetation at the archaeological site is somewhat drier than that of the surrounding blanket bog; this appears to be a product of the removal of peat for domestic fuel, the 1970s archaeological excavations and road-building. The vegetation in the drier areas consists of Poaceae, Cyperaceae, *Calluna vulgaris,* Ranunculaceae, *Bellis perennis*, *Cirsium*, *Taraxacum officianalis, Plantago lanceolata, Potentilla erecta, Potentilla palustris* and *Trifolium repens.* Wetter areas of the site contain various *Sphagnum* species. The surrounding blanket bog vegetation in the vicinity of the area under investigation (see Figure 3.1 and Plate 3.1) consists primarily of typical Atlantic bog species such as *Molinia caerulea, Drosera rotundifolia, Eriophorum vaginatum, Schoenus nigricans, Juncus, Hydrocotyle vulgaris* and *Narthecium ossifragum.* The bog area as a whole generally corresponds to the western Irish equivalent of the M17 *Scirpus cepitosus-Eriophorum vaginatum* blanket mire as described by Rodwell (1991, 179), with the main difference being the higher representation of *Schoenus nigricans* (ibid.), probably due to the extreme oceanicity of the Irish Atlantic seaboard (Sparling 1967).

Use of the land surrounding the site is today limited to low-intensity sheep grazing. It appears that within living memory and local historical recollection, only small-scale crofting was practised. It is thus unlikely that the intensity of activity has changed substantially, at least over the past century or two. Domestic peat cutting for fuel has occurred around the site throughout living memory.

3.2.2 History of investigation

3.2.2.1 Belderg Beg

Pre-bog stone walls have been known in the area from the 1930s when a local teacher, P. Caulfield, reported their occurrence to the National Museum, Dublin. In the 1970s their significance as indicators of prehistoric occupation was explored by his son, Professor Seamas Caulfield, and Dr Michael Herity in a survey uncovering over thirty such features, often in close proximity to court tombs, along the north Mayo coastline (Herity & Eogan 1977, 50; Caulfield 1978, 137; 1983, 196-7). This survey led to Caulfield's excavations at Belderg and at Behy/Glenulra, now known as Céide Fields (Caulfield 1978; 1983).

Belderg Beg was excavated between 1971 and 1976. The excavation results have not been fully published, so the summary reports published annually in The Excavations Bulletin (currently titled Excavations) are included in Appendix B. A plan of the site is presented in Figure 3.4; this is not a full excavation plan drawing but has been printed in a guide to the area (Caulfield 1988). This plan has been used as the basis for the current investigation, with some annotations added. Radiocarbon assays from the excavation are included in Appendix A. Figure 3.5 shows the interpreted phases of the site.

As no full publication exists, the main results and interpretations have been summarised from the Excavations reports (see Appendix B), summaries in later publications (Caulfield 1978; 1983; 1988) and personal communication from the excavator.

Earliest occupation

The earliest archaeological remains at Belderg were considered to be Walls 1, 2 and 4 and Enclosures 5 and 6 (see Figure 3.4 and 3.5a and Plates 3.2 and 3.3). In their excavated sections, the walls were found to be constructed on mineral soil. A pine stump rooted in the soil and dated to c. 5145 cal. BP (UCD-C31: Caulfield *et al* 1998, 633-634; see Appendix B and Figure 3.4) has served as a *terminus ante quem* for wall construction. Enclosure 6 was assigned to the Neolithic phase by its association with Wall 4 and because it was constructed on mineral soil, and Enclosure 5 was assigned an early date because it contained typical Neolithic pottery (Caulfield 1988).

Reoccupation

The roundhouse (see Figures 3.4 and 3.5b and Plate 3.4) was constructed of stone and earth, with timber supports. It contained a central hearth with charcoal spreads, but the only artefacts were saddle querns, rubbers and a polished stone disc (Caulfield 1973; see Appendix B), which influenced the interpretation of the structure as a granary (Caulfield 1988). Wall 3 (see Plate 3.5) was considered to be contemporary with the roundhouse occupation because of the near-identical ages of radiocarbon assays from a structural timber within the house and stakes extending the wall in question. However, the two stakes submitted for radiocarbon assay were adjacent to one another (G. Byrne pers. comm.; see Figure 3.4 and 3.5b). Their age need not reflect the date of construction of any other part of Wall 3.

Agriculture

Evidence for prehistoric agriculture was first discovered in an area close to the roundhouse in 1972. Initially, relict ridges and furrows were discovered to overlie ard-marks, and both features were assigned a Neolithic date (Caulfield 1972). In later excavations, the ard-marked area was discovered to extend beyond the confines of the ridge cultivation and the two cultivation indications were seen to be unconnected with one another (Caulfield 1973; 1974). The stratigraphic relationship between the roundhouse and the ploughed areas seemed to suggest that the house was constructed subsequently to one phase of clearance and ploughing of the ridged cultivation plots, but prior to another phase of stone clearance and agriculture (Caulfield 1975). The ridge cultivation area is shown in Plates 3.6 and 3.7.

Anomalies

Two radiocarbon assays (SI-1474 and SI-1475) from charcoal associated with flints within the round house were dated to the first millennium cal. BP (see Appendix A) and as they were inconsistent with the archaeological evidence, were considered as anomalous (Caulfield 1973; 1978, 142). These assays have not been considered in any subsequent discussion of the site.

3.2.2.2 Belderrig Quartz Scatter

Close to the Belderg Beg site, on a cliff of the sheltered bay at the mouth of the Belderg River (see Figure 3.1 for location), is a scatter of worked quartz, other lithic materials, fishbone and macrofossils including hazelnut shell, sealed in a layer of soil beneath peat. The lithic technology, which includes a uniplanar Larnian core, is characteristically Later Mesolithic

(Warren 2004, 5). Many of the artefacts are distributed in a sub-peat soil layer forming an Old Land Surface (OLS) enclosed by field walls running upslope, possibly part of the Belderg Mór field system (see Section 2.2.2.4).

Chapter 4

Research strategy and methodology

4.1 Introduction

This chapter sets out the research design which was constructed to address the gaps in knowledge pertaining to the palaeoenvironmental and occupation history at Belderg Beg, and to assess the degree of climatic or other environmental marginality under which the inhabitants lived during prehistory. A plan of the site with all sampling locations marked is shown in Figure 4.1.

4.2 Research design

The purpose of this investigation is to reconstruct as fully as possible the Holocene landscape evolution and vegetation dynamics of the Belderg Beg hillslope, with a special emphasis on the mid- to late-Holocene agricultural activity. A research strategy combining on-site and off-site investigations was required to address both the palaeoenvironmental and the archaeological issues, in order to provide a holistic interpretation of landscape dynamics. From the palaeoclimatic and palaeoenvironmental records contained within the peat it will be possible to assess any environmental stresses which the communities were subjected to, and to reconstruct the effects which their activities may have had upon components of the environment, namely the vegetation systems and pedogenesis. On-site bioarchaeological and geoarchaeological analyses are included in order to elucidate the nature of agriculture and supplement chronological control. A threefold research programme was designed:

1. Recording the sediment stratigraphy of the hillslope in three dimensions, encompassing part of the area within the Neolithic field system and a significant portion of the area downslope of it.
2. Detailed palaeoenvironmental and radiocarbon investigation of a peat core from outwith, but close to, the field system; selected on the basis of the results from research strategy 1.
3. Geoarchaeological and palaeoenvironmental investigation of exposed sections of the palaeosols in the vicinity of the Bronze Age roundhouse.

This design is anticipated to complement the previous archaeological investigations at Belderg by providing the missing palaeoenvironmental evidence to address the assumptions (Caulfield 1978; 1983; 1988; Caulfield *et al* 1998) that underlie some of the interpretations of this site:

1. The walls running downslope (Walls 1 and 2, Figure 3.4) are relics of Neolithic agricultural activity. At present, this has been assumed on the basis of post-Neolithic radiocarbon dates from subfossil pine stumps preserved in peat overlying the mineral soil upon which the walls were built, within the enclosed areas.
2. The primary purpose of the field system was pastoral agriculture.
3. Soil deterioration and peat formation were likely causal factors in the abandonment of agriculture.
4. Bronze Age reoccupation of the site was on a smaller scale than that of the previous Neolithic activity and was concerned with exploitation of the chalcopyrite seam at Horse Island.
5. This Bronze Age activity occurred during a period of environmental deterioration associated with the spread of blanket peat.

The research is also intended to further knowledge and understanding of the nature and dynamics of prehistoric settlement and agriculture in western Ireland. Attention was paid to how best to supplement knowledge from the previous palaeoenvironmental investigations at (in particular) Céide Fields (Molloy & O'Connell 1995; O'Connell & Molloy 2001), but also other sites in North Mayo, to build up an integrated regional picture of palaeoenvironment and agriculture in mid-late prehistory.

4.3 Field methods

4.3.1 Site selection

4.3.1.1 Coring transects (Figure 4.1)

East-West transect

In order to elucidate the Holocene evolution of the Belderg Beg hillside a record of the sediment stratigraphies at regular points on the slope was required. A transect of cores sectioning the slope was taken, and the sediment stratigraphies contained within the boreholes was logged as described below.

North-South transect

A sediment-stratigraphic record laterally transecting the field system upslope of the east-west transect was taken in order to highlight any spatial differentiation of activity areas. Specifically, the transect was designed to cross two field walls (Walls 1 and 2) and record the sediment sequences around two pine stumps dated during the investigation by Caulfield *et al* (1998).

As part of the research design it was intended that samples of basal peat would be removed from locations along the transects, selected on the basis of sediment-stratigraphic analysis, and submitted for AMS dating. The results would be instrumental in illustrating the spread of peat over the study area and in highlighting relationships between land use and landscape development.

4.3.1.2 BEL coring site (Figure 4.1)

From the results of the transect 1 sediment-stratigraphical investigations the location that came to be labelled the BEL core was selected for detailed palaeoenvironmental analysis. It was situated in an area of deep blanket peat just downslope of the terminus of the Neolithic field system. The deepest peat deposits were likely to be the oldest and, because of the location beyond the field system, peat growth was suspected to have commenced before its construction and use. Thus it was hoped that pollen preserved in these deposits would contain a full stratigraphic record of the phases of prehistoric agriculture. To ascertain precisely the location of the deepest, most stratigraphically complex sedimentary sequence, a programme of trial probing with an Eijelkamp corer was undertaken. This confirmed that the most suitable location was indeed located on the transect, in a c. 1m peat hagg representing a cutting face, apparently the result of turf cutting. It was thus assumed that a complete sequence from within this hagg would represent uncut peat growth. This core was therefore labelled the BEL core, with the transect cores running downslope (eastwards) of it numbered E1, E2 etc, and those running upslope (westwards), W1, W2 etc (see Figure 4.1).

4.3.1.3 BB Soil sections

Two complete sections of buried soil from the archaeological site were selected for sampling based on interpretation of the 1970s excavations (S. Caulfield pers. comm.).

Section BB1 (Plate 4.1).

This section was taken from the area of cultivation ridges by the roundhouse, formerly sealed by blanket peat. Excavation in the 1970s revealed that the cultivation ridges were formed of a distinct soil layer, in part overlying an ard-marked soil horizon. The cultivation ridges were thought to be associated with the Bronze Age occupation (see Section 3.2.2.1), and the ard-marked layer was tentatively interpreted as representing the Neolithic ground surface, based on its greater spatial distribution and similarity to the mineral soil associated with the Neolithic walls (S. Caulfield pers. comm.).

Section BB2 (Plate 4.2).

This section was taken from an area south-west of the roundhouse which upon excavation was revealed to contain an ard-marked soil horizon directly under blanket peat. It was anticipated that soil micromorphological analysis of both sections, together with radiocarbon dates of the basal peats overlying the mineral soil in each section, would definitively indicate the contemporaneity or otherwise of the two soil layers.

4.3.2 Sampling

4.3.2.1 Coring transects

An Eijelkamp corer with an open-sided chamber 2.5cm in diameter and 100cm in length was used to recover sediment stratigraphies from the boreholes for description. The location and ground surface altitude of each core was surveyed by a Total Station. Each borehole was logged from present-day ground surface to impenetrable basal sediment. At locations selected on the basis of the sediment stratigraphies recorded in this manner, samples for AMS dating were recovered using a closed-chamber 60cm long, 5cm diameter Abbey piston corer which was capable of obtaining sediments in contact with impenetrable substrates. Upon recovery, cores from the piston corer were placed in clean plastic guttering and sub-samples removed in the field and double-bagged for transport back to the laboratory.

East-West transect

A 300m transect of 33 boreholes (including the BEL core) was placed sectioning the hillslope, encompassing the deepest areas of blanket peat and including altitudes within and downslope of the Neolithic field walls.

North-South transect

This 120m long transect of 17 boreholes was placed across the upslope section of the Neolithic field system at roughly the same altitude as the BB sections (see below). Two Neolithic walls were crossed by this transect, in an attempt to elucidate any spatial differentiation within the field system.

4.3.2.2 BEL core

Two complete 300cm sequences (BEL sequence) were obtained by cleaning back c. 30cm from a turf cutting to form a peat face and removing a 100cm section in monoliths (Plate 4.3). A 1m length, 5cm diameter hand-held Russian corer (Jowsey 1966) was used to recover the remainder of the sequence, with overlaps taken using a 30cm length, 10cm diameter Russian corer. All samples were wrapped in heavy-duty plastic film and aluminium foil and cores were transported back to the laboratory in plastic drainpipes cut in half lengthways. The cores were retained horizontally in a cold-store at a constant 4°C.

4.3.2.3 BB sections

Two trench sections from the 1970s excavations were cleaned back by at least 30cm and the stratigraphy was described, drawn and photographed (Plate 4.4). Two complete undisturbed sections from each soil profile were sampled using 8 x 5 x 5cm Kubiena tins: one for soil pollen analysis and radiocarbon dating, the other for soil micromorphological analysis. The Kubiena tins were labelled *in situ* with orientation and provenance details. Once removed, the tins were sealed and wrapped in heavy-duty plastic film and aluminium foil. Bulk soil samples were taken of all identified contexts, except for the recent turf-growth, and double-bagged. All samples were retained in a cold-store at a constant 4°C.

4.4 Laboratory methods

4.4.1 Sediment description

4.4.1.1 Transect cores

Sediment stratigraphies were recorded in the field according to the recommendations of West (1977), describing sediment type, internal structure and stratification, dominant components (and for organic matter, recognisable plant materials) and stratigraphic relations. Particle sizes and organic contents were estimated in the field. Boundaries between units were defined as gradual (>2cm), clear (1-2cm) or abrupt (<1cm).

4.4.1.2 BEL core

For the purposes of comparability to the transect cores, sediment stratigraphy was first described according to the recommendations of West (1977; see above).

For detailed palaeoenvironmental investigation, sediment stratigraphic units identified from the descriptive system above were further described according to the system of Troels-Smith (1955), utilising the modifications to grain-size classes suggested by Aaby and Berglund (1986).

4.4.1.3 BB sections

Organic sediments were described according to the system of Troels-Smith (1955), utilising the modifications to grain-size classes suggested by Aaby and Berglund (1986). Minerogenic sediments were described and characterised by Munsell colour (1992), texture and particle size, structure, consistency, boundaries with adjacent deposits, clasts or inclusions, grading and any other characteristic feature, based upon the descriptive system of West (1977). Particle sizes and organic content were estimated by judgement.

4.4.2 Pollen & microscopic charcoal analysis

4.4.2.1 Pollen incorporation into peats

The pollen input into a mire depends upon factors including its topographical position, the hydrological conditions in which the mire operates and the vegetation upon and surrounding the mire. The classification of mires according to their hydrological conditions divided peat landforms into three principal types (Moore *et al* 1991, 15):

1. Rheotrophic / minerotrophic: the mire vegetation receives water from land drainage and from precipitation, and is generally nutrient rich. Includes marshes, fens, swamps, carrs and flushes.

2. Mesotrophic: intermediate sites where ground water makes little contribution to the total nutrient load. Generally nutrient poor, these sites are usually transition mires or poor fens.
3. Ombrotrophic: rain-fed mires with resulting low nutrient input. Typically raised or blanket mires.

Methods of pollen dispersal have been described by Tauber (1965) and Jacobson & Bradshaw (1981):

1. Local sources of pollen (<20m from the edge of the sampling basin):
   a. The local component (Cl), from the species growing on the mire surface.
   b. The trunk space component (Ct) in part, the pollen falling from a canopy or produced by the herbs and shrubs growing under the canopy, which is transported by subcanopy air movements (e.g. where a woodland borders a mire).
   c. The inwashed, secondary component (Cw) in part, pollen incorporated into the drainage water, which may or may not have been reworked from other, potentially older, sediments within the catchment.
2. Extra-local sources of pollen (20m to a few hundred metres from the basin edge):
   a. Ct in part.,
   b. Cw in part.
   c. The canopy component (Cc) in part, that is some of the pollen produced in the canopy which is carried along by air components above the canopy.
3. Regional sources (from longer distances):
   a. Cc in part.
   b. The rain component (Cr), where pollen grains act as nuclei around which water droplets form, accounting for the majority of pollen removal from the atmosphere.

The relative importance of each pollen source depends upon the size of the site; however these models assume a forested environment and it is essential to consider other types of landscape differently.

As the mire at Belderg Beg is classified as a lowland Atlantic blanket bog, the pollen source components typical of ombrotrophic blanket mires must be considered when analysing the BEL pollen profile. An additional factor is the history of formation of the bog on the Belderg valley side; for instance, early in its formation there may have been a fen peat which underwent a process of terrestrialisation, or alternatively small raised mires may have formed in hollows, which expanded laterally in the transition to blanket mire (e.g. Charman 2002, 10, 74-75, 150-153).

Previous studies (e.g. Molloy & O'Connell 1995; O'Connell & Molloy 2001) indicate that blanket peat spread in North Mayo began in a forested environment. Anthropogenic maintenance of open areas in this environment was possibly the ultimate force causing blanket mire spread over much of western Ireland (O'Connell 1990a). The scheme of Tauber (1965), which assesses the pollen sources in a small lake or mire within a wooded landscape, is therefore considered applicable to interpretation of part of the BEL core (see results below). In one study of pollen sampled from a woodland floor, the source area was estimated as the surrounding 20-30m (Andersen 1970). The potential of vegetation reconstruction from wooded sites is therefore limited to the scale of the woodland stand (Jacobson & Bradshaw 1981, 91).

It is evident from the landscape and sediment stratigraphy (see below) that Belderg Beg has been covered by this type of peatland for the majority of its sedimentary history. Ombrotrophic bogs have a low or negligible Cw pollen component. Blanket mires on water-shedding sites such as slopes or ridges will be subjected to certain air-flow patterns which must be considered when assessing the pollen input patterns. The pollen at such sites will derive from the rainfall component (Cr), the canopy component from neighbouring valleys (Cc), and the local mire plants (Cl) (Moore *et al* 1991, 15). Analysis of moss polsters in modern north-west Scottish blanket peats suggest the non-arboreal pollen components are likely to have an extremely small source area, in the region of 0.5 – 2m (Bunting 2003). Local vegetation dynamics rather than wider landscape changes are therefore reflected in the non-arboreal components of moorland or blanket bog taxa.

Pollen accumulation rate diagrams for peats often show high internal variability and therefore are frequently spiky in appearance. Three contributing factors are suggested by Jacobson & Bradshaw (1981, 90): growth gates may be irregular, uneven distribution of plants growing on the peat can cause over- or under-representation of taxa at some times, and volumetric sampling may be inaccurate. It is possible to assess the first and third of these factors: standardised, thorough laboratory methodology can improve sampling precision and radiocarbon dating is often used to quantify growth rates (see below). Degree of humification may also indicate the rate of growth.

4.4.2.2 Pollen incorporation into soils

Pollen profiles from soils must be interpreted differently to those from peats and usually with great caution. The aerobic nature of the soil environment results in a poor quality of preservation. Furthermore, stratification is less secure as vertical mixing will take place in biologically active soils with populations of biota such as invertebrate detritivores (Andersen 1986). Some soils are nevertheless useful for palynological investigation. In soils with a pH below 5 the level of pollen preservation is generally high, regardless of the soil classification (Moore *et al* 1991, 22).

4.4.2.3 Pollen evidence of human activity

Palynological detection of agricultural activity depends upon recognition of destruction or modification of the pre-existing vegetation, the introduction of crop species, the presence of weed species associated with arable or pastoral activities and, following abandonment of the site, the recovery of vegetation (Moore *et al* 1991, 9). The study of weed species commonly occurring in agricultural habitats has led to certain pollen taxa routinely being identified as 'anthropogenic indicators' (Behre 1981).

Recognition of agriculture from the representation of cereal pollen grains is problematical. Cereals such as wheat and barley are self-pollinating and therefore produce low quantities of pollen. Their pollen grains tend not to disperse great distances from the parent plant (Vuorela 1973). Pollen investigations are therefore likelier to contain cereal grains originating from past agricultural activity with increasing proximity to the formerly cultivated area (Edwards & McIntosh 1988, 180). A further difficulty regarding cereal pollen identification is that taxa in the Poaceae family to which cereals belong bear close morphological similarities. Whilst cereal pollen grains are usually larger than those of non-cultivated grasses (typically larger than 37μm), there is a degree of overlap with certain species (Andersen 1979; Dickson 1988). Further criteria are usually considered, principally the pore and annulus diameters and the surface sculpturing patterns (Andersen 1979). Large grass pollen grains, particularly those in pre-*Ulmus* Decline levels, are often described as 'Cereal-type' (e.g. Edwards & Hirons 1984; Edwards & McIntosh 1988; O'Connell 1987).

Analysis of modern pollen rains in blanket peat have recorded low percentages of anthropogenic indicator taxa which were not part of the local vegetation communities, suggesting that sporadic or occasional low percentage occurrences of 'anthropogenic indicator' taxa in pollen records from blanket bog landscapes need not be interpreted as recording agricultural activity in the near vicinity of the sampling point, but may instead originate from the wider landscape (Bunting 2003).

4.4.2.4 Microscopic charcoal analysis

Microscopically identified charred products of the burning of biospheric material (chiefly vegetation) are here referred to as microscopic charcoal (condensed to 'microcharcoal' in pollen diagrams). Microscopic charcoal analysis can be combined with pollen analysis to understand vegetational successions and their causes. The cause of fires, anthropogenic or climatic *via* lighting-strike frequency, can be estimated (Tolonen 1986, 485). Sizes of microscopic charcoal particles transported in smoke vary from micro- to macroscopic, and the distance that different sized particles are carried in the atmosphere before deposition varies. The charcoal influx to a particular sampling location will also depend upon meteorological conditions at the time of transport and deposition, basin morphology and local and regional topography (ibid., 486).

Several methods are used to quantify the microscopic charcoal content of pollen preparations. The total area may be estimated by either counting individual particles within size classes, or by a point-count method (Clark 1982). A total area of charcoal per unit volume sediment is then estimated for each preparation. Alternatively, particles may be counted as encountered during routine pollen counting and expressed as a percentage of the pollen sum. Charcoal particles are usually differentiated from other black discrete objects (decomposed plant debris: *Substantia humosa* cf. Troels-Smith [1955]; Tolonen 1986, 488) although in practice identification may be more difficult in the case of smaller particles. Most analysts therefore employ a minimum diameter of particles included, which may vary from 5 to 50μm (ibid., 489).

4.4.2.5 Incorporation into research design

Charcoal particles

Charcoal particles of >37μm were counted during routine pollen analysis and calculated as a percentage of TLP (see below). This size was selected as a threshold (see above) because it equates to that used in the investigation at Céide Fields (Molloy & O'Connell 1995) and it was hoped that comparability would thus be aided.

BEL core

Levels to be palynologically analysed were selected as a skeleton diagram was built up and intervals varied between 1cm and 6cm. Slices were 0.5cm or 1cm thick. Analysis necessarily occurred at closer intervals in the archaeologically significant levels of the core, i.e. generally below 80cm depth. Where evidence of anthropogenic activity was recorded, 0.5cm thick slices were taken to increase the likelihood of recovering cereal grains.

BB sections

Sampling for pollen analysis took place contiguously in 1cm slices from Kubiena tins K6, K7 and K8 (BB1) and K12, K13 and K14 (BB2). Sampling occurred through the earliest *in situ* peat layers and as far as was possible into the underlying palaeosol: that is, as far as pollen was preserved in sufficient quantity and satisfactory quality to be counted.

4.4.2.6 Methodology

Laboratory methodology

Standard laboratory procedures were employed (Moore *et al* 1991):

1. One cm^3 was subsampled by displacement into 10% hydrochloric acid. Two *Lycopodium clavatum* tablets were added for pollen concentration calculations.
2. Hot digestion in 10% sodium hydroxide was used as an alternative to potassium hydroxide for removal of humic acids.

3. Samples were sieved at 150µm and 7µm to remove large and small particles. A 7µm mesh was selected for fine sieving as a smaller mesh (e.g. 5µm) easily becomes clogged, and larger meshes (e.g. 10µm) result in the loss of pollen in the filtrate, whereas losses with a 7µm mesh have been determined (by absolute techniques) to be negligible (Cwynar *et al* 1979).
4. Where necessary, digestion in boiling 40% hydrofluoric acid for 15 minutes was carried out to remove silica, followed by resuspension in 10% hydrochloric acid to remove any silicofluorates formed during treatment with hydrofluoric acid.
5. Acetolysis for 3 minutes in a 1:9 mixture of concentrated sulphuric acid to concentrated acetic anhydride resulted in removal of cellulose.
6. Samples were dehydrated in 2-methylpropan-2-ol and stained with aqueous safranine.
7. Silicone oil (200/12500cS) was used as a mounting medium.

Analysis

Analysis was carried out using an Olympus BH-2 optical microscope. Routine counting occurred at 400x magnification, with 1000x oil immersion used for critical identifications and measurements. Identification was made to the highest possible taxonomic levels using the keys in Moore and Webb (1978), Moore *et al* (1991), Oldfield (1959), Punt & Blackmore (eds., 1991), Punt, Blackmore & Clarke (eds., 1988) and Punt & Clarke (eds., 1980, 1981, 1984), and the reference collection of silicone oil mounted type-slides in Archaeology, University of Edinburgh. Special criteria for particularly difficult taxa are detailed in Appendix C.

4.4.2.7 Pollen sum

A minimum of 500 pollen grains were identified per sample for the BEL core samples, and a minimum of 1000 grains per sample for the BB samples, excluding obligate aquatics and spores. No attempt was made to identify local pollen sources and exclude such taxa from the sum (*contra* e.g. Molloy & O'Connell 1995). All taxa are presented as percentages of TLP. Charcoal particles with minimum length 37µm were also counted (see above) and expressed as a percentage of TLP.

4.4.2.8 Nomenclature

Taxon nomenclature follows Moore *et al* (1991) with minor amendments: in some cases, where confusion would not be possible, names were changed to comply with Stace (1997), e.g. Poaceae rather than Gramineae. Asteraceae were subdivided as suggested by Bennett *et al* (1994) into the Asteraceae (Lactuceae), the Asteroidea (*Aster* type and *Anthemis* type), and the Cardueae (*Serratula* type, *Cirsium* type and *Centaurea*).

Nomenclature follows the standardised set of conventions for taxon determination as described by Birks (1973, 225-226), repeated in Appendix C for explanation. Where a greater degree of certainty than was available in pollen keys could not be established by the use of reference slides, the degree of determination remains at the level published in the appropriate keys, according to the above convention.

4.4.2.9 Presentation

Pollen diagrams were constructed using the programs *Tilia*, *Tiliagraph* and *TGview* (Grimm 1991; 2002). Pollen profiles are presented as both pollen percentage and pollen influx diagrams. Influx data are preferable to raw concentration data as the latter do not account for sedimentation rates. The 'raw' pollen percentage data are presented here (i.e. all AP and NAP expressed as a percentage of TLP – see above) although for the purpose of clarity, most interpretation is based upon a percentage diagram in which *Alnus* has been removed from the TLP sum (cf. Chiverrell *et al* 2004; Lomas-Clarke & Barber 2004). This is because *Alnus* may grow on the bog itself and therefore show variations which are independent of the tree species outside the bog (Janssen 1959, 55). Preliminary analysis of the BEL peat and pollen stratigraphy confirmed that *Alnus* was likely to have grown on the bog itself and that it was dominant in the palynological record for a significant length of time, therefore including it in the TLP sum would result in a filtering-out of the species from beyond the bog (Rybníčová & Rybníček 1971, 173). CONISS was used to aid zonation; however, in using this program the placing of zones is still subjected to the analyst's bias.

4.4.3 Loss-on-Ignition

4.4.3.1 Fundamentals of loss-on-ignition

Loss-on-ignition is a reasonable reflection of organic carbon content in most sediments (Aaby 1986, 150; Bengtsson & Enell 1986, 428). In peat, the residual material after loss-on-ignition (the ash content) represents the inclusion of mineral material transported by precipitation or dry fallout. The quantity of ash varies according to vegetation structure, filtration capacity, deposition rate of such particles, rate of peat decay and the degree of peat compaction (Aaby 1986, 160). Ombrotrophic peatlands are the most reliable for investigating ash content fluctuations as they are totally rain-fed and therefore mineral inclusions can be definitively traced to atmospheric deposition. Field erosion of soil is a common occurrence especially in arable agriculture where soil may be bare for a certain period of time. Dust particles removed from fields by erosion can be deposited at a distance, and in this way phases of former agricultural activity have been traced in the sediment stratigraphy of ombrotrophic mires, with typical prehistoric agriculture increasing the ash content of peats by two- to ten-fold values (e.g. Vuorela 1983). Quantified dust contents may indicate the extent of arable fields, as permanent pastures would contribute no additional dust unless severely overgrazed. In combination with detailed examination of pollen types, such investigation may indicate the nature of the agricultural systems in place (Aaby 1986, 161-162).

4.4.3.2 Incorporation into research design

Percentage organic matter is commonly employed to define peat as a substance (Charman 2002, 4), with the typical threshold being that it is a substance composed of the partially decaying remains of plants with over 65% organic matter on a dry weight basis and less than 25-30% inorganic content (Clymo 1983). In this investigation, the percentage loss-on-ignition was measured as part of further methodologies (see below); to provide a potential indication of anthropogenic activity; and also to provide an independent indication, supplementing the information gathered from sediment inspection, peat humification and pollen analysis, as to the point of transition to a true peat in the BEL core.

4.4.3.3 Laboratory Methodology

Slices of 1cm thickness from BEL cores and monoliths were oven-dried at 105°C overnight. A 2-3g subsample was weighed, ashed in a muffle furnace at 400°C for 5 hours and re-weighed to provide loss-on-ignition values. The residual ash from ignition was retained for digestion for geochemical analysis (below).

4.4.4 Humification

4.4.4.1 Fundamentals of humification

Humification refers to the degree of decay of peat. This seemingly simple description masks inherent complications: there exists no single scale on which humification is measured and no accepted definition of what it measures (Charman 2002, 137), hence interpretation is intrinsically problematic. The basic principle is perhaps most clearly defined by Blackford & Chambers (1993, 11): "Humic acids are produced by the decomposition of organic material. They are dark brown in solution, giving humus its colour. As peat decomposes, the proportion of humic acid increases, and attempts have been made to estimate the quantities of humic acid in peat and organic soil". Detailed discussion of the theoretical and practical concepts of humification is presented in Appendix D.

4.4.4.2 Assessing degree of humification

The most commonly employed method of humification measurement is the alkali-extraction technique refined by Blackford (1990) and Blackford & Chambers (1993), whereby an alkali extract of peat is determined by colorimetric assessment at 540nm, based on the principle that the alkali absorption is proportional to the amount of humic matter dissolved, and therefore of the extent of decomposition. A recent luminescence spectroscopy study has prompted suggestions that the alkali-extraction method itself is responsible for much of the breakdown of peat and alters the organic matter present (Caseldine *et al* 2000). Nevertheless, applied rigorously, percentage transmission of alkali-extracts is widely accepted as a reasonable qualitative proxy of humification (ibid; Charman 2002, 137).

4.4.4.3 Interpreting humification data

Humification data are generally accepted to indicate changes in hydrological conditions on and within mires: shifts towards increasing humification values suggest warmer, drier conditions with increased decay, whilst cooler, wetter periods of decreased decay would result in a lesser degree of humification. The technique is most often used on ombrotrophic mires to reconstruct climatic changes, as peatlands which are wholly dependent on atmospheric precipitation for their moisture are assumed to show strongest links to climatic fluctuations (Charman 2002, 137; 182).

Investigations of ombrotrophic mires in the UK and elsewhere have successfully produced humification data correlating well with other proxy records of climatic change (Section 2.3.3.3). Correspondence of certain humification shifts with vegetation shifts apparent in the palynological record have been noted (Chambers *et al* 1997, 396; Anderson *et al* 1998). Palynological taxonomic discrimination is usually at a lower level than that achieved in macrofossil or testate amoeba (rhizopod) investigations (Chambers *et al* 1997, 396), therefore investigations of bog-surface wetness records have tended to employ either or both of these methods in addition to humification.

Multi-proxy investigations have advanced understanding of the nature of the humification signal, surmising that humification represents a relative (semi-quantitative) measure of average effective summer precipitation (Blackford & Chambers 1993, 8; Mauquoy & Barber 1999a, 265). The degree of humification is dependent upon the time the plant remains take to pass from the biologically active acrotelm to the near-inert catotelm; which is itself controlled by water table depth. Where water tables are shallow, under conditions of high effective precipitation, there is less time for decay before peat passes into the catotelm where decay rates are extremely slow (Clymo 1984; Mauquoy & Barber 1999a, 265). Furthermore, the ability of different mires to respond to changes in effective precipitation in this manner has been shown to depend upon mire size, internal hydrology and geographical position (Section 2.3.2.2).

The degree of peat humification can be affected by factors other than surface wetness or humidity. Coulson & Butterfield (1978) showed that rates of decomposition of litter from different peat-forming plant species differ substantially, with some species being inherently resistant to decay. Concerns exist that humification values may in part reflect changes in local species composition (Chambers *et al* 1997, 395-396). Multi-proxy analyses utilising palaeovegetation identification, principally palynology or plant macrofossil analysis, can help identify whether humification shifts correspond with vegetational shifts. At Talla Moss, Scottish Borders, (subjectively identified) minor humification shifts were found to correspond to changes in vegetation species representation in the palynological record, whereas major shifts in humification were not apparently accompanied by major vegetational changes (ibid.). This situation is further complicated by the consideration that climatic fluctuations may be a direct cause of changes in vegetational species composition. Use of cores from multiple bogs in the same region can help to identify externally-forced (i.e. climatic) shifts, which will coincide in all mires, whereas autogenic changes are likely to operate independently (Mauquoy & Barber 1999a, 263).

A problem with interpretation and correlation of peat-based studies is one of dating control; calibrated radiocarbon dates can only provide estimates and thus calculated periodicities must be treated with caution (Chambers *et al* 1997, 397-398). Additional dating techniques may help refine chronological control; in particular analysis of any tephra layers in peats (ibid.) and AMS wiggle-match dating (van Geel *et al* 1996).

Several studies have recommended manipulation of raw percentage transmission data for presentation and interpretation purposes. Percentage transmission can be transformed to percentage peat humification by linear transformation of the optical density (absorbance) data using the formula $x = 8.3\ (10y + 0.1)$, where x is the claimed percentage peat humification and y is the mean of three recorded optical density readings (Aaby & Tauber 1975, 3). Although some studies have made use of this percentage humification measure (Chambers *et al* 1997; Mauquoy & Barber 1999a) it has been suggested that such transformation is essentially a form of data manipulation, as percentage transmission data are measured on a linear scale, whilst absorbance values should be seen as a semi-quantitative estimate (Blackford & Chambers 1993, 16-17). Percentage transmission is also used in many studies (e.g. Blackford & Chambers 1991; Blackford & Chambers 1995; Anderson *et al* 1998).

Detrending the percentage transmission or humification data is sometimes carried out if a clear increase in humification is seen towards the base of the profile; a phenomenon usually interpreted as indicative of continuous peat decay in both the aerobic acrotelm and, albeit at a much reduced rate, in the anaerobic catotelm (Clymo 1984). Calculation of the linear regression line for the data points allows subtraction of the aging factor. Such trends for increased decay with depth have been found at some sites and correction may be applied (Blackford & Chambers 1995; Anderson *et al* 1998; Mauquoy & Barber 1999a; 2002; Langdon *et al* 2003). There exists the consequent question as to why some sites do not show such continuous decay with depth, and this raises the following issue of whether such detrending transformations are a form of data manipulation that may limit comparability of datasets, particularly between those detrended and those not so corrected.

A further problematic aspect of interpreting humification results is discerning at what level a shift is classed as significant. In the majority of studies, the significance of a particular humification episode is subjectively judged (e.g. Aaby & Tauber 1975; Blackford & Chambers 1991; Chambers *et al* 1997; Anderson *et al* 1998; Langdon *et al* 2003). Alternatively, negative percentage humification values may be used to delimit significant changes, whereas directional shifts are considered less certain (Mauquoy & Barber 1999a), or site-specific criteria may be chosen (Mauqouy & Barber 2002). Spectral analysis has been used to identify statistically significant spectral peaks (Baker *et al* 1999). The method employed here is to consider significant changes as those differences between depths in the smoothed curve (3-point running mean) exceeding one standard deviation (1.0σ) above or below the mean value for the profile (cf. Tisdall 2000; Tipping *et al* 2003)

4.4.4.4 Incorporation into research design

It was anticipated that the BEL core would yield a satisfactory humification record as its location fulfils the requirements implicit from reference to literature (see above): the mire is extremely close to the Atlantic Ocean (c. 2km, see Figure 2.25) and, as the sampling location is situated on a break-of-slope (see coring transect results below, Section 5.2.1.1 and Figure 5.2) from a shallow slope uphill to a larger gradient downhill, it can be considered a water-shedding part of the blanket mire. It was accepted from the outset that palaeohydrology may have been altered by human activity in the upslope field systems; however, the utilisation of geochemical analysis was employed as a further check on human activity and palaeoclimatic fluctuations (see Section 4.4.5).

Humification analysis was carried out on the most archaeologically significant section of the peat profile. Humification was tested after pollen analysis was completed, and the preliminary indications of the pollen record were that the upper 80cm of the core would not aid interpretation of human-environment interactions in prehistory. A high-resolution record was desirable, but as material had already been removed and destroyed in geochemical and palynological analysis by this point, analysis at less than 1cm was impossible.

4.4.4.5 Laboratory methodology

Methodology followed Blackford (1990) and Blackford & Chambers (1993). Contiguous 1cm slices of peat were oven-dried at 40°C and crushed with a pestle and mortar. A 0.2g subsample of powdered peat was weighed into a 150ml conical flask and 100ml of freshly mixed 5% sodium hydroxide ($NaOH$) was added. A batch of 15 such samples was placed on a hotplate in a fume hood and simmered gently for 1 hour. After cooling, the contents of the flask were transferred to a measuring cylinder, topped up to 200ml with de-ionised water, and shaken well. Samples were filtered through Whatman Qualitative 1 paper with the aid of a vacuum pump to accelerate the process. Of the resultant mixture, 50ml were transferred to a measuring cylinder, diluted to a 1:3 mixture with de-ionised water, and shaken. The percentage transmission at 540nm was measured using a Hach DR/2000 direct reading spectrophotometer which was zeroed to 100% transmission with de-ionised water between samples. As the vacuum pump speeded up the filtration process, readings for all samples were measured within 4 hours so no corrections for time were necessary.

Loss-on-ignition values (see above) were used to calculate organic content for correction of the percentage transmission in line with Blackford (1990, 192). In so doing, percentage organic content is multiplied by percentage transmission to give percentage transmission corrected for mineral content.

4.4.5 Geochemistry

4.4.5.1 Fundamentals of peat geochemistry

Certain trace elements in peat can be of significance to palaeoenvironmental reconstructions (Charman 2002, 137). Lake sediments have been more frequently investigated for quantitatively determined geochemical evidence of anthropogenically-induced erosion (e.g. Mackereth 1966; Engstrom & Wright 1984); however peat-based studies have been increasing in number in recent years (e.g. Gardner 2002; Lomas-Clarke & Barber 2004). A recent upsurge of interest has resulted from the recognition of peat bogs as archives of atmospheric pollution (see Shotyk *et al* 1997; and other papers in the same volume). The incorporation of different metals into peat may occur by different processes, and certain metals are mobile in the peat profile; hence interpretation of geochemical records is not always straightforward (Shotyk *et al* 1997, 213).

4.4.5.2 Geochemical evidence of climatic change

Sodium (Na) and magnesium (Mg) are components of seawater, therefore increased concentrations are expected in peat in maritime locations as a result of sea-spray contribution (Shotyk 1988, 134). In peat profiles, changes in their concentration may identify variation in the importance of the maritime influence. This may indicate atmospheric circulation patterns and storm-tracks. Sodium:potassium (Na:K) and calcium:magnesium (Ca:Mg) ratios are usually used to indicate the maritime influence (Bengtsson & Enell 1986, 494). Higher Na:K and lower Ca:Mg ratios would be expected in times of more maritime influence; however, the latter are also used to distinguish ombrotrophic from minerotrophic bogs (Shotyk 1988, 150).

4.4.5.3 Geochemical evidence of agricultural activity

Geochemical analysis of the ash content of peat, particularly when combined with the proportion of inorganic (ash) content itself, can indicate periods of increased erosional intensity in the catchment as inorganic material is deposited on the peat surface. An advantage of using ombrotrophic peat rather than lake sediments for palaeoenvironmental analyses, particularly those concerned with human activity, is that the catchment area will be considerably reduced and the reconstruction will be at a much more localised scale. The alkali and alkaline-earth elements (Na, K, Mg), common in detrital minerals, are often seen to increase in concentration during times when other erosional indicators (ash content, pollen indicators) increase (Engstrom & Wright 1984, 27-29). Other studies have used soil-derived silicon (Si) and titanium (Ti) as indicators of erosion from deforestation and farming activities (Hölzer & Hölzer 1998; Lomas-Clarke & Barber 2004).

4.4.5.4 Geochemical evidence of metal mining

Geochemistry is potentially important in addressing the nature of Bronze Age occupation at Belderg. Although Bronze and Iron Age agricultural activity is in evidence at Céide Fields (Molloy & O'Connell 1995) it has been suggested that the spread of blanket peat by the mid Bronze Age at Belderg Beg would have precluded intensive or extensive agriculture, and that the seam of chalcopyrite might have been the primary reason for settlement (Caulfield 1978). If this were the case, then evidence of industrial activity might be expected in the geochemical archive of nearby peat. Chalcopyrite, a copper sulphite ore, is particularly difficult to smelt (Rapp & Hill 1998, 119), requiring up to three smeltings before any copper is produced (Marshall 2003, 11). Extraction from the rock face would also involve fire-setting (O'Brien 1996, 22; cf. Timberlake 2001; Mighall *et al* 2002; Gale 2003, 32). The required volume of wood fuel for the necessary fire-setting and smelting would inevitably leave a signal in the palaeoenvironmental record; a significant peak in microscopic charcoal deposition and reductions in arboreal pollen percentages and absolute frequencies may be expected (cf. Marshall 2003).

There have been several studies of peatland archives of atmospheric pollution from recent, historic and prehistoric mining activities, and a number of these have been concerned with copper mines and/or smelting sites. Studies of modern and recent sediments at known distances from industrial sites are usually concerned with the spatial scale of atmospheric transport and deposition of airborne pollutants, or the retention of pollutants in peatland ecosystems (e.g. Stiennes 1997; Nieminen *et al* 2002). The distance from copper mining and smelting sites at which peat enrichment is seen is important in locating past industrial sites and constructing metal deposition chronologies, and is therefore significant to this study. The distance over which atmospheric pollutants are dispersed varies considerably, according to the prevailing winds and also the particle sizes (cf. Mighall *et al* 2002; Nieminen *et al* 2002) but it appears that the majority of particulate matter is deposited within 3km of the source (Davies & Roberts 1978).

4.4.5.5 Incorporation into research design

There may be multiple causes for certain phenomena in the geochemical record of peat, as with the palynological and humification record. For this reason a multi-proxy approach is most valuable; the use of several indicators may provide a check on a particular theorem based on an individual proxy.

Flame AAS was identified as the most practical and cost-effective method available. Using this method only one element can be measured at once, and so six elements were selected for analysis:

1. Copper (Cu) was anticipated to be present at elevated concentrations in any levels of peat accumulating during times at which the chalcopyrite at Horse Island was being industrially exploited or mined. Although the BEL coring site is approximately 2km to the south of the chalcopyrite source it is possible that prevailing wind directions may have been such during the Bronze Age occupation that the atmospheric dispersion halo would have extended south to the sampling site.
2. Zinc (Zn) is commonly used as an indicator of industrial activity (Bengtsson & Enell 1986, 494)
3. Sodium (Na) to indicate soil erosion from upslope, and to indicate relative storminess.
4. Potassium (K) to indicate soil erosion, and *via* the Na:K ratio, to indicate storminess.
5. Calcium (Ca) to indicate salt-water influence *via* the Ca:Mg ratio.
6. Magnesium (Mg) to indicate salt-water influence and therefore storminess.

4.4.5.6 Laboratory methodology

Sampling

The closest interval sampling occurred in the lower, more archaeologically significant peat layers. Above 150cm depth, 1cm slices were sampled at 4cm intervals. Below 150cm, 1cm slices were sampled at 2cm intervals. As loss-on-ignition testing is a necessary precondition for the digestion method selected (see below), the amount of peat sampled at each level was not crucial but all measurements of weight before and after loss-on-ignition were recorded to 3 decimal places for maximum precision.

Glassware pre-treatment

Prior to each processing session, all glassware and plasticware was boiled in a large vessel in 10% nitric acid in deionised water for at least 1 hour and left to air-dry.

Digestion

A modification of the standard 'aqua regia' (hydrochloric acid/nitric acid digestion) was used (P. Anderson, *pers. comm.*). The ash residue from Loss-on-ignition testing (above) was digested in boiling concentrated nitric acid (69%, AnalaR grade) for 2 hours on a hotplate, then filtered through Whatman 541 paper and made up to 50ml with de-ionised water.

Analysis

Na, K, Cu and Zn were analysed using a Solaar Unicam flame AAS system with an air/acetylene flame at the Contaminated Land Assessment and Research Remediation Centre (CLARRC), Edinburgh. Ca and Mg were analysed using a Solaar Unicam flame AAS system with a nitrous oxide/acetylene flame at Geography, University of Edinburgh

4.4.5.7 Expression of results

Results of geochemical analyses are most usefully and usually expressed as parts per million (ppm), which equates to milligrams per kilogram (mg kg^{-1}) and this usually relates to dry weight. The spectrometer systems calculate the concentration of the metal solution in micrograms per millilitre (μg ml^{-1}) which also equates to ppm. Reference to the original weight of ash in the solution, and also the weight before ignition, allows calculation of the concentration of metal in dry peat.

4.4.6 Magnetic susceptibility

4.4.6.1 Fundamentals of magnetic susceptibility

Soil magnetic susceptibility is affected by pedogenesis, particle size, weathering history, drainage and mineral content (Thompson & Oldfield 1986). Magnetic properties of archaeological soils and sediments are subject to alteration by thermal activity. Three measures of magnetic susceptibility are commonly used to aid interpretation of archaeological sediments:

1. Volume susceptibility (κ), a dimensionless measurement of the ratio of the magnetic field created to the magnetization of the sample, in SI units.
2. Mass specific magnetic susceptibility (χ), provides an indication of the concentration of magnetic particles within the sediment measured in $\mu m^3 kg^{-1}$.
3. Frequency dependent magnetic susceptibility (χfd%) distinguishes between the sizes, or domain states, of the magnetic particles.

4.4.6.2 Incorporation into research design

BEL core

Insufficient material was available from the BEL cores to assess χ and χfd% with the available equipment (Bartington MS2B sensor: Dearing 1994). An MS2 meter used in conjunction with a MS2F can be adapted for laboratory measurement of volume susceptibility of cores at low frequency (χlf). Peat generally shows very little variation in χlf as it is composed largely of water and vegetation, which are both diamagnetic (i.e. they display weak and negative magnetic susceptibility due to an absence of unpaired electrons in the various electron shells of their constituent atoms [Dearing 1994, 15; Smith 1999, 7]). Inwash layers containing mineral material (which may exhibit magnetic properties), would usually only show up under dual frequency measurement, where the diamagnetic component of water was removed by drying. However, volume susceptibility is useful in conjunction with loss-on-ignition in identifying the transition to blanket peat from soil.

4.4.6.3 Laboratory methodology

BEL core

Volume susceptibility (κ) was measured at 1cm resolution on all cores whilst still in their plastic half-pipes, and on 2cm thick slices of the vertical faces of the 'b' monoliths. A Bartington MS2 meter with a 1cm diameter MS2F probe attached was used; the probe was clamped in a vertical position and the core or slice passed horizontally underneath it, then raised by a wedge until the sensor was normal with, and just touching, the peat face. Magnetic susceptibility was then measured at low frequency (0.46kHz, 0.1mT).

4.4.7 AMS ^{14}C dating

4.4.7.1 AMS ^{14}C dating of peat

Despite the advances in ^{14}C dating brought about by the introduction of AMS technology, there are still problems associated with the methodology and interpretation of ^{14}C dates from peat. Pretreatment methods can vary according to which particular fraction of the peat is being dated. The selected fraction may vary according to the research question: for instance, to date a change in a pollen profile, it is ideal to assay the pollen itself (e.g. Brown *et al* 1992). However, this technique is rarely applied as it is laborious and inherently problematical and dating the peat itself is much more common (Shore *et al* 1995, 382). Traditionally, peat samples for radiocarbon dating purposes are seen as being chemically broken down into three fractions: the alkali and acid insoluble humin fraction (which can be further broken down e.g. by fine sieving to date the 'fine fraction'); the acid and alkali soluble fulvic acid; and the acid insoluble, alkali soluble humic acid (Shore *et al* 1995, 374). These fractions may however give different radiocarbon ages.

Fulvic acid is usually younger than the humic acid and humin fractions from the same peat sample. This tendency is attributed to its likely high degree of mobility in peat, as it is soluble in both acid and alkali and therefore susceptible to downward leaching (Shore *et al* 1995, 379). For this reason it is usually chemically removed from peat samples prior to dating. The humin (Bartley & Chambers 1992) and humic acid (Johnson *et al* 1990) fractions have both been considered to most closely represent the radiocarbon age of peat samples. Humin material may give too young dates due to contamination from intrusive rootlets penetrating downwards, whereas humic acid may give too young ages due to downward transport of water soluble organics (Shore *et al* 1995, 374). In recent years it has become increasingly common to date discrete plant macrofossils, in particular those of *Sphagnum* or other mosses, as they have been shown not to assimilate either 'old' carbon dioxide sufficiently to contaminate their ^{14}C composition, or 'young' carbon *via* root exudates and vascular plant roots (Nilsson *et al* 2001). Depending upon the sediment stratigraphy of the material in question, however, this may not be practical. It becomes apparent that the nature of the sediment should be carefully considered before selection of the fraction to be dated.

4.4.7.2 Incorporation into research design

BEL and transect cores

Whilst it is widely accepted that *Sphagnum* or bryophyte moss fragments may be considered to give the truest reflection of the radiocarbon age of a peat sample (cf. Törnqvist *et al* 1992; Wohlfarth *et al* 1998; Nilsson *et al* 2001), in this investigation, owing to the nature of the BEL core sediment stratigraphy (see results below), this method would not be possible for all required dating levels. The basal peat developed from an organic rich mud, composed of highly degraded detrital plant material, from which it was not possible to identify discrete plant macrofossils. Furthermore, it was doubtful that *Sphagnum* or bryophyte macrofossils would be preserved in certain other levels of the core, in particular the considerable depth of wood peat. It was therefore considered that comparing like with like was of primary importance, especially considering the likelihood that different fractions would give different radiocarbon ages. The decision regarding what material to date was thus limited to the humin and the humic acid fractions. Considering that the humin fraction may be contaminated by the penetration of younger rootlets from above, that the humin fractions at different levels would be composed of different types of plant remains, and that the humin fraction in the wood peat could be composed of older woody material around which finer peat has accumulated (Shore *et al* 1995, 379), it was decided that the humic acid fraction of the selected levels would be assayed. In addition to the BEL assayed levels, four samples were selected from the transect cores for radiocarbon dating.

As a check on the relative ages of different peat constituents it was decided that two levels should have both the humin and the humic acid fractions assayed. These dual-dated levels were selected on the basis that they would be the likeliest to have undergone hydrological translocation (see section 5.2.1.2).

There are further problems associated with the interpretation of radiocarbon assays from basal peat layers, which are assumed to date the onset of peat accumulation. The issue of definition of peat initiation is one such crucial factor. Defining the transition in a hydroseral succession is fairly straightforward palynologically, by identifying the shift from aquatic to terrestrial fen communities (Charman 2002, 79). When paludification is concerned, however, the change from a highly organic soil to true peat is much less clear-cut. The organic carbon content of a highly organic sediment such as that in the base of the BEL core (see Section 5.3.1 below) may have a long residence time (ibid.).

BB sections

Where peat overlies soil there may have been a time period of unknown duration between the cessation of activity on the soil profiles and the initiation of peat accumulation. Furthermore, the date obtained from the peat will represent the average age of the organic carbon in the humic acids of the sample, and not the date at which accumulation commenced (Carter 1993-1994, 86). If blanket peat growth was immediate, the soil and climatic conditions must have been favourable (ibid., 86-87). As there is some evidence of organic accumulation in the BB soil sections – plant macrofossils preserved in the sub-peat soils – it can be assumed that this might be the case. A further indication of the accuracy of a radiocarbon age of a basal peat sample in relation to the true basal age would be achieved by assaying a second, contiguous sample, just above the basal peat sample. The more rapid the rate of growth, indicated by the difference between the ages, the more accurate the estimation of the basal age. This technique has been used to suggest radiocarbon assays from basal peat overlying ridges at Lairg, northern Scotland, provided a good estimate of the age of accumulation (ibid., 88).

For this study only limited funding was available for radiocarbon assays and obtaining sufficient radiocarbon dates to answer questions regarding whole-site formation, including landscape-scale analysis, was judged to be of higher significance. Therefore only single radiocarbon assays were taken from each of the BB sections. However, as a sample from N10, a Transect 2 borehole close to BB2, was assayed (see Figure 5.2), it was hoped that a viable interpretation of peat accumulation might be possible.

4.4.7.3 Laboratory methodology

Samples were submitted to the Scottish Universities Environmental Research Centre, East Kilbride for preparation and analysis.

4.4.7.4 Presentation of results

In construction of age-depth models, necessary for the calculation of sediment accumulation rates, the use of calendar years is preferable to radiocarbon years (Bennett 1994, 339; Bartlein *et al* 1995). Age-depth models calculated using radiocarbon years implicitly make the implausible assumption that variations in sediment accumulation rate cancel out wiggles in the calibration curve (Bartlein *et al* 1995; Telford *et al* 2004, 1). Using calibrated dates adds an extra complication in that the resulting probability distributions are not Gaussian (Bennett 1994; Telford *et al* 2004, 1). Various models are commonly used for constructing age-depth relationships: linear interpolation, splines, linear regression models (Bennett 1994), fuzzy regression (Boreux *et al* 1997) and mixed-effect regression (Heegaard *et al* 2005), all of which can give very different answers (Telford *et al* 2004). It is accepted that the low number of dates available to this investigation is less than ideal, as it is ideal to optimise precision by maximising the number of dates in the sequence. The most practical models to apply to a sequence with few dates are linear interpolation or polynomial models. Application of these models would necessarily assume that the sediment deposition rates changed abruptly at the depths of the dates or followed a polynomial of the appropriate order respectively; both of which are not necessarily correct assumptions for sites with just a few dates (Telford *et al* 2004, 3). It is recognised that linear interpolation forces the age-depth model to pass through the dates, meaning that the model cannot deviate too far from reality, although this results in the incorporation of noise from the uncertainties of radiocarbon dating into the model (ibid., 4). For this reason, linear interpolation has been selected to calculate age-depth relations in this investigation.

4.4.8 Thin section soil micromorphology

4.4.8.1 Fundamentals of thin section soil micromorphology

Soil micromorphology involves thin section examination of undisturbed sections of soil-sediment. Individual signatures identified in thin sections offer insight into the formation of the soil itself ('site formation processes'), the nature of previous human activity and landuse practices, and post-depositional processes that have acted upon it (usually) since burial. Anthropogenic signatures in the sections are identified by empirically defined relationships of human effects on archaeological soil-sediment formation. These effects are expressed in the thin sections by a hierarchy of observed spatial and temporal patterning of various features that are used to reconstruct sequences of sedimentary, pedogenic, and anthropological events. The principle of stratigraphy is used to match the microscopic analysis to field-observed stratigraphic units. Thus chronologically and spatially varying human activities and environmental conditions can be identified, adding a detailed dimension to the archaeological interpretation of a soil known to have been subject to human modification.

4.4.8.2 Soil micromorphological evidence of palaeoenvironmental change

Various features of soils and sediments can inform of post-depositional processes caused by environmental conditions. Shrink-swell transformations, drastic changes in microfabrics, result from repeated wetting-drying episodes. Examples include the formation of vertisols typified by compaction, a lack of horizonation, uniform colour, and a blocky or prismatic microstructure (FitzPatrick 1984, 145-159; Courty *et al* 1989, 151). A massive microstructure is more indicative of continuously wet soils. Freeze-thaw conditions are signified by soils with angular blocky, subcuboidal or lenticular microstructure (FitzPatrick 1984, 147-162). Frequent fires can be indicated by high concentrations of charcoal, and this can relate to lightning strikes which occur frequently in suitable climatic conditions, as well as being an indicator of deliberate anthropogenic clearance. Storm events can be signalled by single-event deposition of windblown sands in certain geographic areas. Whilst pedogenic processes such as podzolisation are often a natural evolutionary process of some soils, they can be enhanced or accelerated under certain environmental or climatic conditions and an integrated investigation including soil micromorphology may be able to establish causal or contributory factors.

4.4.8.3 Soil micromorphological evidence of former agricultural activity

Clearance

Uprooting is recognisable at the field level in plan and section, and has disturbance effects on soil horizonation (Macphail 1987; Courty *et al* 1989, 127). The manner in which the subsequent hollow was infilled is recognisable in the soil microfabric, which is examined in thin section. Rapid infilling is characterised by strongly mixed, heterogeneous fabric composed of material from different soil horizons (Macphail 1987, 15). The inclusion of artefacts or coarse wood charcoal can indicate that anthropogenic activity was associated with the uprooting (Courty *et al* 1989, 127). Slower infilling and gradual recolonisation of the surface by vegetation is indicated by more homogenous microfabric showing evidence of substantial reworking by biological activity (ibid.; Macphail 1987, 15).

Former clearance by burning is often recognised in soil thin sections by a microfabric containing finely mixed charred organic fragments as well as some remnants of charcoals and burned wood, with rubified aggregates representing burnt topsoil, in a clay-containing soil. Clay coatings rich in fine charcoals can be seen in lower topsoil levels of rapidly sealed burned soils (Courty *et al* 1989, 129).

Agriculture

Pastoral agriculture is recognised in palaeosols by the stable, deep crumb structure with intensive fine rooting that is typical of grassland surfaces (Courty *et al* 1989, 129). In addition, the effects of trampling can be recognised by platy structures near the soil surface, and increased quantities of organic matter and fungal bodies are representative of herbivore grazing (ibid.).

Arable soils can be recognised at field-scale (by ard-marks or relict cultivation ridges) or in thin section. The mixing action of ploughing activity will have eliminated the upper soil horizons, therefore a homogenous ploughed layer including humic material as well as mineral material from the underlying A horizon, may have been created (Courty *et al* 1989, 131; Courty *et al* 1994, 262). The disruption features commonly associated with agricultural soils have been identified from modern analogues or experimental work. Such disruption features include certain types of textural pedofeature: clay infills and coatings, which are usually silty or dusty, and agricutans, coatings, infills and pans composed of fine plasma, fine sand grains and fine organic materials, which form as a result of surface slaking of bare soil surfaces, followed by translocation resulting from ploughing (ibid., 131-132).

The redistribution of soil fines material (the fine fraction) and the pattern of textural pedofeatures can aid identification of former cultivation implements (Macphail *et al* 1987, 652). Recent experimental work, supported by archaeological investigations, has resulted in the identification of further micromorphological features characteristic of former agriculture (Lewis 1998). Silt-dominated lenses and pans of soil fines characteristically form beneath and around implement cut marks, as a result of trickling-down and density boundaries within the tilled horizon (ibid.). Certain structural features (angular or subangular blocky aggregates and smaller rolled or rounded aggregates) are characteristic of feature fills. A compaction zone including stress-induced shear planar voids, possibly infilled by fines, echo implement mark bases and cuts (ibid., 190). Certain characteristics are indicative of tillage implements in general, whilst some features can distinguish between implements. For instance, turning implements (spades and mouldboard ploughs) tend to result in enhancement of the organic content of soils within the marks, whilst pushing implements (ards) increase the organic character of the cultivation layer as a whole (ibid., 339).

A further aspect of former agriculture which may have left tangible identification evidence in thin section is that of soil amendment practices such as manuring. Addition of organic manures such as animal dung may be recognised by the presence of higher amounts of organic fragments, including phytoliths, which may be fractured as a result of ingestion (Courty *et al* 1989, 134; Courty *et al* 1994, 257). Calcium spherulites, evident in crossed polars at high magnification, which source from animal dung, are a further indication of manuring (Dockrill & Simpson 1994, 88; Canti 1997; 1998). Seaweed added as manure can also be recognised by the presence of marine calcium carbonate shell fragments (Dockrill & Simpson 1994, 86 & 91). The addition of domestic wastes to arable land, namely the practice of middening, can be recognised in thin section. Typical indications of the addition of midden material would be the presence of animal or fish bone fragments, charcoal, and ash (which is recognised as fine red/brown mineral material in crossed polars, often with rubified mineral grains) (Courty *et al* 1994, 263). In acidic contexts, bone can decompose and recrystallise, producing characteristic textural pedofeatures: amorphous and crypto-crystalline calcium-iron-phosphate nodules, infills and coatings (Jenkins 1993; Simpson *et al* 1998b).

Addition of midden material has been recognised in North West European arable soils from the Late Neolithic (Bakels 1997; Dockrill & Simpson 1994). The use of burnt turves and domestic waste continued throughout the Bronze Age, and the application of animal dung as manure apparently began later, in the Iron Age (ibid., Simpson *et al* 1998b).

4.4.8.4 Incorporation into research design

The Kubiena tin samples from sections BB1 and BB2 were described in detail, allowing the stratigraphy to be studied and provisionally interpreted. The sections that were anticipated to record the fullest history of pedogenesis were submitted for thin section preparation. The remaining sections were retained for analysis of pollen content and physical properties (see above). The aims of the soil micromorphological analysis are outlined as follows:

- To investigate the hypotheses that:
    1. The ard-marked soil horizons recognised in both sections represent the same layer, and that this is the layer cultivated during the utilisation of the Neolithic field system;
    2. The cultivation ridges in section BB1 relate to the Bronze Age occupation.
- To investigate the formation of the soil deposits, including environmental and climatic factors in their modification.
- To investigate any evidence of human modification of the soils, especially relating to their agricultural utilisation.

- To assess whether deteriorating soil conditions may have been a factor in abandonment of occupation of the site and the causal factors behind any such changes.

4.4.8.5 Methodology

Laboratory methodology

Thin sections were produced by George McLeod of the Micromorphology Laboratory, Department of Environmental Science, University of Stirling, based on the procedures of Murphy (1986). Samples were dried in acetone vapour, checked by specific gravity measurement. The samples were impregnated with crystic 17449 resin (polyester). The ratio was 350ml resin:1.75ml catalyst (Methyl Ethyl Ketone Peroxide):75ml acetone. This is about half the standard amount of catalyst to allow for the slower cure rate needed by peaty samples. Samples were cut into 1cm slices, lapped, mounted on glass slides then ground to approx 30-40μm thickness. Finally they were polished with 3μm diamond in oil suspension.

Analysis

Analysis was performed using a Nikon transmitting light microscope using a range of light sources (plane polarised, crossed polars, oblique incident) at a range of magnifications (x 1 – x 400). Thin section descriptions conform to internationally accepted terminology by Bullock *et al* (1985), with components and features within the sediments semi-quantified by the aid of frequency charts in the same handbook.

Chapter 5

Off-site investigation: results and interpretation

5.1 Introduction

The investigations at Belderg Beg consist of off- and on-site analyses with respect to the archaeology. The investigations defined as on-site relate to those conducted within the area of archaeological remains. In this study, this refers to the geoarchaeological and palynological analyses of the sub-peat soil sections near the roundhouse. The results and interpretation from those investigations shall be considered in Chapter 6. Chapter 5 concerns the palaeoenvironmental aspect of the investigations, away from the excavated site: the analysis of the coring transects and the BEL core. In each section, results are presented first, and interpretation is considered in a separate sub-section.

Unless stated otherwise, all radiocarbon dates in text or diagrams and used to calculate sediment accumulation rates are quoted in calibrated years BP (midpoint of 2σ range), calculated using OxCal v. 3.9 (Bronk Ramsey 2003) and atmospheric data from Stuiver *et al* (1998).

5.2 Sediment-stratigraphic transects

5.2.1 Results

5.2.1.1 Sediment descriptions and sediment stratigraphy

Figure 5.1 shows the location of each transect core plotted on a plan of the Belderg Beg area, which also shows the locations of the main archaeological features. Figure 5.2 shows the sediment stratigraphies of individual boreholes plotted against altitude (Irish OD) on Transect 1 and inferred sediment-stratigraphic correlations. Note the change of scale between 5.2b and 5.2c. Figure 5.3 shows the sediment stratigraphies of individual boreholes plotted against altitude on Transect 2 and inferred sediment-stratigraphic correlations. Sediments are described according to the system outlined in Section 4.4.1.1. Detailed descriptions of the sediment stratigraphies of each core in Transects 1 and 2 are presented in

Appendix D. Descriptions of Transect 2 sediments are less detailed than those of Transect 1 due to particularly inclement weather conditions preventing such thorough field analysis from taking place. In these tables, the final column, labelled Unit, refers to the identification of a recurring sediment type, developing inferred sediment-stratigraphic correlations.

5.2.1.2 AMS radiocarbon dates

To interpret the sediment sequences of the transects it was necessary to understand the chronology of the hillslope stratigraphy. Six samples of basal peat were submitted from the transects for AMS radiocarbon dating. This chronological control aided interpretation of sediment formation and thus landscape evolution, although the potential problems associated with dating basal peat from paludified ground (see Section 4.4.7.2) must be borne in mind. The samples were selected with respect to their locations and sediment stratigraphies:

- The BEL core was selected because it has the greatest depth and most complex sediment stratigraphy. For these reasons it was anticipated that this would be the best core to use for detailed palaeoenvironmental analysis.
- W2 was chosen because it is close to the BEL core and at its base has a similar sediment stratigraphy. Although on a slight slope, its base is at a similar altitude to that at BEL, and it lies above the break of slope between BEL and E1 (see Figure 5.2). A similar date of peat initiation was expected to that at BEL.
- W7 is located immediately downslope of the terminal Wall 1, and is therefore situated outside of a field wall assumed (Caulfield pers. comm.) to have been Neolithic. As well as its usefulness in assessing rates of lateral peat spread, W7 is important to compare with W8, upslope of Wall 1.
- W8 is located just upslope of Wall 1 and is thus situated inside the inferred Neolithic field wall. The age of peat initiation at W8 may be cross-referenced to the BEL pollen profile to infer whether or not abandonment of agricultural activity occurred coincidentally with the spread of peat on to the field system. Furthermore, any significant delay in peat initiation between this location and W7 may represent deliberate strategies to retard peat spread within the fields by human agency, such as cultivation, peat stripping or intensive manuring.
- W21 is upslope and within the inferred Neolithic field bounded by Wall 1. Peat initiation is assumed to have occurred relatively late at this location because upslope spread has been hitherto supposed. As rare silt grains are disseminated throughout the core, peat

initiation possibly began when human activity in the form of agriculture was still occurring. The possible disturbance of sediment stratigraphy in this location made it a good choice to investigate any differences in age determinations between peat fractions (see below).

- N10 is outwith the large area apparently enclosed, to the north of Wall 1 and the south of Wall 2 and is assumed to have been in the area of Bronze Age agricultural activity. It was hoped that by comparing the age of basal peat at N10 with that at W21, it might become apparent whether or not attempts had been made by people to retard the spread of peat.

As there are known problems inherent in the radiocarbon dating of peat (see Section 4.4.7.2) the reliability of the use of the humic acid fraction for dating was checked by separately dating the humin and the humic acid fractions of two samples:

- W2 was selected because it was most comparable in sediment stratigraphy (and therefore presumably age) to the basal peat date from the BEL core (GU-11634). It thus provided an indication of the reliability of the humic acid age of GU-11634.
- W21 (P2) was selected because, as it was upslope, it was considered likely to represent later peat initiation. As it appeared to be within the area of Neolithic activity (see proximity to Wall 1 in Figure 5.1) groundwater movement from open ground upslope may have affected the relative radiocarbon ages of the peat fractions.

In addition to the basal peat samples, one further sample was submitted for radiocarbon dating:

- W21 (P1) was taken from 38-40cm in W21, immediately underlying a band of mineral sediment inwashed at 37-38cm. This horizon was selected for dating purposes in order to determine the age of the inwash band and, by comparison with the pollen profile, whether it represented erosion from human activity occurring upslope.

Table 5.1 shows the AMS radiocarbon age details obtained from the transect cores. The calibration details of each assay are presented graphically in Figure 5.4.

5.2.2 Interpretation

5.2.2.1 AMS radiocarbon dates

To assess the reliability of using the humic acid fraction to date selected levels of cores and sections, two samples, W2 and W21 (P2), also had their humin fractions dated. As discussed in Section 5.2.1.2, W21 (P2) was considered more likely to have been affected by groundwater movement resulting from inwash. From Table 5.1 it is seen that the calibrated 2σ ranges overlap therefore the samples are statistically indistinguishable. Had downwashing of water-soluble organics occurred *via* groundwater movement, the humic acid fraction would be expected to be significantly younger than the humin fraction. As this is not the case it can be interpreted that the humic acid fraction gives an accurate reflection of the sample age.

A basal peat sample from W2 was chosen as it was comparable in stratigraphical terms to the basal peat in the BEL core. Again, as the calibrated 2σ ranges are statistically indistinguishable, the interpretation is that both fractions give a reliable indication of sample age.

5.2.2.2 Overall transect stratigraphy

From examination of the stratigraphy of the transect cores, with the added information given by radiocarbon ages, it is possible to construct a chronology of the evolution of the Belderg Beg hillslope. Peat initiation occurred in the BEL core at c. 5465 cal. BP. BEL is not in a basin but rather at the top of a break of slope: a small basin exists just below it (core E1; see Figure 5.2). Whilst peat might be expected to form at the lowest points, such as in a basin, earlier than on a slope, comparison of the sediment stratigraphy of the BEL core with that of the E1 core suggests that there was probably little temporal difference in peat initiation between these locations. Both cores have till at the base. This is overlain in BEL by an inorganic sand, and in E1 by a silty fine sand with low organic content, then by a waterlain banded coarse sand, equivalent to the sand layer in BEL. The next stratigraphic layer in BEL, the organic-rich mud, is not present in E1, where the sand layer was superseded immediately by wood peat. As it is reasonable to assume that the yellow sand layers in the two profiles represent the same event, there is no reason to expect a difference in age between the sediments that immediately overlie the sand in each profile. The differences in sediment stratigraphy between the two cores perhaps indicates episodes of erosion during which soil material accumulated in the basin (E1). Following deposition of the inorganic yellow sand which is present in both profiles, the surface at BEL was apparently stable enough to allow accumulation of an increasingly organic detrital sediment, while wood peat began to accumulate downslope at E1. Wood peat apparently began to accumulate very soon after this in the BEL area.

Till is absent at the base of all the profiles downslope of E1, and several of those upslope, and this confirms that till cover is patchy (cf. Coxon 1991, 6-13). The sediment sequences along the hillslope profile are complex. Towards the base of the transect this is complicated further due to the loss of loose basal sediments from the coring equipment. The sand layer around BEL is discontinuous (see above), as is the amorphous organic silt mud which featured at the base of the BEL core. Erosion or redeposition of sub-peat mineral soils or sediments may have occurred patchily, creating these different profiles. Many of the cores show that peat developed directly on bedrock, with both herbaceous and herb/wood peat seen in such positions. As lacustrine deposits are not found below the peat, it is evident that in all profiles paludification rather than terrestrialisation was the route to peat initiation (*sensu* Charman 2002, 74).

A further consideration for landscape evolution is related to the date of initiation of deep peat on the hilltop plateau (see Figure 3.2). There, a *Pinus* expansion is recorded in the form of a dense concentration of sub-fossil stumps preserved at some considerable height above the mineral soil/peat transition. A peat sample from 5cm above mineral soil, below a subfossil *Pinus* stump, was assayed to c. 6150 cal. BP (see Appendix A; Caulfield *et al* 1998, 633). It is evident that peat growth commenced significantly earlier on the plateau than lower down the hill slope.

5.2.2.3 Sub-peat stratigraphy

There were no developed soil profiles below the peat recorded downslope of the cultivated areas, as recognised during the excavations (see Figures 5.1 and 5.2 and Appendix D), and even at altitudes above those of the walls, there were profiles recording peat apparently growing directly on bedrock (e.g. W17). None of the cores in Transect 1 can be described as having true soils beneath peat, although mineral-rich detrital peat layers and/or organic sediments were common. There are two possible reasons for the absence of full soil profiles:

1. Throughout the early- and mid-Holocene, the lower hillslope at Belderg Beg had always been characterised by bare rock with only patchy coverage of till, sands and silts, and with thin soil profiles developing in topographically suitable locations. From such points, peat initiation began in the mid-Holocene when climatic, hydrological and pedogenic conditions were suitable, and this peat spread from *foci* onto the surrounding surfaces. The likelihood of this scenario being correct appears to be slim, taking into account contrary evidence such as the considerable depth of soil profiles (including horizon development) in the vicinity of the roundhouse (see Figures 5.1 and 5.3 and Appendix D). Should the soils around the roundhouse be entirely human-made ('plaggen soils'), the possibility of an entirely soil-free hillslope might not be so unlikely. However, horizonation is evident in the soils in question. Whilst the walls of the field system may well have acted in a retaining capacity, preventing substantial soil erosion from the fields, and significant amendment strategies may have been continually made to maintain the soil structure and fertility, it appears unlikely that sufficient soil development for agricultural purposes took place within the walled areas, while just outside this, bare rock existed and soils never really developed.

2. The more likely scenario appears to be that a soil profile developed over the entire Belderg Beg hillslope, and that much of it was lost prior to the earliest peat initiation at c. 5465 cal. BP. Loss of this soil could have occurred by erosion. Sub-peat pockets of soils remaining in topographically suitable positions were covered by peat at different times, leaving open the question as to whether erosion was a single event or progressive, multiple events occurred. Alternatively, people could have stripped soils from some areas in order to amend soils at other locations (cf. Davidson & Carter 1998). Whilst widespread use of plaggen soils is generally considered to have been a Medieval phenomenon (Spek 1992), earlier examples are known, and the earliest yet dated are within Atlantic Britain. Turf stripping for plaggen soil formation to support arable agriculture elsewhere is evidenced from micromorphological analysis of Late Neolithic (Simpson *et al* 1998a) and Late Bronze Age / Iron Age soils at Tofts Ness, Orkney Isles (Dockrill & Simpson 1994, 89; Simpson 1998, 96). Late Iron Age soils at Old Scatness, Shetland, incorporated turves that had evidently been used as animal bedding, adding a further component to the integrated farming system (Simpson *et al* 1998b, 121-123). 'Scalping' of soils has been suggested to have occurred in Neolithic Scotland more widely than previously believed (Edwards 2004, 65-66).

Soil micromorphological analysis of the ridged cultivation plots near the roundhouse (Sections 6.2.3 and 6.3.3) does not indicate that soils in these locations were amended by the addition of turves from elsewhere. Horizonation is evident in those profiles. Of course, amendment could have occurred in other locations within the field system. Erosion of soils within the area enclosed by Wall 1 is evidenced by progressive deepening of soils downslope towards borehole W8 (see below). It is therefore accepted that soil erosion did occur at Belderg, but whether it was responsible for the almost entire loss of soil from below the field system is unknown. A situation in which soil from downslope of the field system was stripped and utilised to amend the eroding soils within the fields might be appropriate.

Transect 2 boreholes show that the sediment stratigraphy at the altitude of the assumed Bronze Age activity contains a relatively well-preserved soil profile that is fuller than that seen in Transect 1. Eleven of the seventeen boreholes contain a basal mineral soil, and of the remaining six, two (N7 and N8) have sandy fibrous peat at the base, whilst four exhibit peat growing directly on bedrock (see Figure 5.3 and Appendix D).

In examining the sediment stratigraphy of Transect 1 boreholes it became apparent that true mineral soils comparable to those in Transect 2 are not recorded in any of the profiles. Many of the borehole sediment stratigraphies contain mineral-rich basal sediments. The absence of a soil profile is vital in understanding the landscape development at Belderg Beg throughout prehistory. Before the earliest peat initiation in the mid-sixth millennium cal. BP the soils were evidently sufficient to support a forest (Section 5.4.2), and to sustain agriculture on the mid-altitude slope of the valley side. Before peat had spread over the landscape, most of this soil had been lost from altitudes below the Bronze Age activity.

Looking first at the area within the field enclosed by Wall 1, i.e. boreholes W8 and upslope (see Figures 5.1 and 5.2), it is seen that the thickness of basal mineral sediments increases with proximity to Wall 1 (i.e. 3cm in W9 increasing to 14cm in W8e: see Appendix E). This indicates that a certain amount of erosion occurred within the field *via* slopewash or soil creep, resulting in the banking up of mineral rich soils against the terminal wall (lynchet formation). This occurred prior to the development of true peat at c. 4930 cal. BP, and was relatively long-lasting, as evidenced by the depth of organic matter accumulation with mineral inclusions in the affected boreholes (6cm of peat with silt in W10; 13cm in W15; 5cm in W8). An estimation of the period of time in which soil erosion was active is reached by dividing the depth of organic matter with mineral inclusions in the W8 core – 100mm (68–78cm depth: see Appendix E) – by the estimated growth rate of the BEL core at that particular point in time (c. 0.34mm/cal. yr: gradient of appropriate section [Trendline 5] of age/depth curve in Figure 5.8). This equates to c. 294 years, which when rounded up for simplification suggests 300 calendar years of soil erosion is represented.

Downslope of the field system (boreholes W7 to E8) the mineral inclusions in basal peat layers become less frequent and of lesser thickness. Exploratory Eijelkamp coring in the area between the Belderg River and the E8 borehole site (see Figure 5.1) displayed similar sediment sequences to those between E8 and W7. Had gravitational soil erosion truncated the soil below the field system, redeposition at the base of the slope would be expected. Instead, slopewash and groundwater transfer from upslope may have resulted in wetter soils forming on these flatter areas near the floodplain, causing paludified soils and inhibiting soil maturation and profile development. This still does not adequately address why some of the boreholes (E8 and E7) record peat growth directly on bedrock. The basal peat in these instances is woody, compared with the detrital amorphous silty peat overlying basal layers in E6 and E5. There is perhaps a conceptual difficulty in concluding that wetland trees successfully colonised a thin peat layer overlying bare rock.

5.2.2.4 Peat initiation and expansion

Peat development through paludification requires a shift in local hydrological conditions sufficient to reduce the rate of organic decay significantly below that of its production, though there need not be any external forcing mechanism involved (Charman 2002, 74). Peat spread from the early *foci*, followed by coalescence of these islands of peat to form a large blanket, can account for the increasing extent of cover (Chapman 1964b; Smith & Cloutman 1988, 197-200; Smith & Taylor 1989; Moore 1993), although some workers have questioned whether blanket peat does in fact expand upslope from basin mires (Chambers 1982, 38; with reference to Chambers 1980). Nevertheless, the data from Belderg Beg are indicative of blanket mire spreading upslope. The sequence of sedimentary deposit evolution leading to upslope spread in this case may be more complex than this seemingly simple description would suggest.

The basal peat assays show that peat initiation at various points along the Belderg Beg hillslope was diachronic. Lateral expansion of peat could occur by different mechanisms.

Firstly, paludification and organic matter accumulation could occur in multiple locations under conditions of, say, rising groundwater. A time-transgressive 'front' of peat could creep laterally, altering the hydrology of adjacent soils and triggering vegetational successions towards mire communities (Kuhry 1985). Predictive modelling has shown that substrate morphology affects blanket mire spread (Granerio & Price 1999, 250). Mires expand across a range of topographical types, and whilst no particular substrate morphology limits expansion, concave morphologies seem to counteract the effect of downslope water loss (ibid., 250-251; Charman 2002, 153). Peat expansion up slopes has frequently been evidenced by radiocarbon assays from basal peats at various points along slopes, similarly to this investigation (e.g. Foster & Fritz 1987; Charman 1994).

Rates of peat expansion are calculated in Tables 5.2a and 5.2b. The mean rate of peat spread is calculated at c. 0.091m/cal. yr, not including the trendline between W7 and W8 (either side of Wall 1; see Figure 5.1). Initially, the spread from BEL to W2 (c. 5465 to c. 5180 cal. BP) proceeded at a roughly average rate (0.095m/cal. yr), on a relatively gentle slope (gradient 0.029). Rates of spread between W2 and W7 (c. 5180 to c. 4935 cal. BP) increased to 0.161m/cal. yr, along a steeper slope (gradient 0.053). The basal peat assays from W7 and W8 (either side of Wall 1) are inseparable (c. 4935 to c. 4930 cal. BP at 1.56m/cal. yr) suggesting that peat grew at both these locations at the same time. After this time, peat spread proceeded at reduced rates, perhaps because the slopes were slightly steeper. Between W8 and W21 (c. 4930 to c. 2860 cal. BP) spread occurred at 0.071m/cal. yr along a slope of 0.067. Between W21 and N10, peat spread was much slower (c. 2860 to c. 2030 cal. BP), at 0.036m/cal.yr, along a slope of 0.065. The pertinence of these results to dating the archaeological remains is important and is discussed further in Section 5.2.2.5 below.

The hydromorphic mire type represented by the wood peat layer below the Neolithic walls can be described as a soligenous sloping fen *sensu* Charman (2002, 7): peat on sloping terrain receiving water from runoff and (in this case, decreasing amounts over time of) groundwater. The appropriate model is apparently one of a valley mire (soligenous fen), as a mesotope formation on the lowermost part of the Belderg Beg slope, within the larger blanket mire macrotope (see Charman 2002, 27). Whilst damp soils such as peat would typically be expected at the base of a slope, valley mire formation may be enhanced or accelerated by human activity, particularly anthropogenic forest clearance, in certain areas (ibid., 86). In North Wales, woodland removal, soil acidification and valley mire initiation around the fringes of a lake at c. 6300 – 5700 cal. BP has been attributed to Late Mesolithic /

Early Neolithic human activity (Mighall & Chambers 1995). The critical factor appears to be increased runoff.

The evolution and expansion of a sloping fen carr system through to blanket bog by increasing ombrotrophy may have proceeded according to the primary, secondary and tertiary peat growth model (Moore & Bellamy 1973). This model essentially describes the physical mechanisms by which peat initiation and lateral spread occurs, and is regarded as a conceptual aid to the visualisation of peatland development in landscape terms (Charman 2002, 78-79). According to this model, primary peats tend to form in water-collecting topographical locations such as basins or depressions, where they are often preceded by limnic developmental phases. Secondary peats grow as the ground surrounding the primary peatland tends to become waterlogged, without necessarily implying external triggers, and allow the peat to expand beyond the depression *foci*. Tertiary peats develop above the influence of groundwater, with conditions allowing peat to cover most areas of the landscape, and these occur mostly in ombrotrophic mires.

This model was reviewed for its application to palaeoenvironmental investigation of landscape development by Edwards & Hirons (1982), who considered the influence of topography. Whilst acknowledging the importance of microtopographical depressions on slopes in acting as initiation *foci* (see Figure 5.5), they applied the primary-secondary-tertiary peat growth model to a smooth-sloped hillside (see Figure 5.6). Their conclusions were that accurate determination of the true spread of peat would depend upon the growth rates being within the resolution limits of radiocarbon dating, coupled with the identification of the correct fraction of the most appropriate deposit for analysis and dating (ibid., 34-35).

In applying this model to mire development at Belderg Beg, the primary peats are those initiated in the microtopographically suitable depressions of early peat growth, such as the BEL and E1 core locations. The primary-secondary transition is frequently particularly difficult to determine (Charman 2002, 79), and at Belderg Beg the boundary between primary and secondary peat is less easily identified from examination of the transect stratigraphy. It is likely to represent the main phase of expansion of the fen carr; from the stratigraphic transition to woody peat in the BEL core to the palynological indication of blanket bog inception, lasting from c. 5170 – 3775 cal. BP (c. 268cm – 180cm in BEL). This may suggest that a strict primary-secondary-tertiary model is not particularly useful and that site-specific conditions and variations in mire growth and spread are more important to palaeoenvironmental study. Nevertheless, the pollen profile in BEL shows a sharp transition to woodland-dominated vegetation cover just prior to the 268cm sedimentary shift (see Figure 5.16). There might be some screening effect, by which open patches of the mire-dominated landscape existed without being represented in the pollen profile, but overall a synchronous shift in landscape and vegetation dynamics is interpreted.

The secondary/tertiary peat transition is typical of shifts from fen to bog conditions (Charman 2002, 79) and can be more easily identified as the stratigraphic boundary between woody and herbaceous peat, for instance at 180cm (c. 3775 cal. BP) in the BEL core (although a somewhat earlier transition to ombrotrophic conditions is implied by the palynological profile than the peat stratigraphy; the former recording principally blanket bog vegetation composition from c. 190cm [c. 3945 cal. BP]: see Section 5.4.5).

When considering the hillslope over a wider area than that covered by Transect 1, it is apparent that the Moore & Bellamy (1973) model would identify the earliest peat growth at both the top of the hill (a water-shedding location), and the base of slope in the floodplain of the Belderg River (see Figure 3.1), with other initiation *foci* occurring within hill-slope depressions such as the BEL-W2 and E1 core locations. This is confirmed by the earliest date of peat initiation occurring on the hilltop plateau, early peat also at the base of the slope (BEL) and the youngest peat deposits located mid-slope.

5.2.2.5 Linking peat spread to archaeology

The knowledge of rates and timing of peat spread over the Belderg Beg hillslope allows a critical review of previously held assumptions regarding the sequence of activity on the archaeological site.

The age of Wall 1

As outlined in Section 3.2.2.1, previous studies have assumed that Walls 1 and 2 were remnants of a Neolithic field system. The primary evidence offered for this was that their upslope extremities were constructed on mineral soil, and that the outer rings of a subfossil *Pinus* stump rooted in that mineral soil, near the upslope end of Wall 1, were assayed to c. 5145 cal. BP (see Figure 3.4 and Appendix A). Second is the implicit assumption that peat would have covered a significant proportion of the area enclosed by Wall 1 by the time of Bronze Age occupation (Caulfield 1978, 140).

Approaching the question of the age of Wall 1, the date of peat spread either side of it must be taken into account. There is no significant difference between the age ranges of basal peat at W7 (5040-4830 cal. BP) and at W8 (5030-4830 cal. BP). It is evident that there was no measurable delay in peat spread either side of Wall 1 (in terms of the resolution of radiocarbon dating), and therefore it can be concluded that no effort was made by people to retard peat spread inside the field.

There are two possible hypotheses. Firstly, that the walls were indeed constructed in the Neolithic period. If they were constructed on mineral soil for their entire lengths, they would have had to have been built before c. 4900 cal. BP, because that was the approximate date at which peat inception occurred at the W7 and W8 borehole locations. At c. 4900 cal. BP peat formed on either side of the wall unimpeded. Alternatively, the walls could have been constructed later, extending downslope on to peat, and the terminal section of Wall 1 (running across the slope) was constructed on peat of the same age either side of it. As that terminal section of wall remains unexcavated and its dimensions marked only by probing, the question must be addressed by palaeoenvironmental analysis of the BEL core. As shall be seen below (Section 5.4.2) the palynological record supports the former hypothesis; that Wall 1 was a functional barrier in a very early phase of agriculture.

5.3 BEL core results

5.3.1 Description of sediment stratigraphy.

Table 5.3 records the sediment stratigraphy in detail using the Troels-Smith (1955) system as modified by Aaby & Berglund (1986). In addition to the Troels-Smith notation, a brief description of the sedimentary units is included, utilising the same descriptive criteria as those used to describe the transect cores (see Appendix D). This is to aid comparison with the transect cores, which were described in the field, where pressures of time and inclement weather prevented full description using the Troels-Smith system.

5.3.2 AMS radiocarbon dates and accumulation rates

5.3.2.1 Presentation of results

Table 5.4 shows the details of the radiocarbon assays for the BEL core. Graphical representations of calibration details are presented in Figure 5.7. Figure 5.8 shows the age/depth relations for the BEL core, adopting linear interpolation to assess age-depth relations.

5.3.2.2 Sediment accumulation rates

From Figure 5.8 it can be seen that sediment accumulation rates in the BEL core have not been constant over time. The key in Figure 5.8 explains calculation of the changing rates of growth (sediment accumulation rates), which are calculated by linear interpolation between each assayed level. The relatively shallow gradient between the lowest two assays (c. 4935 to 5465 cal. BP, Trendline 5) indicates an initially slow sedimentation rate of 0.34mm/cal. yr. The gradient between the uppermost assay (c. 1440 cal. BP) and the surface (Trendline 1) is also relatively shallow, with an accumulation rate of 0.28mm/cal. yr, which could result from either slower peat accumulation or reduced compaction, which acts upon peat at greater depths. Between c. 1440 and c. 4110 cal. BP (Trendlines 2 and 3) the accumulation rate was 0.6mm/cal. yr. The accumulation rate was 0.73mm/cal. yr between c. 4110 and c. 4935 cal. BP (Trendline 4). The age of the basal sediment is estimated at c. 5525 cal. BP from linear extrapolation of the lowermost accumulation rate (Trendline 5).

5.3.3 Magnetic susceptibility

5.3.3.1 Presentation of results

Figure 5.9 shows the volumetric magnetic susceptibility (κ) of the BEL core. As overlapping cores and monoliths were taken, susceptibility was tested on each core and monolith and Figure 5.9 shows these results superimposed. The curve in Figure 5.10 represents the mean value of these individual curves.

5.3.3.2 Interpretation

Figure 5.9 shows that there are differences in volumetric magnetic susceptibility between cores at the same depths, such as the peak seen in core 3 between c. 242 and 248cm, not apparent in cores 2 or 4. This peak skews the curve representing the mean volumetric susceptibility, resulting in a small peak in that curve at 244-250cm. The cores were taken approximately 50cm apart so it is unlikely that there are any significant differences in sediment stratigraphy between them. As was explained in Section 4.4.6.2, the volumetric susceptibility of peat is of little interpretational value due to the overwhelmingly diamagnetic components, vegetation and water. It may be that post-sampling loss of moisture is responsible for the variations in susceptibility between cores from the same level.

Nevertheless, the volumetric susceptibility curves are useful in determining the transition between minerogenic and organic sediments, i.e. identifying the precise depth at which mire deposits began to accumulate. From Figure 5.10 it is seen that 268cm is the lowermost depth at which the mean volumetric susceptibility is zero. In the sediment stratigraphy (Table 5.3) this marks the transition between 'dark grey-brown organic deposit with common highly decomposed plant remains and abundant silt particles' and 'dark brown moderately humified wood peat with abundant wood fragments including small fragments and rare deciduous roundwood pieces'. The combination of these two lines of evidence is strongly indicative that the transition to true mire conditions commenced at c. 5170 cal. BP.

5.3.4 Loss-on-Ignition

5.3.4.1 Presentation of results

Figure 5.11 shows the percentage loss-on-ignition of the BEL core. Figure 5.12 shows the inverse of this: the percentage ash content.

5.3.4.2 Interpretation

From Figure 5.12 it is seen that 268cm is the lowermost depth at which ignition residues (inorganic content) form less than 20-30% of the sediment mass on a dry weight basis, fulfilling the criteria of Clymo (1983) used to define peat as a substance (see Section 4.3.3.2). This identification of 268cm as the transition to mire sediments is in agreement with the evidence from the volumetric magnetic susceptibility investigations and the sediment stratigraphic descriptions (above).

5.3.5 Humification

5.3.5.1 Presentation of results

Figure 5.13 shows the percentage transmission profile of the BEL core. The y-axis records percentage transmission following correction for mineral content (Blackford 1990). Columns represent individual percentage transmission values and the line represents the 3-point running mean. Figure 5.14 shows the 3-point running mean with the whole-core mean percentage transmission (thick bar) and 1.0σ either side of the mean (thin lines). Zonation of the profile has been constructed according to the points delimiting significant changes of the averaged curve (exceeding 1.0σ above or below the mean).

Interpretation of the percentage transmission results occurs in conjunction with those of the geochemical and palynological investigations, in Section 5.4 below. A holistic analysis was preferred because it permits comparison of any coincident phenomena in multiple proxy records, thereby maximising the interpretive value of the investigations.

5.3.5.2 Zonation

Eight zones from the percentage transmission patterns have been identified.

Zone a: 280-68cm; c. 5525 - 5170 cal. BP. Initially percentage transmission values are lower than the whole-core mean, but become increasingly elevated after c. 5320 cal. BP.

Zone b: 268-254cm; c. 5170 - 4850 cal. BP. This period is characterised by the highest percentage transmission values in the profile, peaking at 260cm; c. 4935 cal. BP.

Zone c: 254-232cm; c. 4850 - 4550 cal. BP. A rapid shift to lower percentage transmission at c. 4850 cal. BP is followed by c. 400 cal. years in which transmission values are higher than the whole-core-mean.

Zone d: 232-228cm; c. 4550 - 4495 cal. BP. This is a short-lived phase of significantly high transmission values (greater than 1σ above the mean).

Zone e: 228-180cm; c. 4495 - 3775 cal. BP. During this time, transmission values fluctuate around the whole-core mean, shifting towards higher values at the top of the zone.

Zone f: 180-135cm; c. 3775 - 3025 cal. BP. The opening of this zone marks a transition from relatively high to relatively low transmission values, although neither of the extremes range beyond the 1.0σ bars.

Zone g: 135-132cm; c. 3025 - 2975 cal. BP. This period records a brief phase of significantly low percentage transmission.

Zone h: 132-80cm; c. 2975 - 2110 cal. BP. This phase records relatively percentage transmission values, lower than the whole-core mean but not outwith the 1.0σ range.

5.3.6 Geochemistry

5.3.6.1 Presentation of results

Figure 5.15 shows the profiles of the six elements analysed in the BEL core, with ratios of Na:K and Ca:Mg also plotted. All concentrations are in mg/kg (= ppm) relative to dry weights. Interpretation of the geochemistry results occurs in conjunction with those of the percentage transmission and palynological investigations, in Section 5.4 below, for the reasons stated in Section 5.3.5.1 above.

5.3.6.2 Zonation

Four principal zones were identified, with three of these sub-zoned. Zones were identified subjectively by eye.

<u>CZ BEL-1: 280-260cm; c. 5525 - 4935 cal. BP</u>

The basal zone is typified by increasing concentrations of all measured elements except for K, which exhibits decreasing concentrations.

CZ BEL-2: 260-164cm; c. 4935 - 3510 cal. BP

CZ BEL-2a: 260-225cm; c. 4935 – 4455 cal. BP

In this zone the elements K and Na remain relatively stable at low levels compared to other zones. Ca, Zn and Cu also remain more-or-less stable. Mg concentrations increase to c. 2000ppm, reducing the Ca:Mg ratio to below 1.

CZ BEL-2b: 225-164cm; c. 4455 – 3510 cal. BP

Zinc concentrations fluctuate between 10 and 20ppm, peaking at c. 45ppm at c. 180cm. A minor decrease of copper is registered at the opening of zone 2b, followed by a very gradual decrease and its eventual disappearance from the sedimentary record at 170cm. K remains at the low levels established in zone 2a. Na and Mg increase throughout the zone, whilst Ca shows a very gradual constant decrease, further reducing the Ca:Mg ratio.

CZ BEL-3: 164-52cm; 3510 - 1640 cal. BP

CZ BEL-3a: 164-104cm; c. 3510 - 2510 cal. BP

This zone is characterised by high concentrations for Na and Mg, although Na decreases somewhat towards the upper boundary. Zn and K remain at low levels. A slight increase in Ca at the lower boundary and maintenance of such concentrations means the Ca:Mg ratio is similar to the previous subzone.

CZ BEL-3b: 104-52cm; c. 2510 - 1640 cal. BP

A brief peak in Zn concentrations at the base of the zone is followed by persistence at low levels. K increases gradually throughout the zone. Mg, and to a lesser extent Na, decrease throughout the zone. Until a decline at the upper boundary, concentrations of Ca remain more-or-less equivalent to those of C-3a, causing a very minor increase in the Ca:Mg ratio, although this remains below 1. The Na:K ratio, which peaked at the 3a/b boundary, declines to less than 5 by the upper boundary.

CZ BEL-4: 52-0cm; c. 1640 - 0 cal. BP

CZ BEL-4a: 52-20cm; c. 1640 - 720 cal. BP

This zone is characterised by major fluctuations in the concentrations of some analysed elements. Peaks in Zn and Ca occur, bringing these elements to their greatest concentrations in the profile. Mg peaks but at a lower level than Ca; therefore the Ca:Mg ratio peaks briefly at almost 2. Na and K remain more-or-less constant, meaning that the ratio of these elements is stable at low levels. The upper boundary is marked by troughs in Na, Ca, Mg, and to a lesser extent, K.

CZ BEL-4b: 20-0cm; c. 720 – 0 cal. BP

The topmost zone is characterised by rapidly increasing levels of Ca, Mg and K, which completes its C-shaped profile. Zn and Na remain stable. The Ca:Mg profile remains at about 1, and the Na:K profile approaches zero.

5.3.7 Pollen analysis

5.3.7.1 Presentation of results

The pollen data are presented in six separate diagrams. Shaded (coloured) curves represent a tenfold exaggeration (the colour of which corresponds to that of the appropriate group's summary diagram) and a cross represents a single pollen grain or spore.

Figure 5.16. Percentages based on the TLP sum grouped in the summary as Trees, Shrubs, Bog & heath taxa and Herbs.

Figure 5.17. Percentages based on the TLP sum grouped in the summary as Trees (excluding *Alnus*), Shrubs, Bog & heath taxa and Herbs.

Figure 5.18. Percentages based on the TLP sum grouped in the summary as Trees (excluding *Alnus*), Shrubs, Bog & heath taxa, Herbs, Pastoral indicators and Arable/disturbed ground indicators.

Figure 5.19. Principal taxa percentages (based on TLP excluding *Alnus*) with CONISS plotted.

Figure 5.20. Influx values of main taxa.

Figure 5.21. Concentration values of main taxa.

Ecological groupings were constructed principally with reference to Webb (1943), Godwin (1975), Grime *et al* (1988), Stace (1997) and Preston *et al* (2002). Anthropogenic indicator herbs (the Pastoral indicators and the Arable/disturbed ground indicators) are further identified with reference to Turner (1964) and Behre (1981). The term 'pollen influx' is used rather than 'pollen accumulation' to distinguish from sediment accumulation rates, which are discussed above in Section 5.3.2.2. Pollen influx is a measurement of the quantity of pollen grains incorporated into a set area of ground surface during a set period of time.

Pastoral indicators: Lactuceae indet., *Plantago lanceolata, R. undiff., Rumex acetosa, R. acetosella, R. obtusifolius* and *Trifolium* type.

Arable/disturbed ground indicators: Cereal type, *Anagallis arvensis, Artemisia,* Chenopodiaceae, *Papaver rhoeas* type, *Plantago major/media, Polygonum aviculare, P. persicaria* and *Urtica.* This group comprises indicators of both arable agriculture and of bare or disturbed ground, including ruderals which are generally positively correlated with human settlement (Behre 1981). It is recognised that this is a particularly difficult grouping. As some taxa occupy both arable field and settlement-area habitats, generally as a result of their occupation of disturbed or bare ground, these types are here combined into a single indicator group. The *Rumex* family is particularly problematic to interpret; different workers have included *Rumex* species in different ecological groups. Varying levels of pollen taxon identification add to the difficulty: *R. acetosa/acetosella* type has been used as a pastoral indicator (Donaldson & Turner 1977), while Riezebos & Slotboom (1978) define *Rumex* undiff. as an arable indicator. The more exhaustive scheme in Behre (1981) considers *R. acetosa* as particularly indicative of wet meadows and pasture, whilst *R. acetosella* is apparently more catholic in its ecological inclinations, though with tendencies towards winter cereal crops as well as pasture and fallow lands. Kramm (1978) found a positive correlation between *Rumex* pollen and dust content, suggesting it is a biotype of open and disturbed conditions. Such variation in interpretations has led workers to question or reject the use of ratios of certain pollen types to devise arable/pastoral indices designed to objectively evaluate the changing trends in prehistoric farming practices (e.g. Maguire 1983, 13; Buckland & Edwards 1984, 244). For this reason, no such calculations have been attempted in this investigation, and the more general 'pastoral' and 'arable/disturbance' indicator groups are used.

Size details of all pollen grains identified as 'cereal-type' are presented in Table 4.4. Selected photomicrographs with scale are presented in Plates 5.1-5.17.

5.3.7.2 Lithology column

For ease of visual interpretation, the pollen diagrams utilise a lithology column which records only the most significant sedimentary units (see Table 5.2 for further details).

5.3.7.3 Zonation

Percentages are based on the TLP sum excluding *Alnus*. Zonation was achieved using CONISS (see Section 4.4.2.9).

<u>PAZ BEL-1: Poaceae-*Corylus-Betula*. 280-275cm; c. 5525-5375 cal. BP.</u>

Poaceae fluctuate between 20 and 40% TLP. There are low frequencies of *Plantago lanceolata* and occasional grains of other pastoral and arable/disturbance indicators: Lactuceae indet., *Rumex acetosa*, *R. acetosella*, *Polygonum aviculare* and *Urtica*. The arboreal and shrub component is dominated by *Corylus* at 20% TLP, with *Betula* and *Alnus*. The main arboreal pollen types (*Alnus*, *Betula*, *Ilex*, *Pinus* and *Quercus*) and *Corylus* expand. There are low percentages of *Calluna vulgaris* and *Empetrum*. At the upper zone boundary, the NAP components decrease in representation. Influx rates for all taxa are high, and the total influx rate is also relatively high.

<u>PAZ BEL-2: *Alnus-Betula-Corylus*. 275-226cm; c. 5375-4465 cal. BP.</u>

At the opening of the zone there is a small temporary peak in aquatic plant pollen. This zone is characterised by the expansion of tree taxa, especially *Alnus*. *Betula*, *Ilex*, *Pinus*, *Quercus* and *Corylus* remain well-represented through most of the subzone, and *Ulmus*, *Salix*, *Sorbus* and *Taxus* pollen are also present intermittently in low proportions, while *Fraxinus* and *Lonicera* are only occasionally recorded. *Calluna* is at lower percentages than in BEL-1, and other heathland taxa are only sporadically recorded. There is lesser representation from open ground indicators such as Cyperaceae and Poaceae, although at 240cm there is perhaps a minor expansion of open ground recorded: most tree taxa decline slightly, and the herbs

Ranunculus type, Rosaceae, *Saxifraga* undiff., *Urtica* and *Plantago lanceolata*, as well as *Pteridium aquilinum* are all present in low numbers. Just below the upper boundary, at c. 232cm, *Pinus* and *Alnus* expand to the detriment of *Betula*. Immediately above this, from 231-228cm (c. 4520 cal. BP), the *Pinus* decline (from 24% to 5% TLP) is recorded, with an accompanying reduction in *Ilex*. *Alnus*, *Betula*, *Ilex* and *Quercus* all expand initially in response to this, however at the upper zone boundary *Alnus* decreases sharply from 523% to 89% TLP and there is also a decline in *Quercus*. Small increases in Cyperaceae, Poaceae and *Sphagnum* are apparent. Fern spore values fluctuate between 10% and 40% TLP. Pollen influx rates are very low between 264 and 260cm, but increase rapidly and a peak in influx rate occurs at 250cm (c. 4800 cal. BP).

PAZ BEL-3: *Betula*-Cyperaceae. 226-219cm; c. 4465-4370 cal. BP.

All tree pollen and *Corylus* values decline in this zone, although at the upper boundary there is a slight, temporary resurgence in *Alnus*. There are short-lived appearances of the heath taxa, *Calluna*, *Empetrum* and *Erica tetralix*, as well as Cyperaceae and Poaceae. *Sphagnum* peaks at its highest percentage (372% TLP) in the profile and there is the first significant peak in microscopic charcoal percentage. Both peaks are also apparent in the influx values. As total influx values and influx values of other individual pollen taxa do not peak, these can be seen as recording real phenomena. At the upper boundary, fern spores all but disappear in percentage representation.

PAZ BEL-4: *Betula*. 219-190cm; c. 4370-3945cal. BP.

PAZ BEL-4a: 219-204cm; c. 4370-4165 cal. BP.

The opening of this subzone is marked by reductions in percentages of the tree taxa *Alnus*, *Ilex*, *Pinus*, *Quercus* and *Ulmus* to very low values, from which they never recover. *Betula* expands rapidly from 25% to 72% TLP. *Corylus* fluctuates between 5% and 10% TLP. Bog and heath taxa are sporadically represented, and whilst there is an overall decrease in Cyperaceae from initially high values (45% TLP), Poaceae remain more or less stable at low values. Pollen influx values remain relatively stable until a sharp, major peak in all taxa occurs at 210cm. This peak is only evident in a single pollen spectrum.

PAZ BEL-4b: 204-196cm; c. 4165-4045 cal. BP.

This subzone records a short-lived reduction in *Betula* percentages; a decline from 63% to 27% TLP is recorded at 200-197cm. Very slight, temporary increases in *Quercus* and *Salix*, and a peak in *Sorbus*, accompany this decline. Open-ground herbs are better represented in this subzone than previously; *Ranunculus* type, Rosaceae, and *Potentilla* type are all recorded. *Plantago lanceolata*, *Rumex acetosa*, *R. acetosella* and *Urtica* are occasionally recorded. The first instance of a single cereal pollen grain (see Table 5.5 and plate 5.17) and occasional *Plantago major/media* grains are recorded at 196cm (c. 4045 cal. BP). There is a peak in *Sphagnum* (174% TLP at 201cm) followed by a small, short-lived increase in fern spores.

PAZ BEL-4c: 196-190cm; c. 4045-3945 cal. BP.

Betula is rapidly re-established at 70% TLP. The small peaks in *Sorbus*, *Quercus* and *Salix* sharply decline and other tree and shrub taxa remain at extremely low values. Percentages of fern spores decline at the opening of this subzone and *Sphagnum* values are also suppressed. Pastoral and disturbance indicators are at generally lower percentages than in BEL-4b.

PAZ BEL-5: Poaceae-*Calluna*. 190-161cm; c. 3945-3460 cal. BP.

PAZ BEL-5a: 190-177cm; c. 3945-3725 cal. BP.

Following an initially sharp decline, *Betula* percentages fall steadily throughout BEL-5a, reaching 7% TLP by the upper boundary. *Ilex*, *Pinus*, *Quercus* and *Corylus* values remain at low levels. Other tree and shrub taxa are sporadically recorded. The *Calluna* curve becomes continuous by the upper boundary, and other heath taxa (*Erica tetralix*, *E. cinerea* and *Myrica gale*) are also recorded. Poaceae percentages reach their maximum levels in the profile during this subzone, and other indicators of grassland are also represented, for instance *Caryophyllaceae*, *Filipendula*, *Ranunculus* type, *Hypericum perforatum* type, *Saxifragaceae*, *Potentilla* type and *Succisa pratensis*. The pastoral indicators *Plantago lanceolata*, *Rumex acetosa* and *R. acetosella* are present but in low numbers. There are two cereal grains recorded at the upper boundary (see Table 5.5 and Plate 5.16). A small increase in microscopic charcoal is seen from the previous zone. At 180cm there is a slight yet sustained increase in total pollen influx rates.

PAZ BEL-5b: 177-161cm; c. 3725-3460 cal. BP.

A minor, temporary increase in *Betula* percentages marks the opening of the subzone, though they again decrease by the upper boundary to 7% TLP. *Pinus*, *Ilex*, *Salix*, *Taxus*, *Ulmus* and all shrub taxa excluding *Corylus* are only occasionally recorded from this subzone. *Calluna* begins a rapid increase, the *Erica tetralix* and *Myrica gale* curves become continuous and *E. cinerea* and *Empetrum* are also represented in increased frequencies. *Vaccinium* is occasionally recorded. Cyperaceae values increase, those of Poaceae decrease to 18% TLP and open-ground herbs such as *Ranunculus* type, *Potentilla* type, Rosaceae and *Hypericum perforatum* type are still represented. Disturbance and pastoral indicators are present at low, continuous levels, including cereal pollen grains (Table 5.5 and Plates 5.14 and 5.15). *Sphagnum* values are higher than in subzone BEL-5a and *Pteridium aquilinum* appears briefly.

PAZ BEL-6: *Calluna*-Poaceae-Cyperaceae. 161-0cm; c. 3460 cal. BP - present.

PAZ BEL-6a: 161-111cm; c. 3460-2625 cal. BP.

Tree and shrub pollen do not regain their former levels after this depth, and during BEL-6a there is an overall increase in the *Calluna* curve. Poaceae pollen values fluctuate although the overall trend is of a slight decrease in representation. Values of other heath taxa fluctuate throughout the zone. Cyperaceae remain at relatively high levels, reaching 40% TLP. Herbs are well-represented, although *Ranunculus* type becomes discontinuous after 144cm. *Plantago lanceolata* is better represented than in previous zones, and both pastoral and disturbance indicators are relatively well-represented, especially in the lower half of the zone. After 138cm, cereal grains are extremely sporadic. In the upper part of the zone there is a relatively small peak in aquatic plant pollen, although *Sphagnum* values remain negligible. Microscopic charcoal values rise until they reach 242% TLP at 132cm, and then decrease for the remainder of the zone.

PAZ BEL-6b: 111-51cm; c. 2625-1625 cal. BP.

The dominant pollen taxa are *Calluna* and Poaceae, with lower, also varying, percentages of Cyperaceae. *Plantago lanceolata* is initially well-represented, but for most of the subzone there are few, sporadic palynological indicators of disturbance or indeed pastoral activity. In the top few centimetres of the subzone (above 55cm) there is a slight resurgence of *P. lanceolata* and occasional disturbance indicators are also recorded. Total pollen influx rates are slightly reduced in this zone compared to the rates established in PAZ 5b.

PAZ BEL-6c: 51-30cm; c. 1625-1080 cal. BP.

This subzone records a period during which *Calluna* and other heath species were the dominant pollen types, and when values of Poaceae, Cyperaceae and most herbs were depressed.

PAZ BEL-6d: 30-0cm c. 1080 cal. BP – present.

Cyperaceae initially expand over *Calluna*, followed by an increase in Poaceae. Other herbs are well represented, including pastoral and disturbance indicators. *Plantago lanceolata* attains its highest percentages and cereal pollen is once again recorded (Table 5.5 & Plates 5.1-5.4). In the upper half of the zone a few grains of obligate aquatic taxa are recorded.

5.4 Interpretation of the BEL sequence

5.4.1 Basal sediment stratigraphy

The 5cm thick deposit of yellowish-brown coarse sand overlying till at the base of the BEL profile (see Table 5.3) is well sorted texturally, suggesting that it represents high energy deposition (Brown 1992, 77; Rapp & Hill 1998, 41). It is massively bedded rather than laminar, which suggests a single event was responsible for deposition as opposed to, say, an ongoing fluvial event. Such a succession can be identified as typical of a glaciogenic sequence, resulting from episodes of glacial and glaciofluvial activity during a single glacial event (Lowe & Walker 1997, 300-301). As was discussed earlier, it appears likely that the soil which formed above this sand was lost prior to organic accumulation and peat initiation, possibly as a result of farmers stripping turves to supplement agricultural soils elsewhere (Section 5.2.2.3)

5.4.2 c. 5525 – c. 5375 cal. BP

The boundary at 280cm between sand and organic deposits was dated to c. 5525 cal. BP by linear extrapolation of the lowermost radiocarbon assay, explicitly assuming linear sedimentation rates (see Section 5.3.2.2). As was discussed above (Sections 4.4.7.2 and 5.2.1.2) it is likely that the residence times of organic carbon in mineral-rich detrital sediments are much longer than those in peat, hence sedimentation rates could be much slower than would be indicated by assuming linear sedimentation rates. Humification and pollen concentration data could be used as indices of growth rates, but as the sediment in question is only 2cm deep (278 to 280cm) any significant revision of the age estimate is unlikely.

The organic deposit overlying the sand layer is formed of *Substantia humosa*, detrital plant remains and silt (see Table 5.3). This sediment is 12cm thick, and accumulated relatively slowly (see Figure 5.8). Despite its relatively low mineral content in comparison to organic matter it clearly supported vegetation communities, as evidenced by its macrofossil content, but arguably does not represent a soil *sensu stricto*. Considering that the BEL borehole is situated at the lip of a basin (see Figure 5.2) a more appropriate scenario might be that the basin at that time (c. 5525 cal. BP, see above) consisted of a shallow mire or marsh, and the organic detrital sediment in the BEL core formed a higher shelf overlying the coarse sand base (cf. Rapp & Hill 1998, 57-58). This interpretation is supported by the presence of a minor peak in aquatic plant pollen prior to 268cm (see Figure 5.16c). Figure 5.22 shows this interpretation applied to the Belderg Beg valley side.

The basal deposit in the BEL core and other boreholes along Transect 1, the black amorphous organic-rich silty mud, can be compared to sub-peat deposits present under blanket peat in upland South Wales (e.g. Smith & Cloutman 1988). A comparison could be the sub-blanket peat 'mor' deposits; black greasy amorphous peats, often charcoal rich, and including graded mineral content increasing towards the base (ibid., 163). This mor often developed on stones or sand (ibid., 204-208). However the basal deposits underlying nearby fen carr peats in the same study tended to be described as coarse detrital muds. The difference can probably be accounted for by trophic status; a more nutrient-rich basal material would be required for establishment of a fen carr, whilst the more acid, anaerobic conditions of a mor deposit would be more restrictive for vegetational succession, and acid-tolerant blanket peat species would be best suited to these substrates.

Taken uncritically, the percentage transmission curve can be interpreted to represent an initially dry surface which became increasingly wet after c. 5320 cal. BP (273cm). However, the sediment below 268cm is not a true peat (see Sections 5.3.3.2 and 5.3.4.2), and although the percentage transmission value was corrected for mineral content (Blackford 1990; see Section 4.4.4.5) it may be that organic sediments such as this deposit do not react in the same way as peat to alkali extraction of humic substances and therefore do not accurately reflect surface wetness. The palynological evidence is of a somewhat patchy vegetation environment, with aquatic, grassland, woodland and heath taxa all represented. It may well be that the drier areas newly exposed by terrestrialisation of the retreating marsh were colonised by acid heath taxa such as *Empetrum* and *Calluna vulgaris*.

High Poaceae pollen percentages (c. 20% TLP, or c. 35% if *Alnus* is excluded) indicate that there was significant grassland vegetation cover in between c. 5525 and c. 5375 cal. BP (see Figures 5.16 – 5.18). The occurrence of Lactuceae, *Plantago lanceolata* and *Rumex* pollen grains suggests that pastoral agriculture was being practised. The question of cereal cultivation is more complex. There are no cereal pollen grains recorded in the appropriate spectra. However, arable/disturbance indicators *Urtica* and *Polygonum aviculare* grains are occasionally present, which perhaps indicates that there may have been some cereal cultivation. If arable cultivation occurred some distance from the sampling location, cereal pollen might not be expected to be represented in the BEL core, considering the poor dispersal and low pollen production of cereal crops (see Section 4.4.2.3). Nevertheless, arguing for cereal cultivation without direct evidence from palynology, plant macrofossils or geoarchaeology can be dangerous (see Chapter 6 for geoarchaeological investigation). A cereal-importing economy may be represented. This issue shall be returned to in Sections 7.2.4.2, 7.3.1.2 and 7.4.1 below. Arboreal pollen values are relatively low in comparison to overlying spectra (c. 60 - 70% TLP compared to c. 90%; see Figure 5.16). This indicates a patchy landscape, including agricultural land as well as *Alnus*-dominated woodland. At this depth in the BEL core (280 to 275cm) the sediment is a silt-rich organic detrital material, and the few plant macrofossils are highly degraded but of an herbaceous nature (see Table 5.3). As the BEL core is considered to contain the earliest peat accumulation in the area, it is unlikely that thicker substrates capable of supporting trees existed in the vicinity. This suggests that trees were not growing at that location at that point in time. The arboreal pollen content of the palynological record therefore represents open woodland in the wider landscape. The spatial area of grassland indicated by the pollen profiles is difficult to calculate, but the interpreted scenario of a patchy, differentiated landscape might support the interpretation of Walls 1 and 2 (see Figure 5.1) as enclosing agricultural fields at this time (see Section 5.2.2.5 above).

Outwith the agricultural fields the vegetation cover was evidently patchy. There were high values of *Alnus*, suggesting a carr environment close by, but there was also vegetation cover of a scrubby nature rather than a full woodland canopy. Pollen values of light-demanding taxa such as *Betula*, *Corylus* and *Pinus* are higher than those of the canopy trees *Quercus*, *Ilex*, *Taxus* and *Ulmus*. Dwarf shrub/heath taxa such as *Calluna vulgaris* and *Empetrum* were also present. The landscape was thus much more differentiated and varied than seen in the present day, with probable acid heath below the agricultural fields, scrub in areas of thicker soils, and *Alnus* carr fringing the wetland below the BEL core location. The presence of acid heath indicates that soil/sediment acidification was well-developed by the mid-Holocene. The location of field walls (e.g. Walls 1 and 2, see Figure 5.1) were apparently planned with consideration to soil quality. This is suggested by the existence of soil profiles above the altitude of the terminus of Wall 1 (see Figure 5.2 and Section 5.2.2.3 above). Furthermore, the landscape downslope of the fields was patchy at this time and included acidified organic accumulating sediments. Extending this interpretation, it is evident that the Neolithic farmers at Belderg Beg did not maintain a completely open landscape beyond the limits of the field system.

The palynological record indicates that agriculture ceased at c. 5375 cal. BP (275cm), as Poaceae and agricultural indicator values decline in frequency to near-negligible levels. An alternative interpretation to abandonment relates to the changing vegetation dynamics of the landscape. The concurrent increase in tree pollen values, especially *Alnus*, could suggest that a filtering effect was in existence, if the trees occurred as a barrier between the agricultural fields and the BEL sampling location. At this time, the sediment at BEL was still an organic detritus containing herbaceous macrofossils and silt (see Table 5.3) and organic accumulation had not commenced 30m upslope at W2 (see Figure 5.2 and Table 5.1), suggesting that there was insufficient sediment to support tree communities between BEL and the agricultural fields. The abandonment is therefore interpreted as real rather than apparent. The difference between the opening of the palynological profile (c. 5525 cal. BP;

see Section 5.4.1 above) and the observed agricultural abandonment (c. 5375 cal. BP) is just 150 calendar years. The date of onset of agriculture at Belderg remains elusive.

5.4.3 c. 5375 – c. 4550 cal. BP

The abandonment of agriculture at c. 5375 cal. BP is characterised palynologically by a sharp decline in Poaceae and a near-absence of pastoral and arable/disturbance indicators (see Figures 5.16-5.18). Both *Alnus* and *Betula* expanded relatively rapidly. The especially marked expansion of *Alnus* suggests it had colonised the mire surface by this point in time. The first record of wood macrofossils in the sediment stratigraphy of the BEL core (see Table 5.3) occurs at c. 268cm (c. 5170 cal. BP). The small peak in aquatic plant pollen at 275cm (c. 5375 cal. BP), in combination with the rapid increase in *Alnus*, supports the indication of an increasingly wet mire surface at BEL. Increasing wetness was also suggested by the humification curve (Figures 5.13 and 5.14), but the sharp increase in percentage transmission may be wholly or partially a factor of the transition to true peat at 268cm (see Section 5.4.2 above) as suggested by the humification curve. When the soil erosion associated with agriculture in the field enclosed by Wall 1 (see Section 5.2.2.3) is combined with this evidence for increasing surface wetness downslope of the fields, an interpretation of increased run-off caused by agricultural activity may be reached. The especially marked sharp increases in *Alnus* and *Betula* (Figure 5.17) support this interpretation. However, dryland trees such as *Quercus*, *Corylus* and *Ilex* increased also, suggesting that it was not only taxa of wet soils which expanded. However the dryland trees did not increase at such marked rates and to such high percentages, so it seems likelier that these taxa colonised some drier areas upslope, which had been newly abandoned. Expansion of *Alnus* following the mid-Holocene *Ulmus* decline is a common feature in pollen profiles from central Ireland, where *Ulmus* tended to be well-represented (Godwin 1975, 470). Although the *Ulmus* decline was not recorded in the BEL profile as sedimentation began later, its date can be estimated with reference to regional data. Despite *Ulmus* being relatively poorly represented in north Mayo its decline is well-dated: c. 5840 cal. BP at Céide Fields and c. 5900 cal. BP at Garrynagran (O'Connell & Molloy 2001, 104 & 108-9).

The loss-on-ignition curve supports the interpretation of the sediment stratigraphy, which suggests a rapid transition from a silty detrital mud to woody fen peat occurred at c. 5170 cal. BP. Potassium concentrations were high in the detrital mud. Similar basal enrichment of K has been seen in other profiles from ombrotrophic bogs (e.g. Walsh & Barry 1958;

Chapman 1964b). This could be due to two factors (see Steinmann & Shotyk 1997). Groundwater diffusion followed by formation of stable complexes is a possibility; suggestions have been made that K (also Ca) is more soluble in higher than lower levels of blanket peat profiles (Walsh & Barry 1958, 327). More likely is the presence of K in the mineral component of the basal sediment. Low Ca concentrations in the basal geochemical zone support the latter interpretation. Bedrock-derived K in an area of quartzite and psammitic schist geology would originate from the feldspar, and microcline (alkali, K-rich) feldspar is a component of the Grampian group (Chew *et al* 2003) which forms the regional geology of much of North Mayo, including Belderg (see Section 2.3.1.2). K typically exhibits a C-shaped profile in peat sections, with basal enhancement from bedrock influence (Grattan *et al* 1996, 33; cf. Chapman 1964b) and surface enhancement from plant uptake (Damman 1978, 491). Low levels of the other elements analysed suggest that the soil was relatively nutrient-poor.

During and after abandonment, the former agricultural land seems to have become overgrown, initially by scrub taxa such as *Betula* and *Corylus*, and then by woodland taxa such as *Quercus*, *Ilex* and *Pinus*. Classically, the small, temporary nature of Neolithic forest clearances allowed passing expansion of pioneer genera such as *Betula*, *Corylus*, *Fraxinus*, and *Alnus* (Godwin 1975, 471) and such regeneration is recorded between c. 5375 and 5000 cal. BP. The fine resolution pollen analysis at these depths of the BEL core allows estimates to be made regarding the rates of woodland establishment. *Alnus* rapidly expanded (73% to 200% TLP) between c. 5465 and c. 5400 cal. BP (278–276cm), which probably represents the establishment of a single pioneer generation, which persisted until c. 5050 cal. BP before beginning a slight overall decline. *Betula* expanded from 10% to 30% TLP between c. 5400 and c. 5350 cal. BP (276-274cm), again this probably represents a pioneer generation which declined slowly until it reached c. 20% TLP at c. 5050 cal. BP. The establishment of *Corylus* took longer, from c. 5525 to c. 5290 cal. BP (280–272cm; 17–33% TLP). *Quercus* also took longer to expand, from c. 5465 to c. 5230 cal. BP (278–270cm; 3–10% TLP). The expansion of *Ilex* commenced at c. 5465 from occasional palynological presence and reached 11% TLP by c. 5050 cal. BP (264cm). *Pinus* actually decreased in pollen percentage representation at c. 5400 cal. BP (276cm) but increased between c. 5290 and 5170 cal. BP, probably representing a single generation expansion as *Betula* declined.

A landscape-scale picture of vegetation succession can be estimated from these data. Vegetation cover on the mire surface in the immediate vicinity of the BEL core probably consisted of *Alnus*, *Betula* and *Pinus* in varying proportions. For instance, *Alnus* was initially favoured at c. 5465–5050 cal. BP, probably due to extremely wet sediment conditions, which are suggested by the humification curve (Figure 5.14). As the mire became established and spread, *Betula* seems to have been favoured, especially as the surface became drier after c. 4870 cal. BP (c. 255cm; Figure 5.17). *Pinus* seems to have been a mire-dwelling taxa, as its dynamics in the first half of PAZ BEL-2 appear to inversely correlate with those of *Betula*. In the wider landscape on drier ground, *Corylus* was apparently replaced by woodland consisting of *Quercus*, *Ilex*, *Ulmus* and *Taxus*. These woodland dynamics, together with the reduced, sporadic representation of pastoral and disturbance indicators, suggest that abandonment of the field system was followed by much reduced human activity in the vicinity.

The most appropriate modern plant community equivalent to PAZ BEL-2 (c. 5375-4465 cal. BP) would appear to be the W6 *Alnus glutinosa – Urtica dioica* woodland (Rodwell 1991a, 30-33; 91-101), elsewhere defined as fen carr (e.g. Binney *et al* 2005; Waller *et al* 2005). This community is poorly defined and is therefore characterised by a variety of canopies, with the dominant species being *Alnus glutinosa*, *Salix* spp. and *Betula pubescens*, and a range of floristically diverse but typically species-poor understorey layers (Rodwell 1991a, 91). There are certain palynological indications that the woodland in the vicinity of the BEL core during PAZ BEL-2 was at the drier end of the spectrum of W6 woodland (cf. *Betula pubescens* sub-community: Rodwell 1991a, 94). The principal such indicator is the dominance of *Betula* over *Salix* as a secondary canopy component (see Rodwell 1991a, 91). This is supported by the low representation of *Urtica* and the presence of *Lonicera* and Pteridophyta. A wetter W6 woodland would be indicated by more substantial percentages of *Urtica* and Cyperaceae (ibid., 92). Such an interpretation of the community is further supported by the observation that the *Betula* sub-community of the W6 group may develop directly from *Betula - Molinia* woodlands on disturbed acid peat in basin mires on base-poor substrates (ibid., 96). Unfortunately, the sediment record begins in the BEL area only as the *Alnus glutinosa – Urtica dioica* woodland community was establishing, so it is impossible to verify the nature of its precursor.

That the species present in the palynological profile in BEL-2 do not match exactly those species listed as typical of fen carr (Binney *et al* 2005; Waller *et al* 2005) or of the W6 woodland and associated sub-communities (Rodwell 1991a, 92-101) is indicative of the wider landscape component of the palynological record. The main difference is the sporadic representation of Ericaceae in BEL-2; a family not reported in the above characterisations of fen carr communities. These heath pollen taxa are likely to derive from the abandoned agricultural fields upslope. Generalising the taxa representation as percentages of TLP throughout BEL-2, *Alnus* fluctuated between 50 and 85%, with *Betula* and *Corylus* both typically present at around 10%. *Pinus*, *Quercus* and *Ilex* all fluctuated between 0 and 10% TLP. Perhaps atypically for a fen carr, *Salix* was poorly represented (but screening may have caused this; see below). Also present in low quantities were *Fraxinus*, *Populus*, *Taxus* and *Ulmus*. Distinguishing the source areas of the recorded pollen taxa is vital in describing the nature of the community. The extremely high dominance and over-representation of *Alnus* over all other taxa in BEL-2 may account for the low palynological diversity; less prolific pollen producers including the (probably patchy) herb understorey are likely to be under-represented in the pollen record.

From c. 5170 cal. BP until c. 4850 cal. BP, the mire surface was wetter than at any other time in the profile, with wetness peaking at c. 4935 cal. BP, at the point when loss-on-ignition values reached 95% (Figure 5.11), a figure which is typical for ombrotrophic peat (Aaby 1986, 160-161). Coincidental with this peak in mire surface wetness, total pollen concentration values were very low, indicating rapidly accumulating sediments; i.e. enhanced growth rates. From c. 4935 cal. BP, as the fen carr persisted, there are indications of an increasingly oceanic influence upon the mire hydrology. This need not have a climatic origin (see below). At c. 4935 cal. BP, whilst the influx of Mg had increased, a corresponding increase in Ca means that the ratio between the two elements (Ca:Mg) was relatively high at above 1.0, indicative of minerotrophic (fen) rather than ombrotrophic (bog) conditions (Shotyk 1988, 150). The decrease of this ratio between c. 4935 and 4455 cal. BP illustrates the increasing importance of seawater (with a typical Ca:Mg ratio of 1:3) over freshwater (ratio 3:1) (ibid.). Rather than indicating a climatic shift involving changing weather patterns, the increased oceanicity of the mire water may result from the spread of peat and consequent isolation of the mire from freshwater sources. Fen (wood) peat formation has the effect of making areas of peat more dependent upon direct rainfall, and less upon surface drainage for their water supply, accelerating the shift towards ombrotrophic conditions, and lowering Ca:Mg ratios (Chapman 1964b, 319). A compounding increase in climatic oceanicity is unlikely, as concentrations of Na fluctuated around 550ppm until c. 4500 cal. BP.

At c. 4850 cal. BP the humification data recorded a relatively rapid shift to relatively drier mire surface conditions, indicating slower peat accumulation. This is corroborated by the pollen concentration diagram (Figure 5.21) which shows a short-lived peak in total fossil concentrations from c. 4900 to c. 4800 cal. BP (258-250cm). The humification curve suggests that this episode was followed by c. 300 years of a wetter than average mire surface. Whilst initially receiving nutrients from outside its confines (minerotrophic), the geochemical profile is by c. 4800 cal. BP indicative of a rather oligotrophic (nutrient poor) fen.

5.4.4 c. 4550 – c. 3945 cal. BP

As the mire system developed, it may have changed into an ombrotrophic system. More acid-tolerant plant taxa invaded the mire surface and blanket bog vegetation successfully out-competed fen carr species. This transition occurred in two stages. Firstly, *Alnus* was relatively rapidly replaced by *Betula* as the dominant species between c. 4465 and 4370 cal. BP. Later, at c. 3945 – 3775 cal. BP *Betula* itself declined, to be replaced by more typical blanket bog taxa such as Poaceae and *Calluna vulgaris*.

The humification curve shows there was a brief phase of significantly enhanced surface wetness at c. 4550 – 4495 cal. BP, and a small, short-lived decline in pollen concentrations at the same point supports the implied inference of a brief phase of increased sedimentation. When compared with the sediment stratigraphy (Table 5.3), the humification curve (Figure 5.14) shows that the mire surface remained more than averagely wet (not exceeding 1σ outwith the whole-core mean) for most of the fen peat phase, which lasted until c. 3775 cal. BP. Total pollen concentration values suggest there were no significant changes in sedimentation rates.

A *Pinus* decline was dated by interpolation to c. 4520 cal. BP. This slightly predated declines in other arboreal pollen taxa (*Quercus*, *Corylus* and *Ilex*) which occupied the wider landscape (see Section 5.4.3 above), suggesting that there was a complex sequence of vegetation successions in the region. The *Pinus* decline was accompanied by a small decline in proportions of *Ilex*, a small increase in *Quercus* and a sharp, short-lived increase in *Alnus*. The *Alnus* peak is so large (> 500% TLP when *Alnus* is excluded from the TLP count - see Figure 5.17) that it appears anomalous, possibly being the result of the preservation of a flower rather than a true palynological representation of the vegetation cover. However if

Alnus is included in the TLP count (see Figure 5.16) the peak does not appear so skewed. Furthermore, the influx diagram (Figure 5.20) does not show an anomalous peak in *Alnus* at 230cm. It can therefore be concluded that *Alnus* experienced a brief, rapid expansion on the mire surface at the time of the *Pinus* decline, indicating a direct competitive relationship between the taxa. *Betula* also declined during this *Alnus* expansion. This succession may have been promoted by the increase in surface wetness indicated by the humification curve. This c. 4520 cal. BP decline in *Pinus* can be interpreted as the representing the classic 4500 cal. BP *Pinus* decline discussed in Section 2.2.3.4.

The *Alnus* expansion was short-lived. Woodland loss commenced at c. 4500 cal. BP, beginning with a drastic reduction in *Alnus*, suggesting its disappearance from the mire surface. *Betula* and *Corylus* remained more or less stable, whilst *Ilex* and *Quercus* declined, over perhaps 50 calendar years. This phase was also characterised by minor, short-lived peaks in the dwarf shrub and heath taxa, *Calluna vulgaris*, *Empetrum* and *Erica tetralix*. *Empetrum*, intolerant of severe waterlogging (Grime *et al* 1988, 240), is associated with the drier parts of a mire surface, such as hummocks, peat hagg caps and gully sides (Bell & Tallis 1974; Tallis 1997). A widespread drying of the surface can be discounted, however, as PAZ BEL-3 is also characterised by a large peak (in percentage, concentration and influx values) of *Sphagnum* spores, which may suggest a wetter surface. The humification curve suggests that the mire surface had become relatively drier after the c. 4500 cal. BP wetness peak, but that it was still more than averagely, although not significantly, wet. The total pollen concentration data suggest that there was a very slight decrease in sediment accumulation rates after c. 4500 cal. BP. Together, these factors indicate a variable mire surface in terms of contrasting relatively dry and wet areas. Drier patches of the mire will have been colonised by *Betula*. The virtual disappearance of fern spores (Pteropsida [monolete] indet. and *Hymenophyllum*) by c. 4450 cal. BP is probably related to the reduction in woodland cover.

The peak in microscopic charcoal at c. 4500 cal. BP suggests that fire may have been a causal factor in woodland clearance. Although there is a small peak in Poaceae during the clearance phase, and occasional disturbance indicators are recorded, pastoral indicators are almost totally absent. If the clearance was local to the BEL core, then it is considered unlikely that human activity was the agent of deforestation. Fires induced by lightning strikes may have been responsible for the peak in microscopic charcoal particles, with open-ground taxa and ruderal herbs opportunistically moving into newly created open spaces.

However, the scale of the peak in microscopic charcoal indicates that this would have been an extreme event of lightning strikes above the background rate of their occurrence. An alternative interpretation would be that the clearance was occurring at a more distant location, i.e. within the regional pollen source area (canopy and rainfall components: see Section 4.4.2.1).

The putative trend toward increasing oceanicity continued after c. 4455 cal. BP. This is indicated by Mg concentrations, which continued to increase, and Ca:Mg ratios, which declined further and stabilised at around 0.4, and an overall increase in Na was also registered. The Na and Mg curves followed similar patterns between c. 4455 and 3510 cal. BP, with comparable small-scale peaks and troughs. As Na and Mg are associated with a maritime influence (Walsh & Barry 1958; Damman 1978, 492; Shotyk 1988, 150), this subzone contains evidence for increasing climatic oceanicity.

At c. 4370 cal. BP, *Betula* expanded onto the mire surface and fully replaced *Alnus*. *Betula* also probably colonised the areas upslope, from where the deciduous trees had been lost. There were additional associated vegetation shifts; a short-lived decline in frequency of Poaceae percentages and a corresponding increase in Cyperaceae. Whilst this could be construed as resulting from a wetter mire surface, the replacement of *Alnus* by *Betula* and the decrease in *Sphagnum* representation contradict such an interpretation. Neither the pollen concentration nor the humification curves indicate any significant change in sedimentation rate at this point (c. 219cm). The possibility of preferential clearance by humans of *Alnus* carr remains. However, because there is an absence of human activity indicator taxa, this suggestion appears unlikely. The total replacement of *Alnus* by *Betula* is therefore best accounted for as a natural vegetation succession, part of the trend established at c. 4500 cal. BP.

There was a major, marked peak in total pollen concentration rates at c. 4250 cal. BP. As all taxa show the peak and therefore it is not mirrored in percentage curves of any particular taxa, it might indicate a slowing or perhaps temporary cessation of peat growth. However, the humification curve at that point (210cm: Figure 5.14) shows average percentage transmission values, which contradict such an interpretation. An extreme forcing factor would be required to stop peat growth completely on such a slope as the Belderg Beg valley side. That interpretation would have severe implications for palaeoenvironmental reconstruction. Alternatively, especially as the peak is so large, it might be the product of an anomalous sample or a laboratory error. The latter interpretation is favoured due to the ambiguous signals given by the various palaeoenvironmental proxies. Had peat growth temporarily ceased, a definitive signal to this effect would be apparent in the humification curve.

Renewed changes in woodland composition occurred from c. 4165 cal. BP. This was characterised by a major decline in *Betula*, accompanied by slight, temporary increases in *Quercus*, *Salix* and *Sorbus*. Although it is possible that the latter may have resulted from their increased visibility in the palynological record as a consequence of the reduction in *Betula*, the influx curve of *Quercus* shows a small peak at c. 4110 cal. BP (200cm: Figure 5.20), suggesting that its increased percentage representation was indicative of its greater population in the landscape. If this temporary woodland expansion occurred at some distance from the sampling location, there is no need to infer a conflicting signal from that of scrubland loss near the BEL core. Increases in Poaceae, Cyperaceae and open-ground herbs, with the occurrences of *Plantago lanceolata*, *Rumex acetosa*, *R. acetosella* and a cereal pollen grain, suggest that the clearance was occurring for agricultural activity. This is the first definitive indication of any post-Neolithic human activity occurring at the site.

A temporary but marked resurgence of *Betula* was apparent at c. 4045 cal. BP, suggesting that scrubland may have become re-established over a limited part of the cleared areas. Whilst there was a significant reduction in percentages of Cyperaceae, the decline in Poaceae was of a lesser magnitude, suggesting that the better quality, drier grassland was maintained whilst the wetter areas were perhaps allowed to revert to scrub. Although *Ranunculus* type pollen remained at its previous levels, other open-ground herbs declined and pastoral and disturbance indicators were sporadic. This supports the interpretation that active clearance had ceased, and that poorer quality land outside the farmed area had been allowed to return to *Betula* scrub. Abandonment or cessation of agriculture within the fields was not necessarily indicated; the *Betula* scrub is likely to have acted as a filter or screen, restricting the probability of pollen from the areas of agricultural activity reaching the coring location.

5.4.5 c. 3945 cal. BP – c. 3460 cal. BP

Renewed clearance commenced at c. 3945 cal. BP, where a decrease in *Betula* was accompanied by the virtual disappearance of *Ilex*, *Pinus* and *Taxus* from the palynological record. Continued pastoral activity is signalled by increases in the *Plantago lanceolata* and

Rumex spp. curves. A disturbed biotope is indicated by two cereal pollen grains, and occasional occurrences of *Papaver rhoeas* type and *Plantago major/media* pollen. The rise in representation of heath types, *Calluna vulgaris*, *Erica cinerea*, *E. tetralix* and *Myrica gale* (including the establishment of a constant *Calluna* curve) suggests that heathland began to replace the *Betula* scrub in the landscape around agricultural areas from c. 3860 cal. BP.

At c. 3945 cal. BP the palynological profile also records a sharp shift between birch-dominated and NAP-dominated conditions. This suggests that the transition from fen carr to blanket bog conditions (see Section 5.2.2.4 above) was synchronous over the area. Were this transition merely extra-local, with trees simply disappearing from the fen carr area, a significant influx of AP would be expected to persist until the transition was complete over the wider pollen source area. This interpretation of linkage between the loss of woodland and changing hydrology has major significance for the study. Identification of the forcing factor behind these changes is of primary importance.

Short-lived troughs in the profiles of Na and Mg at c. 3945 cal. BP perhaps indicate a temporary cessation or reversal of the trend to increased oceanicity. However, as the wood peat was replaced at the BEL borehole location by herbaceous peat at c. 3775 cal. BP, the humification profile records a concurrent shift from a relatively stable phase of higher than average mire surface wetness to another relatively stable phase, this time of lower than average surface wetness (see Figure 5.14 and Table 5.3). In support of this interpretation of the humification data, there was a coincidental slight increase in pollen influx rates, which suggests a reduction in peat growth. Scrubland was gradually replaced by heath and blanket bog in the wider landscape from c. 3945 cal. BP for the following two centuries. *Betula* reached stable low values at c. 3640 cal. BP. Mixed arable and pastoral agriculture continued throughout this phase of landscape evolution, as seen in the pastoral and disturbance indicator curves. The increases in *Sphagnum* and *Calluna vulgaris*, when taken in conjunction with the sedimentological transition from wood peat to herbaceous peat, signal a shift from fen peat to blanket bog in the vicinity of the sampling area. The pollen concentration data suggest that peat growth rates remained more or less stable for the remainder of the profile.

Copper ceases to be detected in the sediment record after c. 3610 cal. BP. The concentrations of copper previous to this varied between 0 and 20ppm, averaging at around 10ppm (Figure 5.15). Such values are similar to those recorded throughout other peat profiles in Irish

Atlantic blanket bogs (Walsh & Barry 1958). Its absence in the profile after c. 3610 cal. BP is curious. It is unlikely to have been leached from the profile, as Cu has a strong affinity for organic matter, and is often enriched in peat deposits relative to its abundance in crustal rocks (Shotyk 1988, 156). Cu is a bioessential nutrient and so was presumably present in concentrations below the detection limit after c. 3610 cal. BP. Routine calculations made during AAS analysis determined that the detection limit was 2.83ppm. Flame AAS has the poorest sensitivity for detection of the various methods available (US EPA 1986). However, in background British sites far from atmospheric pollution sources, Cu concentrations throughout ombrogenous peat profiles were found to average roughly 15ppm (Livett *et al* 1979, 877), though due to its presence as a sulphide (DiToro *et al* 1990) or strong organic ligands, peat may be deficient in available copper for plant growth (Adriano 1986). Studies have shown that anomalies in the distribution of elements within the profile can be attributed to differences in vegetation composition, although zinc has been shown to be more affected than lead, and copper was not analysed (Livett *et al* 1979, 879-881).

As the point at which copper ceased to be detected in the BEL profile occurred just after a major change in peat stratigraphy, recognisable by macrofossils, from wood to herb peat, it may be that the two phenomena were related. If the change in vegetational composition of the peat from woody to herbaceous triggered increasingly acidified, anaerobic conditions with higher concentrations of humic and fulvic acids, the copper might have become more strongly bound in organic complexes (Neubecker *et al* 1983; Coale & Bruland 1988; Allen & Hansen 1996) and the digestion method used may not have adequately isolated it. However, separation from the (removed) organic matrix has been considered 'generally achievable' with the method utilised (open vessel oxidative degradation with aqua regia), although other methods are considered perhaps more sensitive (IPCS 1998). As bryophytes lack a root and cuticle system they obtain nutrients as particulates and in solution directly from atmospheric deposition (Mulgrew & Williams 2000). The surfaces of moss-rich ombrotrophic bogs, isolated from crustal sources, might be expected to have lower uptake of heavy metals such as copper than those rich in higher (e.g. herbaceous or ligneous) plants, which also take up heavy metals in the soil/sediment by their root systems. However, the levels of the BEL core where copper is not detected did not contain appreciable quantities of bryophyte macrofossils; the peat was instead herbaceous with occasional to frequent ericaceous components, hence in this case this is an unlikely explanation for sub-detection level concentration of Cu. The digestion method utilised is therefore concluded to be responsible for the observed absence of Cu from the profile.

A peak in zinc concentrations is registered at c. 3775 cal. BP (Figure 5.15). Zinc was selected as a potential index of atmospheric pollution in this study. However, the behaviour of its profile suggests it has been mobilised in the BEL core and its vertical distribution has probably been altered. Although, like Cu, Zn has a high affinity for organic matter, its vertical distribution in mires is affected by numerous processes, causing it to be regarded as the most variable of commonly-studied elements (Shotyk 1988, 159). Vegetation composition is known to affect Zn distribution (Livett *et al* 1979), whilst peaks in profiles at roughly the depth of the water table have been reported (e.g. Damman 1978, 493). This latter feature is probably due to oxidation to mobile (soluble) sulphates in lower water levels, and reduction (precipitation) as a sulphide or carbonate at a higher water level (ibid., Shotyk 1988, 160). Other researchers have suggested that ash enrichment may be a simpler explanation for apparently anomalous peaks in zinc concentration (see discussion in Shotyk 1988, 159-160). There was only a minor temporary decrease in loss-on-ignition just prior to the c. 3775 cal. BP Zn peak suggesting this latter interpretation was not applicable in this case. As the Zn peak under consideration, and also the peaks at c. 2450 and c. 1080 cal. BP, occurred close to major changes in sediment stratigraphy, a more likely explanation is a combination of the changing vegetational composition of the peat and the varied (related) hydrological and redox statuses.

Sustained high concentrations of Na and Mg indicate the climate was at its most oceanic from c. 3510 until c. 2950 cal. BP. During this period, the water supply to the bog had a higher marine-derived component than at any other time under study. Calcium levels increased at c. 3510 cal. BP and remained relatively steady, fluctuating around 1025ppm until c. 1950 cal. BP. Ca, despite being relatively stable in aerobic peat, adsorbed to peat or in organic forms, is easily lost below the acrotelm (Damman 1978, 493) and the profile appearance in the BEL core may simply be a function of time. However its steplike progress rather than typical fall-off curve would suggest that, although losses occurred, the shape of the profile may in fact replicate supply over time.

5.4.6 c. 3460 cal. BP – present.

A blanket bog flora was established as the dominant vegetation in the vicinity of the sampling site by c. 3600 cal. BP. For the next millennium, there was an overall replacement of grassland by bog and heath vegetation, indicating expanding blanket bog. Mixed agriculture persisted, as evidenced in cereal pollen and disturbance and pastoral indicator records. Cereal pollen grains cease to be recorded at c. 3060 cal. BP. This line of evidence can be interpreted to indicate a cessation of agriculture, as both pastoral and disturbance indicators were also generally less well-represented after this point. Abandonment of agriculture can be difficult to interpret in palynological records, and woodland regrowth need not be expected in a blanket-bog landscape such as this. Many of the taxa comprising the pastoral and arable/disturbance indicator groups also inhabit 'natural' and bog communities to a lesser extent (e.g. Poaceae, *Rumex acetosella*, *Polygonum aviculare*, *Persicaria maculosa*, Lactuceae, *Artemisia* type and *Urtica*: Behre 1981, 233). Therefore, although such taxa would not be widespread in the wooded environment prior to clearance at Belderg, their persistence in the post-abandonment blanket bog environment in all likelihood makes palynological interpretation of the cessation of agricultural activity vastly complex. Whilst it may be argued that the cereal-type pollen record is the most reliable indicator of anthropogenic activity, a cereal-importing economy must also be considered (see Section 7.4). However, if a purely pastoral agricultural economy were practised, higher values of pastoral indicator taxa and Poaceae would be expected. Between c. 3045 and 2775 cal. BP, however, Poaceae values fluctuated around an overall decline, whilst *Calluna vulgaris* underwent an overall increase in percentage representation. An interpretation of abandonment of this area in terms of both cultivation and pastoralism is therefore supported. There was possibly a minor, short-lived resurgence in activity recorded between c. 2775 and 2600 cal. BP as a small peak in *Plantago lanceolata* was accompanied by occasional disturbance indicators and one cereal pollen grain was recorded. A layer of mineral inwash in Transect Core W21 was assayed to just after c. 2860 cal. BP, suggesting that soil erosion was occurring. This could be related to the farming activity, originating from agricultural soils with reduced vegetation cover from overgrazing or arable production.

Humification records suggest that between c. 3025 and 2975 cal. BP the mire surface was significantly drier than average. The geochemistry record is contrary to this, indicating maxima in Na and Mg influx (Figure 5.15). Whether the humification data record a short-lived event outside the resolution of the geochemical record, or whether the humification curve is recording internal hydrological changes, is uncertain. Perhaps at these depths the bog at this location was less sensitive to shifts in climatic wetness, and the humification curve does not reflect surface wetness. Regardless, until c. 2110 cal. BP, humification indicates the mire surface was drier than average but less so; remaining within the 1σ range of the whole-core mean. From c. 2950 cal. BP, concentrations of Mg, and more markedly

Na, both declined, a pattern which continued until c. 1650 cal. BP. A progressive decrease in marine-derived aerosol spray is perhaps suggested, and that the climate was becoming less oceanic.

From c. 2600 cal. BP the previously established blanket bog vegetation was maintained, although the balance between grass and heath vegetation coverage remained in a state of flux. The pollen source areas for large diameter blanket bogs are calculated as being the local and regional components, with insignificant extra-local pollen (Jacobson & Bradshaw 1981, 82 & 89). The local component is more important in peats than in other sediments, with proportion of the pollen rain represented by local components increasing sharply from the mire edge towards the centre (Caseldine 1981). The BEL pollen diagram at this point indicates a large diameter mire, as non-mire taxa are poorly represented. Therefore, although fluctuations in mire taxa occurred they are likely to represent extremely local floristic conditions only, rather than displaying any wider significance. The peak in *Plantago lanceolata* at c. 2600 – 2400 cal. BP could be interpreted as recording an expansion of pastoral agriculture, or alternatively the recolonisation of abandoned formerly cultivated land (cf. Behre 1981, 228-229). A further putative phase of mixed agriculture is suggested at c. 1935 – 1600 cal. BP, where a single cereal pollen grain and other disturbance indicators, in addition to a peak in *P. lanceolata* and occasional occurrences of other pastoral indicators, were recorded.

The K curve begins to reflect gradually increasing concentrations of that element from c. 2100 cal. BP, which is, on balance, probably evidence for its gradual loss from the profile below the depth of living plant material. K is rapidly removed from dead plants despite being efficiently retained in surface layers of ombrotrophic bogs (Damman 1978, 491). At c. 1640 cal. BP there were major changes in the stratigraphy of Mg and Ca. Na concentrations remained at roughly the same level as previously, and the K curve showed continually increasing concentrations, which further reflect progressive leaching below the surface. Large peaks in Mg and Ca, however, and a further peak in Zn, indicate anomalies in aspects of the bog geochemistry. One explanation might be a hiatus in the sediment record, most likely due to peat cutting in historical times. Humification was not tested at this depth (52cm: see Section 4.4.4.4). Pollen profiles for the main taxa (*Calluna vulgaris*, *Erica tetralix*, Cyperaceae and Poaceae) exhibited sharp changes in percentage representation at this point, supporting the hiatus interpretation. Furthermore, total pollen concentration increased at approximately 50cm (Figure 5.21). Had buried peat been newly exposed by cutting, fresh pollen would supplement the fossil content, thereby increasing total pollen concentration.

Live plants colonising a freshly cut peat surface might have utilised available nutrients, accounting for the troughs in Mg, Ca, and to a lesser extent Na, at c. 50-55cm. As peat developed over time, this surface layer would be progressively leached, but because of its relatively young age due to the hiatus, higher levels of certain elements would still be expected. Na and K, regarded as the most easily leached elements in peatlands (Damman 1978, 489; Shotyk 1988, 149), were in lower concentration than Mg and Ca, which are not so easily lost (Damman 1978, 489). In the topmost zone, bioaccumulation of nutrients by living plants can be seen above c. 20cm. Surface accumulation of K and Ca is characteristic of ombrotrophic peat bogs, as they are efficiently retained by living plants (Damman 1978, 491). Essentially, above the probable disturbance feature at c. 50cm (c. 1600 cal. BP), the geochemical records are considered to represent uptake by living plants rather than their former vertical distribution.

Following this hiatus the chronology must be interpreted as insecure. At some point *Calluna vulgaris* became established as dominant over Poaceae and Cyperaceae. At c. 30cm there was a further marked change in percentage representation of the main taxa, *Calluna vulgaris*, *Erica tetralix* and Cyperaceae. Again, a renewed minor peak in total pollen concentration occurred, which could indicate newly cut-over surfaces. Because no secure chronology exists and the likelihood of at least two inconsistencies in sediment stratigraphy, the palaeoenvironmental records have not been interpreted after the first indication of a hiatus, at c. 1600 cal. BP.

Chapter 6

On-site investigation: results and interpretation

6.1 Introduction

This chapter describes the results and provides interpretations of the geoarchaeological and palynological investigations of two sections of soil near to the roundhouse (see Figures 6.1 and 4.1 for location). The sections were selected because they displayed field-scale evidence of tillage. There were several objectives in investigating these soil sections. The preservation of macroscopic tillage indicators provided ideal conditions in which to explore the agricultural practices used by farmers. Until now the macroscopic evidence has been described from field-scale inspection only (see Section 3.2.2.1 and Appendix B), as a layer of ard-marked soil and overlying ridge cultivation. Arable cultivation has been interpreted on this basis (Section 3.2.2.1 and Appendix B), and is supported by the presence of quernstones in the roundhouse. In certain upland post-medieval contexts, suggestions have been made that ridge-and-furrow traces can over-estimate the importance of arable agriculture (Carter *et al* 1997). Ard-marks under some Neolithic monuments have been explained as cross-ploughing as a ritual act of ground preparation, and in similar contexts there is no reason to necessarily link ard-marks with cereal cultivation (Tarlow 1995). Soil micromorphological analysis offers an opportunity to definitively address these issues, and to determine the tillage implements used in the different soil horizons (Lewis 1998). Pollen analysis is likely to ascertain the cereals cropped, if the tillage plots had an arable function. Furthermore, the burial of the soils by peat allows evaluation of when the tillage occurred in absolute terms and thereby in relation to the other archaeological remains on the site.

6.2 BB1 Section

6.2.1 Description of sediment stratigraphy.

Table 6.1 records the sediment stratigraphy in detail using the Troels-Smith (1955) system as modified by Aaby & Berglund (1986). Figure 6.2 presents the section drawing of BB1 with the contents of Table 6.1 repeated; Plate 4.1 shows the BB1 section before sampling, and Plate 4.4 shows the section with Kubiena sampling tins in place.

The soil profile exhibits visually distinctive layers. These were described as contexts rather than by the traditional method of profile description, because there was potentially significant disturbance and human alteration. However, soil micromorphological analysis (below, Section 6.2.4.2) was able to identify horizonation and apply this to the soil layers. The basal layer (**1006**) appeared to be natural, unaltered subsoil, a stony sand with low silt content. The overlying layer (**1005**) displayed criss-crossing ard-marks in plan (Caulfield 1972: Appendix B) but these were not evident in section. This layer (**1005**) contained charcoal inclusions and a higher proportion of organic material than the unaltered soil. This ard-marked layer was visually distinguished from the overlying soil (**1004**), which formed ridges and furrows evident in plan and section. The distance between the centre of each furrow is approximately 1m (Caulfield 1975: Appendix B) and each furrow is approximately 10cm wide. The vertical distance between the base of a furrow to the top of a ridge was noted in the field to be approximately 5cm, although peat accumulation and sediment infilling since excavation may have altered their original forms. The organic content was higher and there was some peat formation evident by the presence of well-preserved plant macrofossils. Overlying the ridges and furrows was a thin layer of very well humified, highly organic, greasy amorphous peat (**1003**). This was overlain by poorly humified fibrous peat with herbaceous and ericaceous fragments (**1002**). The top layer represented the acrotelm and was probably disturbed by peat cutting (**1001**).

6.2.2 AMS radiocarbon dating

A 1cm slice of basal peat from **1003** was sampled from Kubiena tin K7 (see Figure 6.2) for radiocarbon assay (see Section 4.4.7.2 for justification of sampling strategy). Details of the radiocarbon assay are presented in Table 6.2 with that from the BB2 section, and graphical calibration details (BB1 only) are shown in Figure 6.3. By reference to Table 6.8 the assayed sample can be cross-referenced to the pollen (Figures 6.4 – 6.6) and sedimentary (Table 6.1) profiles.

The radiocarbon assay indicates basal peat (**1003**) began to accumulate at c. 2535 cal. BP. However, due to the mid-third millennium cal. BP radiocarbon plateau, the 2σ error range is very wide (2720-2350 cal. BP). Effectively, samples from between 2400 and 2800 cal. BP have the same radiocarbon age, and it must be stressed that whilst the midpoint is judged the most appropriate estimation of the age of basal peat (see Section 4.4.7.2), in this particular instance the uncertainty surrounding its accuracy is great.

6.2.3 Pollen analysis

6.2.3.1 Presentation of results

By reference to Table 6.3, each spectrum from the BB1 pollen profile (Figures 6.4, 6.5 and 6.6) can be related to both a context and a Kubiena tin sample (shown in Figure 6.2).

The pollen data are presented in three separate diagrams for optimal interpretation purposes. Shaded (coloured) curves represent a tenfold exaggeration (the colour of which corresponds to that of the appropriate group's summary diagram) except for the summary curve of the Aquatics group, which represents a twenty-fold exaggeration. A cross represents a single pollen grain or spore.

Figure 6.4: Percentages based on the TLP sum grouped in the summary as Trees, Shrubs, Bog & heath taxa and Herbs.
Figure 6.5: Percentages based on the TLP sum grouped in the summary as Trees, Shrubs, Bog & heath taxa, Herbs, Pastoral indicators and Arable/disturbed ground indicators.
Figure 6.6: Pollen concentration data of selected taxa.

Taxa forming the Pastoral indicator and Arable/disturbed ground indicator groups are classified as in the BEL profile (see Section 5.3.7.1 above). Size and descriptive details of cereal-type pollen grains are presented in Table 6.3. Selected photomicrographs of these cereal-type pollen grains are presented in Plates 6.1 to 6.9.

6.2.3.2 Zonation

The BB1 pollen profile has been divided visually into two zones; BB1-1 and BB1-2.

PAZ BB1-1: *Alnus-Betula*-Poaceae: 10 to 1 cm below peat boundary. *Terminus ante quem* c. 2540 cal. BP

The dominant taxa in BB1-1 are *Alnus* and *Betula*, fluctuating between 20-45% and 20-40% TLP respectively. Other tree taxa (*Ilex*, *Quercus*, *Taxus*) are present in low percentages. *Corylus* is represented at about 10% TLP. The other main shrub taxon represented is *Hedera helix*. Heath taxa are not well represented, with all taxa remaining below 10% TLP throughout the zone. The best-represented NAP group are the herbs, with Poaceae at around 20% TLP, becoming increasingly better-represented near the upper zone boundary and reaching 40% TLP. Continuous curves are present for Lactuceae, *Plantago lanceolata*, *P. major/media* and *Urtica* for the section of the zone represented by the organic soil (the ridge cultivation horizon). Cereal-type grains are present in low frequencies throughout most of the zone.

BB1-2: *Calluna*–Poaceae: 1 to -8cm below peat boundary. *Terminus post quem* c. 2540 cal. BP

The AP content of this zone is lower than that of BB1-1. *Alnus* and *Betula* rapidly decrease before the lower zone boundary and fluctuate between 0–10% TLP for the remainder of the profile. *Ilex* and *Quercus* are no longer represented by continuous curves and all other AP are represented by low frequencies or sporadic occurrences in the profile. *Corylus* remains at c. 5% TLP for the entire zone. There is a marked rise in *Calluna vulgaris* and other heath taxa at the interface between peat and mineral soil; once established, *Calluna* remains fairly constant between 25–40% TLP. NAP also expands during BB1-2; Cyperaceae values fluctuate between 0-20%, and Poaceae values are at generally higher levels than in BB1-1, between 25-45%TLP. The herb suite becomes generally less diverse, with many taxa (e.g. *Aster* type, Caryophyllaceae, *Digitalis purpurea* type) virtually disappearing from the flora; and others (*Ranunculus* type, Rosaceae, Lactuceae, *Plantago lanceolata*, *P. major/media*, *Urtica*) becoming less prevalent. Cereal-type grains are only represented in two levels. The *Sphagnum* curve becomes continuous and fern taxa decline in frequency. A minor appearance of one or two aquatic indicator grains occurs around the lower zone boundary. Microscopic charcoal particles are represented at higher levels than in the previous zone.

6.2.3.3 Pollen concentrations

There is no great differential between the different sedimentary layers in terms of the total concentration of microfossils (land pollen, aquatics and spores: see Figure 6.6). Context **1005** contains a slightly lower total fossil concentration than **1004**. Spectra from contexts **1003**, the basal peat layer, and **1002**, which overlies it, contain varying concentrations of fossils which do not appear to relate to depth.

6.2.4 Thin section soil micromorphology

6.2.4.1 Description of micromorphological features

The soil micromorphological features noted in the BB1 thin sections are presented in Table 6.5. A summary of the main microscopic features and their interpretation is presented in Table 6.6.

6.2.4.2 Description of soils and sediments

The features noted in thin section (Table 6.5), when compared with the features noted from field examination, can be combined to describe more fully the sediments. The following descriptions result from such combination.

*Context **1006***

The primary soil is characterised by poorly sorted subangular to subrounded mineral material comprised of quartz and with lesser quantities of feldspar, muscovite and hornblende. Fine material is organo-mineral with close porphyric related distribution. There are occasional organic coatings of grains and also infrequent excremental pedofeatures, indicating soil fauna activity. There are occasional inclusions of carbonised material. Plate 6.10a shows K1, the lower half of which is comprised of **1006** (see Figure 6.2 for location in BB1 section). Plate 6.10b shows K1 with annotations. The base of an implement cut mark (base of furrow in **1005**, see below) in K2 is characterised by a compacted zone of fines accumulation, including a cracked fines pan. This is shown in Plate 6.11a in plane polarised light (PPL) and 6.11b in crossed polars (XPL). Another cracked fines pan within a compaction zone at the top of **1006** marks the transition to **1005** in K1 (Plates 6.12a & 6.12b).

*Context **1005***

Viewed macroscopically, thin section K2 is seen to have sectioned an implement mark (see Plate 6.13a & 6.13b; and see Figure 6.2 and Plate 3.4 for location). This has provided ideal conditions for examination of the properties of a relict agriculture soil. Overall, context **1005** has similar characteristics to **1006** but with slightly more frequent pedofeatures and charcoal inclusions and less lignified organic material.

K2 can therefore be described as two parts: the cut sediment and the fill (see Plate 6.13b). The cut sediment, marked on Plate 6.13b, is pale brown in PPL with a low organic content. It has few root channels. There are patches of light yellow/brown fine material seen in PPL which indicate leaching, and yellow patches of fine organo-mineral material (PPL) indicative of iron movement. The base of **1005** is distinguished from **1006** by a discontinuous fines pan – an elongated lens of silt and fine sand c. 100μm in thickness. This soil also contains larger stones than the fill, and the mineral content varies from moderately to poorly sorted, with the level of sorting increasing up the profile.

The fill, marked on Plate 6.13b, has a higher organic content and also a higher quantity of fine organo-mineral material. The fine organo-mineral material is brown and red-brown in PPL. The mineral material is moderately sorted. There are more root channels than in the fill sediment, and these run vertically. Occasional cellular structural material is present. The fill contains fines lenses; angular bands of fine minerals (silt and fine sand), c. 500 x 100μm in dimension (see Plates 6.14a&b & 6.15a&b). There is a discontinuous (cracked) fines pan underlying the cut mark (see above). Dusty (silty clay) infills and coatings are present occasionally. There are very rare rubified mineral grains evident in oblique incident light (OIL) (Plate 6.16). The related distribution is described as vughy.

*Context **1004***

At the base of this context there is a very thin accumulation of organic material. This context contains a lesser coarse mineral fraction with more rounded grains and more organic matter than **1005**. K3 is shown in Plate 6.17a, with annotations in Plate 6.17b. The mineral material is moderately to poorly sorted, with the level of sorting decreasing upwards in the profile. The related distribution is described as close porphyric. The organic material is progressively darker in colour upwards in the profile. The fine organo-mineral material is red-brown and dark brown in both OIL and PPL. There are concentrations of rubified (reddened) mineral inclusions seen in OIL (see Plate 6.18). There are some indications of organic coatings to coarse mineral grains and occasional Ca-Fe-P accumulations in pore spaces. There are also occasional accumulations of phytoliths and fractured siliceous concentrations. The occurrence of occasional patches of yellowish, fine organo-mineral material (PPL) indicates leaching. There are occasional poorly defined fines lenses (see Plates 6.19 and 6.20a&b). There is a thin band near the top of K3 which contains a higher concentration of mineral material (see Plate 6.17a&b). The top 1cm of **1004,** beneath the transition to **1003**, is characterised by a lower mineral content and a spongy microstructure more typical of peat than of soil.

*Context **1003***

The boundary between this layer and **1004** is clear. **1003** contains a much reduced mineral fraction, containing only a few rounded quartz grains with occasional muscovite. There are occasional phytoliths. The coarse organic material consists of fibrous parenchymatic tissue and there is also abundant fine organic material, with rare inclusions of charcoal. The spongy structure and undifferentiated groundmass B fabric suggest that this peat is largely undisturbed.

*Context **1002***

Rare quartz grains comprise the mineral component of this deposit. The coarse organic fraction contains both lignified and parenchymatic tissues, whilst the finer organic fraction largely consists of amorphous black material. There are occasional carbonised particles. The microstructure is complex – a combination of spongy and angular blocky.

6.2.5 Interpretation

6.2.5.1 Pollen taphonomy

The taphonomy of the pollen content of the soil profiles is vital to their interpretation (Tipping 2000). The three taphonomic aspects which may affect a pollen profile are the pollen source area, the processes acting upon the pollen once it has landed in a sediment, and its survival or otherwise in that sediment. Therefore, different pollen assemblages contained in these zones may reflect the different post-depositional and post-burial taphonomic processes acting upon the pollen content of the sediments as well as variations in the local and regional vegetation cover.

Most research has concluded that pollen assemblages from terrestrial soils have an extremely localised source area (e.g. Andersen 1986, 167; Bunting 2003). Multiple soil pollen profiles at a landscape-scale have been used to interpret spatial patterning of former vegetation cover (Whittington & Edwards 1999, 596-597).

The abundance of indeterminate Pteridophyte [monolete] spores (formerly classified as Filicales or undifferentiated Polypodiaceae) has been used as an index of the reliability of soil pollen profiles. The spores are particularly resistant to corrosion and deterioration, hence their abundance relative to the TLP count can indicate whether the profile has suffered preferential removal of pollen (Havinga 1984; Tipping *et al* 1994, 391-395). A value of >40% TLP for these spores has been taken as indicative of differential pollen preservation (ibid., 395). In the soil horizons of the BB1 profiles, values of indeterminate Pteridophyte [monolete] spores do not exceed 5% TLP (see Figure 6.4). By this index, it can be concluded that there is no significant differential pollen preservation or preferential removal. This would argue against the *Alnus* and *Betula* components of the assemblage representing residual pollen content. Research has concluded that the pollen content of most terrestrial soil profiles consists of mixed-age assemblages as a result of earthworm activity (Davidson *et al* 1999; Tipping *et al* 1999). In certain circumstances, a thin surface layer of soil beneath a sealing context can be interpreted as representing a snapshot of vegetation cover just prior to burial (Casparie & Groenman van Waateringe 1980; Andersen 1992; Tipping *et al* 1999, 79; Whittington & Edwards 1999, 595). This may not be applicable to sub-peat profiles where there is a transition layer between soil and peat, and in any case pollen lower down in the soil profile will contain older pollen. Whilst some previous interpretations of soil pollen profiles assume all pollen to be coeval in base-rich, biologically active soils (e.g. Dimbleby & Evans 1974); such interpretations have been extended to buried podzols and base-poor brown earth soils as well (Tipping *et al* 1994, 400). Some particularly robust pollen types such as *Alnus* and *Corylus/Myrica* which are identifiable when deteriorated to 'ghosts' may be considered to potentially skew interpretations *via* residual presence (ibid.).

Detailed analysis of the concentration data suggests significant differentials in pollen survival and destruction patterns. In overall concentration terms, there is no great overall difference in total fossil concentration between the two zones, which might suggest there has been differential deterioration between fossil types, leading to greater losses of pollen compared to spores. The internal differences in the BB1 pollen percentage and concentration profiles reveal more interesting patterns relating to pollen survival and destruction. Within the soil spectra, TLP concentrations are greater in the upper layer (**1004**) than the lower layer (**1005**) (see Figure 6.6), which suggests that decay is greater at depth. This would be expected in a sub-peat soil. However, the known ploughing has complicated matters, and the patterns of particularly resistant pollen and spore types (e.g. Lactuceae and Pteropsida [monolete] indet.) are more informative on this issue.

Whilst percentage representation in the soil profile of indeterminate Pteropsida (monolete) spores is low, they are present in much greater concentrations in zone BB1-1 (the soil spectra) than in BB1-2 (the peat spectra). Rather than necessarily indicating preferential preservation of spores to pollen in the soil, this may reflect an ecological change, as ferns are less likely to grow in peats than in soils (Grime *et al* 1988, 627). The patterning of pollen and spore concentrations within the soil profile supports this suggestion, as there is a sharp decline in concentration of indeterminate Pteropsida (monolete) spores towards the soil/peat interface in **1004** (3cm to 0cm). The extremely resistant pollen taxon Lactuceae is present in the uppermost soil spectra at its highest concentrations, suggesting that these spectra have been affected by significant preferential survival. The various indices of preservation quality in the soil horizons as compared with the overlying peat are contradictory and complex. It is evident that the ploughing activity in the soil has greatly altered the taphonomy of its pollen content. However, the evidence from Lactuceae in particular, suggesting oxidation in the upper spectra of **1004**, might indicate that the destruction occurred post-depositionally in a span of time between cessation of agriculture and burial by peat.

As discussed above (Section 4.4.2.2), the stratigraphic security of pollen in the soil spectra is likely to be poor, as bioturbation and mechanical mixing (by ploughing and downwashing) are more active in soils than in peats, resulting in the vertical distribution of pollen being unrepresentative of age (e.g. Dimbleby 1957; Andersen 1986). The process of incorporation and redistribution of pollen into soil profiles is variable, depending upon the soil type (Davidson *et al* 1999), with the pollen content of well-drained mineral soils being most affected by bioturbation (Tyler *et al* 2001). Only in the actively accumulating organic horizons of peaty soils or podzols can pollen be stratified for palaeoenvironmental interpretation (Davidson *et al* 1999; Tipping *et al* 1999). BB1-2 can be considered to contain securely stratified pollen as it represents the undisturbed peat accumulation over the ridge cultivation horizon.

Applying these considerations to the soil profile BB1, a theoretical model of pollen incorporation can be constructed. **1006** consists of the natural, acid brown earth formed from weathering of the Dalradian quartzite/schist bedrock and/or till. As it has a high sand content (see Table 6.1) it may originate from similar deposits to the compacted sand which features at the base of the BEL core and other sedimentary profiles downslope (see Section 5.2.2.3). There are no macroscopic indications of human modification of the soil, and the charcoals could be relict from natural fires. Initial exploratory pollen analysis suggested that pollen survival was extremely low or negligible and therefore spectra from this layer were not analysed further. In **1005**, an inorganic, leached silty sand, mixing by ard cultivation, downwashing and some bioturbation are likely to have been the primary taphonomic factors affecting pollen distribution. The pollen profile at this point cannot be considered stratigraphically secure. The overlying horizon, **1004**, records the accumulating organic layer of the increasingly peaty acidic brown earth. Although some degree of stratification could perhaps be inferred, at a coarse temporal resolution, the agricultural use of the horizon indicated by ridges and furrows will have involved mechanical redistribution. **1003** is interpreted as representing *in situ* peat which accumulated undisturbed over the cultivation ridges following abandonment. **1002** is interpreted as a fibrous peat which has possibly been disturbed, perhaps as a result of cutting for fuel.

6.2.5.2 Interpretation

As the ridged layer (**1004**) is likely to represent a later period of cultivation than **1005** (see below) it is not possible to definitively identify traditional soil horizonation in the profile. Nevertheless, an estimation can be made. Typically, archaeological ard-marks should be expected to represent the lower parts of the zone of disturbance, rather than the entirety of this zone, due to truncation, later disturbance or difficulty recognising less distinctive parts of such features (Lewis 1998, 78-80). The ard-marked horizon in BB1 (**1005**) may have been disturbed or truncated by the overlying ridges and furrows (**1004**). The part of **1005** visible in the BB1 section varies between c. 5.5 and 12cm thickness (see Figure 6.2). Therefore, the later disturbance in BB1 represented by the ridge cultivation horizon should not be seen as a barrier to interpretation of the ard-marked soils. The ard-marked layer can be described as the homogenous Ap (ploughed) horizon, formed from mixing over the Ah (humic) and O (organic rich) layers (Courty *et al* 1989, 131; cf. Courtney & Trudgill 1984, 92). In thin soils the Ap horizon can include material from the B and even C horizons (Lewis 1998, 65) and, judging by the similarity between **1005** and **1006** (particularly the mineral fractions), such a situation is indicated at Belderg. The sub-peat soil profiles even near the BB1 and BB2 profiles are generally thin (see Section 5.2.2 and Figure 5.2). **1006** is thus interpreted as the B horizon, with some downwashed material from the A horizon and some indications of illuviation, for instance downwashed charcoals. **1004**, distinctive from **1005**, represents a second, discrete Ap horizon, formed from the upper part of **1005** and further accumulated humic material. The overlying peat layers can be described collectively as the O horizon.

1005 is interpreted as representing intensive arable cultivation. With the exception of extremely rare rubified minerals visible in OIL (Plate 6.16) there is no evidence for amendment material in this layer, despite the evidence of leaching and iron translocation that might suggest that the soil was nutrient-poor and some amendment strategies would have been useful to maintain long-term arable cultivability. The rubified minerals do not occur in a matrix of red or red-brown fine organo-mineral material, which suggests they are not derived from ash inclusions. The strongest cultivation indications are in the form of both profile/horizon characteristics and microscopic characteristics, which have previously been identified experimentally and archaeologically to signify tillage (cf. Lewis 1998, 7). These shall be discussed separately.

1. Profile / horizon characteristics.

The primary indication of tillage is the presence of ard-marks in plan and in thin section. The horizonation appears to be distinctive, with stony material from the underlying B horizon pushed up into a ridge, probably as a result of the moving force from the ard tillage (cf. Lewis 1998, 324). The differences between the furrow fill and ridge material are marked. The furrow fill material is looser than that external to the cut, with a particularly compact zone relative to the fill being present below the ard-mark; a particular characteristic of archaeological tillage features (Lewis 1998, 320). The furrow cut is lined by small (<1cm) rounded or rolled aggregates, with larger subangular and angular clods present in the upper fill. These are marked in Plate 6.11b. Again, such features have been seen in laboratory- and field-based experimental tillage, and in archaeological ard-marks at Bjerre, Denmark (ibid., 323). The voids within the fill are a combination of vughs and channels. Plant roots are more frequent in the furrow fill and assume a vertical or near-vertical orientation. Some roots run continuously into the underlying B horizon. These characteristics, added to the palynological evidence, indicate that the ard-marks were created for tillage; i.e. preparation of a seed bed (cf. Lewis 1998, 56) rather than ritual ground preparation (e.g. Tarlow 1995).

The implement cut mark is discernible by typical features – the evident density boundary has resulted in a compaction zone marked by a blocky structure marking the outside as well as the inside of the implement mark (ibid., 320); fines accumulation outside the furrow, especially at the base of the cut (Plate 6.10); and shear planes infilled by fines materials at the base and sides of the cut (ibid., 325; Macphail *et al* 1990, 57). All of these have been seen both experimentally in the field and laboratory, and archaeologically at Bjerre in Denmark (Lewis 1998, 325-327). In particular, fines fraction accumulations – especially silt pans – are characteristic at the base of the tillage zone (Macphail *et al* 1990, 61; Gebhardt 1992).

2. Microscopic characteristics (textural pedofeatures).

Generally (Courty *et al* 1989, 134), dusty-dirty clay infills and coatings are the textural pedofeatures that are considered to indicate tillage, although they also occur in untilled soils. Such features are often laminated, and the degree of limpidity (inversely proportional to the dust or silt content) is reflected by the birefringence upon rotation under crossed polars. Dusty clay coatings are common in tilled heavy textured soils, whilst limpid clay coatings are generally associated with weathering (Macphail *et al* 1990, 56). There are only very occasional and limited indications of dusty infills in the BB1 furrow fill, which is unexpected for a horizon which displays otherwise clear indications of tillage. However, the soil is sandy and low in clay, which might account for the near-absence of clay coatings and infills. Archaeological examples of clay-free soils with ard-marks exhibit only rare and poorly formed coatings (e.g. Phoenix Wharf, London and Lodbjerg, Denmark: see Macphail *et al* 1990, 63). Experimental ard tillage in a soil bin at Silsoe College, Cranfield University, in a silt loam and at Lejre, Denmark, in an argillic brown earth, both utilising reconstructed Donneruplund ards, failed to produce significant quantities of dusty clay textural pedofeatures, despite the resulting thin sections displaying other unequivocal tillage indicators (Lewis 1998, 161-187). Whilst insufficient time for formation might explain the absence of clay coatings in experimental tilled soils, clay illuviation has been known to occur quite rapidly at times, even in less favourable conditions for clay dispersion, such as calcareous soils (Aguilar *et al* 1983). Post-abandonment processes such as biological reworking, trampling, erosion or shrub colonisation may alter or rework formerly cultivated soils and remove or blur the agricultural history from the soil (Courty *et al* 1989, 140-146). The fragmentary nature of some of the fines lenses in the furrow fill (see below) partially supports this as an explanation for the situation at Belderg, but other features such as the relatively sharp ard-mark cut and the well-defined basal fines accumulation would counteract this. Unfortunately, insufficient experimental work has been completed regarding the relationship between tillage frequency and the occurrence of micromorphological features, so it is unknown whether there were simply insufficient repetitions of cultivation at Belderg to produce dusty coatings (cf. Lewis 1998, 175). Therefore, the conclusion is that the soil texture was responsible for the near-absence of clay coatings and infills.

The fines pan at the base of the furrow, overlying the zone of fine fraction compaction, represents a discrete textural pedofeature (cf. Lewis 1998, 187). Whilst these features have been identified in experimental studies at Silsoe soil bin, Lejre, Denmark (ibid.) and Hambacher Forest, Germany (Gebhardt 1992), archaeological examples are also known, at Chysauster, Cornwall (Macphail 1996, 200-203) and West Heslerton, Yorkshire (Macphail 1998). In addition to these fines pans at the base of and underneath furrows, fines lenses were present in experimental ard tilled soils at Lejre, Denmark, infilling voids at the side of furrows (Lewis 1998, 183). Fines lenses are also in evidence in some archaeological samples and occur as fragments within or upon individual peds (e.g. Macphail 1996, 203). Their morphology is clear and can be directly related to ard tillage. They are generally characterised by high proportions of silt, with clay and fine sand components, and are created quickly and with minimal disruption (ibid., 187).

Fines lenses (discrete panning features) are typically composed of very fine microaggregates, rounded or subangular blocky grains, the presence of which are suggested to indicate either their physical movement down into the zone under implement pressure, and/or post-depositional aggregate formation or cracking within a lens of fines that has accumulated through translocation (trickling-down). Both mechanisms are probably involved in most cases (Lewis 1998, 329). Although they normally have a higher silt content than clay, the fines lenses in the BB1 furrow fill have a higher fine sand than silt component, which may be a factor of soil texture.

Whilst the main fines accumulation zone varies between 1 to 3cm at, just above or below, or either side of, implement mark cuts, the BB1 furrow fill contains fines lenses within the main fill (see Plates 6.13 & 6.14 & 6.15). These could result from infilling of a planar void (ibid., 325), or secondary disturbance. The example in Plate 6.15 is infilling a void. Sorted and fragmented fines lenses in archaeological samples are perhaps best explained as incorporated crust fragments (from surface slaking) rather than panning features, but the unsorted nature of the lenses in question and the lack of additional evidence for slaking would argue against this.

1004 indicates continuing cultivation. There is no indication of a substantial hiatus between this context and **1005**. A discrete accumulation layer of mineral material would be expected if soil erosion from upslope had settled on the newly abandoned soils. Significant erosion episodes may be expected after agricultural cessation, reflecting the absence of amelioration by humans in the form of management strategies (Lewis 1998, 46). Had sufficient time elapsed between abandonment and reutilisation of the soil, grassland, heath or scrub would be expected to have colonised the surface. Whilst the pollen profile would not be expected to retain a record of this, a signal would be likely in thin section in the form of accumulated organic material representing vegetative growth. In this case there is only a discontinuous layer of slightly increased mineral inclusions, overlain by a more organic soil, then finally by a limited, c. 0.5cm thick, accumulation of organic material separating context **1004** from **1005** (see Plate 6.17a&b).

Similarly to **1005**, the fabric of **1004** is well mixed, which suggests soil disturbance by cultivation. This is in keeping with the macro-scale evidence from the cultivation ridge formation. There are, however, apparent differences in cultivation strategies. Firstly, there are fewer, less well-defined fines lenses which would suggest ard cultivation, and secondly, there are subtle indications in **1004** of amendment strategies. Ca-Fe-phosphatic infills indicate the decomposition and recrystallisation of animal bone (cf. Jenkins 1993; Simpson *et al* 1998b), and the fact that these features are rare in thin section at BB1 suggests that perhaps soil acidity largely prevented recrystallisation. The fine reddish organo-mineral material and rubified stone (see Plate 6.18), both visible in OIL, indicate ash inclusion, but this is limited and the phytolith concentrations are insufficient to suggest addition of burnt peat.

The addition of domestic waste as manure was concluded from micromorphological examination of ard-marked soils from Bronze Age levels at Old Scatness, Shetland (Simpson *et al* 1998b, 116). Those soils also contained limited evidence of Ca-Fe-P accumulations, red fine organo-mineral material with rubified minerals (visible under OIL) and fractured diatoms (ibid.). The practice of adding domestic waste was continued into the Iron Age; however, animal manures were added to the Iron Age cultivated soils, signalling a further development in amendment techniques (ibid., 121). Late Neolithic and Early Bronze Age cultivated soils at Tofts Ness, Orkney, also used ash and midden material, possibly incorporating animal dung (Dockrill & Simpson 1994, 88). By the Late Bronze Age / Early Iron Age at the same site, amendment techniques had also developed somewhat, apparently being more intensive to offset the increasingly marginal nature of the soils for agriculture (ibid., 89). Soil amendment practices in Atlantic Britain have arguably been developed from the Neolithic onwards, gaining complexity and becoming more intensive through time.

The evidence from BB1 suggests that the earliest cultivation (the ard cultivation of **1005**) did not involve the use of any amendment materials. Maintenance of a cultivable soil was apparently achieved by physical mixing, using an ard. Although no great length of time elapsed in-between cultivation of **1005** and **1004**, tillage of the latter was associated with a significant change in agricultural techniques. Domestic wastes, including ash and animal bone, were added to the soils in attempts to improve structure and/or fertility. The evidence of leaching in **1005** suggests that nutrient loss *via* leaching may have been problematic. The increasingly organic nature of the soil in **1004** and the occurrence of fresh plant materials indicate that the surface may have been beginning to paludify, and therefore amendment was required to maintain a soil structure capable of sustaining arable crops. The soil was becoming increasingly marginal for cereal cultivation.

The ridged cultivation plots were believed by the excavator to record spade cultivation (Caulfield 1972: see Appendix B). This assumption appears to be based on the interpretation that they dated to the Bronze Age, before the mouldboard plough came into use in western Europe. The average width of a combined ridge and furrow was approximately one metre (Caulfield 1975: see Appendix B). This falls into the category of narrow or cord rig (Topping 1989; Carter 1993-1994, 83). Evidence of cord rig cultivation in Britain exists from the Late Bronze Age to the medieval period (Carter 1993-1994, 88). Some workers have suggested that ploughs (Lewis 1998, 103) or a combination of plough and spade was used to create narrow ridges (see summary in Carter 1993-1994, 88). That there was a stony headland separating two ridged areas, upon which the roundhouse was constructed (Caulfield 1975: see Appendix B), suggests ploughing might have been involved (cf. Halliday 1993, 71). An ard rather than a mouldboard plough may have been used, as the latter is not thought to have been introduced to Ireland until the seventh or eighth century AD (Mitchell & Ryan 2001, 234). Spades are believed to have been used in Neolithic Scotland (Barclay 1985; 1989) and spade marks exist in pre-Late Bronze Age levels at Hengistbury Head, Dorset (Lewis 1998, 288). There is thus no reason to believe that the Belderg Beg farmers were unaware of spade technology.

Spade marks can produce macro- and microscopically-identified characteristic features. V-shaped cuts are macroscopically identifiable (Lewis 1998, 294) and there is often a tendency for spade-tilled soils to become blocky, subangular blocky or apedal with depth, and to incorporate vermicular structural elements resulting from increased earthworm activity (ibid., 209). Fabric inversion, mixing and disruption is characteristic (ibid.,151). Archaeologically identified spade cuts contain planar voids, as well as fines lens accumulations at the base of the fill and echoing planar voids, similar to those seen in ard-marks (ibid., 298). However, the turning action of spade tillage results in an enrichment of organic matter within the fill, as opposed to ard tillage where the whole of the Ap horizon is enriched (ibid., 321). Plant roots tend to line the cuts of spade or plough tillage marks (ibid., 304) and clay deposits can line spade cuts (ibid., 327). There is no definite micro- or macroscopic evidence to substantiate the assumption that the ridges and furrows at Belderg were cut by spades. However, fines lenses are not generally seen in mouldboard plough tillage (ibid., 324), so their presence at the base of **1004** does lend support to this theory.

In addition to the soil micromorphological evidence for arable cultivation, the pollen profile of the BB1 section records cereal-type pollen grains in the spectra from **1004** and **1005** (see Plates 6.1 - 6.9). The continuous curve of *Plantago major/media* pollen in this horizon, as well as the occurrence of other arable and disturbance indicator pollen types (*Anagallis arvensis*, Chenopodiaceae, *Papaver rhoeas* type, *Polygonum aviculare*, *Persicaria maculosa* and *Urtica*), further support the inference of arable cultivation. The dimensions of the cereal-type pollen grains are presented in Table 6.4. All of the grains are categorised as *Hordeum* type *sensu* Andersen (1979). Whilst that type does include the pollen of some wild grasses (ibid.), and therefore its presence need not indicate the cultivation of barley, the weight of evidence in the BB1 profile (i.e. the frequencies of *Hordeum* type and arable indicator pollen) suggests that barley was the sole cereal crop cultivated in the BB1 soil. This probably relates to the later cultivation period only (the spade and ridge cultivation of **1004**), bearing in mind the relatively short timespan represented by soil pollen spectra (see above, Section 6.2.5.1).

The interval between abandonment of the spade and ridge cultivation represented by **1004** and the onset of peat accumulation (**1003**) was apparently not long in duration (see Table 6.3). The thin layer in **1004** with a greater concentration of mineral grains (see above and Plate 6.17a&b) may record abandonment of cultivation. Increased soil erosion is expected upon abandonment as the management strategies practiced by farmers decrease in intensity (Lewis 1998, 46). This thin lens of increasingly mineral-rich soil was overlain by a c. 2cm accumulation of soil identical to that comprising **1004** below this mineral layer. The thin organic accumulation at the top of **1004** represents the (undisturbed) transition to peat. The decline from maximum to very low percentages in arable/disturbance indicator pollen between 1cm and 0cm below the peat surface (see Figure 6.5), including the disappearance of cereal-type pollen, suggests that the final cultivation episode is represented by the spectrum 1cm below the peat/soil transition. This supports the above inference that approximately the top centimetre of highly organic soil in **1004** represents the post-abandonment shift to peat accumulation. That the mineral-rich layer in **1004** occurs below the palynological indication of agricultural cessation, suggests that mineral layer does not record abandonment. It may record increased erosion from an earlier hiatus in cultivation, such as a fallow year, or an extreme erosional event.

6.3 BB2 Section

6.3.1 Description of sediment stratigraphy.

Table 6.7 records the sediment stratigraphy in detail using the Troels-Smith (1955) system as modified by Aaby & Berglund (1986). Figure 6.7 presents the section drawing of BB2 with Kubiena sampling tins in place and with the contents of Table 6.7 repeated. Plate 4.2 shows the BB2 section prior to sampling.

Similarly to BB1, the soil profile exhibited visually distinctive layering. Again, these were described as contexts rather than by the traditional method of profile description, because there was potentially significant disturbance and human alteration. The basal layer, **2005**, is a very stony sandy soil of unknown vertical extent, which appeared to represent the natural unaltered subsoil. This is overlain by **2004**, a more organic soil with a higher silt component. This layer displayed ard-marks evident in plan (S. Caulfield pers. comm.) but not in section. **2004** was overlain by **2003**, a thin layer of amorphous, very well humified greasy black peat. The next layer, **2002**, was a poorly to moderately humified fibrous peat with herbaceous and ericaceous fragments. This was overlain by **2001**, the acrotelm, which included the root systems of living plants and has probably been disturbed by peat cutting in modern times.

6.3.2 AMS radiocarbon dating

A 1cm slice of basal peat from **2003** was sampled from Kubiena tin K13 (see Figure 6.6) for radiocarbon assay (see Section 4.4.7.2 for justification of sampling strategy). Details of the radiocarbon assay are presented in Table 6.2 with that from the BB2 section, and graphical calibration details (BB1 only) are shown in Figure 6.3. By reference to Table 6.8 the assayed sample can be cross-referenced to the pollen (Figures 6.9 – 6.11) and sedimentary (Table 6.7) profiles.

The radiocarbon assay indicates basal peat began to accumulate at c. 2840 cal. BP. There is a shorter error range (2930 – 2750 cal. BP at 2σ) than that associated with the BB1 basal peat assay, indicating a higher degree of precision because this date does not fall into the radiocarbon plateau. The two ranges do not overlap, which shows that peat initiation was diachronic at these locations, occurring later in BB1 than BB2.

6.3.3 Pollen analysis

6.3.3.1 Presentation of results

By reference to Table 6.8, each spectrum from the BB2 pollen profile (Figures 6.9, 6.10 and 6.11) can be related to both a context and a Kubiena tin sample (shown in Figure 6.7).

The pollen data are presented in three separate diagrams for optimal interpretation purposes. Shaded (coloured) curves represent a tenfold exaggeration (the colour of which corresponds to that of the appropriate group's summary diagram). A cross represents a single pollen grain or spore, and a large dot represents presence of one or two grains.

Figure 6.9: Percentages based on the TLP sum grouped in the summary as Trees, Shrubs, Bog & heath taxa and Herbs.

Figure 6.10: Percentages based on the TLP sum grouped in the summary as Trees, Shrubs, Bog & heath taxa, Herbs, Pastoral indicators and Arable/disturbed ground indicators.

Figure 6.11: Pollen concentration data of selected taxa.

Taxa forming the Pastoral indicator and Arable/disturbed ground indicator groups are classified as in the BEL profile (see section 5.3.7.1 above). Size and descriptive details of cereal-type pollen grains are presented in Table 6.9. Photomicrographs of pollen grains identified as cereal-type are presented in Plates 6.21 to 6.24.

6.3.3.2 Zonation

The BB2 pollen percentage diagram has been divided visually into three zones; BB2-1, BB2-2 and BB2-3.

<u>BB2-1: *Betula–Alnus*: 6 to -1 cm below peat boundary. *Terminus ante quem* c. 2840 cal. BP.</u>

Betula is the dominant pollen taxon at c. 40% TLP, with *Alnus* pollen secondary at c. 25% TLP. The minor tree taxa also maintain constant pollen values: *Quercus* at c. 10% TLP, and *Ilex*, *Pinus* and *Taxus* at lower percentages. *Fraxinus*, *Salix* and *Ulmus* are only occasionally recorded. *Corylus* is recorded at c. 5-10% TLP. At the top of the zone, *Alnus* and *Betula* pollen begin to decline in percentage, coincident with minor peaks in *Sorbus* and *Taxus*. There are few bog and heath taxa recorded in the zone. Poaceae are steady at c. 10% TLP, rising sharply to 40% TLP at the upper zone boundary. The only constantly present accompanying herb pollen taxa are Cyperaceae, *Ranunculus* type and *Potentilla* type, and *Aster* type are represented occasionally. Grazing indicator taxa are poorly represented until the upper zone boundary, with *Plantago lanceolata* pollen recorded constantly, but in low frequencies. Arable or disturbance indicators are similarly poorly represented by sporadic occurrences, with the occasional cereal-type pollen grain recorded in the upper half of the zone, peaking at the upper boundary. Pteridophyte spores are present throughout the zone, gradually decreasing from c. 10% TLP to <5% TLP. Microscopic charcoal particle percentages are at low values until the upper zone boundary, where a sharp increase commences.

BB2-2: Poaceae-*Calluna*-Cyperaceae: -1 to -9cm below peat boundary. *Terminus post quem* c. 2840 cal. BP

All tree and shrub pollen are at low percentages throughout the zone, with only *Betula* and *Corylus* rising at the upper boundary. *Calluna* fluctuates between 15% and 40% TLP, although values for other Ericaceae are low. Cyperaceae form 10 – 20% TLP throughout most of the zone, falling to c. 5% by -8cm. Poaceae are initially high at 55% TLP, falling to 20% mid-zone and then recovering, beginning a further decline at the upper boundary. *Potentilla* type forms c. 5% TLP. A decline in both pastoral and arable/disturbance indicators occurs in the first half of the zone. Mid-zone, a small increase in *Plantago lanceolata* pollen commences, and occasional cereal-type grains are recorded in the upper half of the zone. The *Sphagnum* spore curve is constant throughout the zone, albeit at low values. Pteridophyte spores are at lower values than the previous zone. An increase in microscopic charcoal particles is seen, reaching maximum values of c. 40% TLP.

BB2-3: *Betula*-Poaceae-*Calluna*: -9 to -12cm below peat boundary.

In the uppermost zone *Betula* and *Corylus* increase to c. 35% and c. 20% TLP respectively. *Calluna* decreases from 30% to 10% TLP, and *Myrica* increases from negligible values to c. 10% TLP. Cyperaceae and Poaceae remain at their relatively depressed values of <5% and c. 20% TLP, which were established at the lower zone boundary. Percentage values for other herb pollen taxa are generally depressed, and decreases are seen in pastoral and arable/disturbance indicators also. *Sphagnum* spore values also fall temporarily, as do those of microscopic charcoal particles, but both are re-established by the top of the profile.

6.3.3.3 Pollen concentrations

With reference to Figure 6.11 it can be seen that, with the exception of the basal spectrum analysed, the spectra from the soil layer (**2004**) have higher fossil concentrations than those from the overlying peat (**2003**). Concentrations increase again in the upper part of the profile, the topmost pollen zone, BB2-3.

6.3.4 Soil micromorphology

6.3.4.1 Description of micromorphological features

The soil micromorphological features noted in the BB2 thin sections are presented in Table 6.10. A summary of the main microscopic features and their interpretation is presented in Table 6.11.

6.3.4.2 Description of soils and sediments

The features noted in thin section have been compared with the features noted from macroscopic examination, and combined to describe more fully the nature of the sediments.

*Context **2005***

This is a soil of low organic content. The mineral material is unsorted, the microstructure channel to intergrain channel, and the related distribution described as close porphyric.

*Context **2004***

The base of **2004** is distinguished by an accumulation of fines materials – silt and fine sand size grains. **2004** is patchy, with accumulations of well-sorted organo-mineral material including silt size grains, and patches of fresh parenchymatic plant material. There are occasional diatoms visible. The level of sorting of mineral material increases upwards in the profile, with the related distribution between materials of different size classes changing gradually from close porphyric at the base to open porphyric at the top of the context. The structure, although compact, is not massive, and the void spaces are a complex mixture of vughs and channels. At the top of the context the mineral material is described as unsorted. At the top of the context occasional phytoliths are present, though not in marked concentrations.

*Context **2003***

2003 is a typical peat with low mineral content and a spongy microstructure.

6.3.5 Interpretation

6.3.5.1 Pollen taphonomy

Regarding the possibility of differential preservation of palynomorphs between the soil and peat layers, indeterminate Pteropsida (monolete) spores form no more than 10% of the TLP count in the soil profile (Figure 6.9). This is around twice the maximum value of the same spores in the BB1 soil profile (see Section 6.2.5.1), perhaps indicating more severe pollen destruction in BB2 than in BB1. Total fossil concentrations fall toward the surface of the soil (Figure 6.11). In a typical sub-peat soil, pollen concentrations would be expected to rise towards the surface as the soil becomes more organic-rich. It is possible that mixing of the topsoil by ploughing occurred before peat accumulation. Soil from lower down in the profile, where pollen was less concentrated, would be mixed with relatively pollen-rich soil from the Ah or O horizon. Concentrations of indeterminate Pteropsida (monolete) spores also decrease towards the soil/peat interface, though rather more sharply than the decrease of total fossil concentrations. Superficially, this might indicate that differential preservation in favour of spores became less distinct towards the surface. However, the increased representation of Lactuceae towards the surface contradicts this. Lactuceae are extremely resistant to decay and the possible preferential preservation of this pollen type in the upper soil spectra suggests differential pollen decay. There are roughly the same numbers of pollen types present in the soil and the peat layers (55 and 57 respectively), which indicates that pollen was not preferentially lost from the soil. The contradictory signals regarding pollen preservation conditions in **2004** might result from a high degree of mixing, such as by ploughing.

6.3.5.2 Interpretation

The soil layer **2005** can be interpreted as the natural, unaltered soil, probably constituting the B horizon. As it is identical to the basal soil layer **1006** in BB1 (see Table 6.1), with a high sand content, the case is strengthened for its interpretation as originating from similar deposits to the compact sand overlying till in the BEL core and in other sediments downslope (Section 5.2.2.3, cf. Section 6.2.5.2). The transition to **2004** is marked by an accumulation of fines materials, but these are not compacted into pans or lenses. The abundance of root channels and preserved plant root material in **2004** indicates that the soil was vegetated. The presence of accumulated fines fraction material at the base of **2004** might be interpreted as an indication of ard tillage, based on comparable results from BB1 and the literature (see Section 6.2.5.2). This is especially pertinent given that ard-marks are visible in **2004** in plan (S. Caulfield pers. comm.). It must be noted that the author only examined the soil in section and could not identify such macro-scale features. The visible parts of **2004** in thin sections from K9 and K10 do not contain either macro- or microscopic evidence of tillage. The combination of these factors does not necessarily imply that tillage was not practiced at BB2. Just as an ard-mark was serendipitously sampled by K2 in BB1, sampling may have missed similar marks in BB2. Sampling strategies are believed to be responsible for the previous rarity of fines panning features in thin sections from tilled soils (Lewis 1998, 329). However, there is an absence in **2004** (K9 and K10) of other micromorphological indications of cultivation, such as variability in fine fraction material, evidence of mixing, and loosening relative to the underlying compacted horizon. The layer of compaction separating **2005** from **2004** may suggest that cultivation had been practiced (cf. the **1006/1005** interface: see Section 6.2.4 above).

The pollen profile from the soil spectra in BB2 (PAZ BB2-1) contains contradictory evidence in terms of preservation indicators (Section 6.3.5.1). The profiles (Figure 6.10) contain lower percentages of disturbance and arable indicators than are seen in the BB1 soil spectra (Figure 6.5), and only three cereal-type pollen grains are seen in BB2-1, with a further three at 1cm above the peat-soil transition layer. Similarly to the soil micromorphology, the pollen evidence from BB2 is equivocal with regards to interpreting the possible occurrence of tillage. Representation of pastoral indicator taxa is also generally low in BB2-1, and *Plantago lanceolata* pollen percentages increase at the transition to peat, which might reflect the vegetational changes associated with the recolonisation of formerly cultivated land (cf. Behre 1981, 228-229). Perhaps this soil was only subjected to limited short-term tillage, and post-abandonment pedogenic processes (both biological and eventual paludification) resulted in the disturbance and destruction of micromorphological tillage features. This would also account for the poor representation of arable indicators in the soil spectra.

6.4 Interpretation of BB1 and BB2 profiles with reference to the off-site investigations

The lowermost zones in BB1 and BB2 (which represent soils with macro- and microscopic scale evidence of cultivation) can be interpreted to record roughly the same chronological period. The evidence for their contemporaneity however is somewhat contradictory. The pollen profiles are similar, which suggests contemporaneity. However, the radiocarbon assays from the basal peat overlying the profiles are different and, despite that from BB1 falling into the mid-third millennium cal. BP calibration plateau, the 2σ error ranges of the assays do not overlap.

It has been accepted that the soil spectra will contain mixed-age pollen assemblages, and that their taphonomy is complicated by ploughing. The *terminus ante quem* of each soil pollen zone, together with an assessment of the levels of particular taxa present, can inform on the chronological span represented by the soil spectra. The pollen taxa most useful as chronological indicators in a mid- and late-Holocene context are *Ulmus* and *Pinus*, because of their well-defined declines (see Sections 2.2.1.3 and 2.2.3.4). In both PAZ BB1-1 and PAZ BB2-1, *Ulmus* is present only occasionally. This would indicate that the pollen content is derived from after the *Ulmus* decline of c. 6000 cal. BP. *Pinus* is present in low percentages in both profiles, in slightly higher frequencies in BB2 than BB1. There is the complicating factor of long-distance transport to be taken into account when interpreting the representation of *Pinus* in pollen profiles, hence there need not have been significant *Pinus* populations in the regional landscape as the soils accumulated. This further delimits the age of the pollen assemblages to between c. 4500 cal. BP (the *Pinus* decline) and c. 2800 cal. BP (the assay from basal peat in BB2).

The apparent upper age limit for pollen in the profile could be due to two factors. The first explanation relies on the eventual deterioration of all pollen grains. Using this argument, the soil profiles are seen to contain mixed-age pollen assemblages, but due to decay there is an absence of pollen older than c. 4500 cal. years. However, this might be considered unlikely. *Pinus* pollen grains in particular are robust and readily identifiable even if fragmented and/or deteriorated. The alternative explanation concerns the age and nature of the soil itself. If the soil itself were built up after c. 4500 cal. BP then it would contain pollen of that age also. Such a situation would occur if earlier soil had largely eroded. Erosion has been interpreted as occurring earlier, before peat expansion onto the Neolithic fields at c. 4930 cal. BP (see Section 5.2.2.3). The soil in the Bronze Age occupation area could have been subject to this erosion, which decreased in intensity after c. 4930 cal. BP. Less severe erosion still occurred after this date, as evidenced by the presence of mineral grains in the post-4930 cal. BP sediment sequences downslope (see Figure 5.2). The soil in BB1 and BB2 could have accumulated naturally, or been amended by the addition of soil removed from elsewhere. A similar situation is postulated for the Neolithic use of the fields (see Section 5.2.2.3). The soil removed from downslope of the field system (e.g. Transect cores E8 to E1: see Figures 5.1 and 5.2) is likely to have been used in the Neolithic occupation phase, because that area would have been covered by peat by the time of the Bronze Age occupation. Therefore, if additional soil was used to amend the profiles around BB1 and BB2, it would have to have come from elsewhere.

The soil profiles at BB1 and BB2 are at least 20cm and 10cm deep respectively (see Figures 6.2 and 6.7). Both of these are deeper than the soil profiles in the nearby Transect 2 cores (N9 to N17: see Figure 5.1) which contain between 1 and 10cm of sub-peat soils (see Appendix D). Interestingly, one of these profiles, N16, features a 10cm soil profile overlying an 8cm sand layer (see Appendix D). The survival of sand at this point perhaps confirms the above suggestion that this area of the hillslope was subjected to soil erosion prior to formation of the sub-peat soil profiles. That there is only limited evidence for amendment in the form of manuring in the later phase of agriculture, at BB1 (the spade and ridge cultivation) only, indicates that earlier amendment strategies were limited to addition of soil from elsewhere to the cultivated areas.

Having concluded that, although the calibration ranges for the basal peat radiocarbon ages do not overlap, the BB1 and BB2 pollen profiles were buried by peat at much the same time, and their ecological indications must now be examined. Considering the basal zones first, *Alnus* and *Betula* are dominant in both profiles, although the latter is more prolific than the former in the BB2 section, whereas the taxa are roughly co-dominant in BB1-1. *Corylus* is represented at c. 10% TLP in both sections, but *Quercus* is more abundant in BB2 than BB1. Poaceae are better represented in BB1. Other than these differences, the profiles record low, constant representations of pastoral and arable agriculture indicators, including cereal pollen grains. Such agricultural indicator taxa are best represented at the mineral soil/peat interface in both sections.

Interesting issues arise when the BB1 and BB2 soil pollen profiles are interpreted in terms of a dynamic landscape, by comparing their pollen content to that from the contemporary depths of the BEL core (4500 – 2800 cal. BP is represented in the BEL core at 228-121cm). High percentages of *Alnus* pollen are seen in the BB soil profiles but not the BEL core during this time, and *Betula* pollen peaks and declines between c. 4465 and c. 3725 cal. BP. Although it is acknowledged that the BB profiles contain mixed-age pollen assemblages, such high proportions of AP are not borne out by the BEL core, especially with respect to

Alnus. Whilst both *Betula* and *Alnus* grains are fairly resistant types which can be easily recognised as ghosts in a pollen preparation and thus might be over-represented, this differential is considered to be mainly a function of the different pollen source areas represented by those deposits at that time. In another landscape-scale study, profiles from upslope near archaeological monuments contained higher tree pollen percentages than those from downslope soil profiles and a downslope pond(Whittington & Edwards 1999, 596-597). This mirrors the situation in this study, where relatively high percentages of AP are present in the upslope soil profiles at times when the peat profile downslope (BEL) contains negligible AP values.

Both blanket bogs and soils are considered to have extremely localised pollen source areas, with local and extra-local components dominating the pollen assemblages (Sections 4.4.2.1, 5.4.6 and 6.2.5.1). The soil pollen profiles may therefore record late stands of woodland located nearby. Another unexpected feature of the soil pollen profiles is the lower than expected representation of cereal pollen and grains from arable weed taxa. Since macro-scale examination and thin section soil micromorphological analysis have confirmed cultivation of BB1 and possibly BB2, significant percentages of cereal pollen would be expected. However, cereal pollen is poorly represented because cereals, which are autogamous, are known to produce low quantities of pollen, and dispersal capacity is poor (Section 4.4.2.3). The picture becomes clearer and a sequence of landscape development can be unravelled.

Cultivation ceased earlier at BB2 than BB1, as short-lived ard tillage only is recorded in the former section. Cultivation at BB2 ceased prior to c. 2840 cal. BP. This may reflect the cessation of ard tillage at both locations, or a contraction of the spatial area of land which was tilled. At this point, the pollen assemblages of the soil horizons in the BB profiles represent the vegetation cover of the immediate locality, and an extra-local component. The extra-local component was largely derived from pastoral land and blanket bog vegetation surrounding the cultivated areas. Within this component, Poaceae dominated over *Calluna* and other Ericaceae from the blanket bog vegetation, largely as a result of the low dispersal capacity of entomophilous Ericaceae pollen, especially in comparison to the wind-dispersed Poaceae (Evans & Moore 1985). The appearance of *Calluna* in a pollen profile is usually considered to reflect local presence of the taxon (ibid.). The extra-local component is also represented by the high values of *Betula* and, to a lesser degree, *Alnus* pollen, which originated from late survival of stands of woodland nearby. The cereal pollen recorded in the soil spectra at BB2 is interpreted as representing the ard tillage evident in macroscopic scale at BB1 and BB2, and in microscopic scale at BB1. Whilst this tillage may have been short-lived at BB2 and ended there before c. 2840 cal. BP, its duration and the date of its cessation at BB1 is unknown, as a result of the superimposition of the ridges and furrows. At some point the cultivation practices changed at BB1 from ard tillage to spade and ridge.

From c. 2840 cal. BP, as cultivation ceased at the BB2 location, blanket peat slowly accumulated over the former agricultural soil. This coincided with the decline of woodland in the locality registered by the decreases in *Alnus*, *Betula* and *Quercus*. The different taphonomic processes operating upon pollen assemblages in the two depositional environments caused different components of the landscape to be recorded in the palynological profile. Blanket bog profiles chiefly record the local component, especially the non-arboreal pollen fraction of the profile (see Sections 4.4.2.1 and 5.4.6), hence the dominance of Poaceae and *Calluna*. In particular, the swamping effect of the presence of *Calluna* at the sampling location reduced the contribution of the extra-local components of the pollen rain to the pollen assemblage. Elevated Cyperaceae percentages and the continuous *Sphagnum* curve are further indicators of establishment of blanket bog vegetation. For a short period (-1 to -7cm), no cereal grains and few arable weeds or disturbance indicators were recorded in BB2. This may represent a brief period of abandonment or a decline in the level of agricultural intensity. In the peat initiation layer, *Plantago lanceolata* and Lactuceae percentages peak, however, which could record either the recolonisation of former arable land by pioneer taxa (Behre 1981, 228-229) or turning over the land to grazing. An increase and persistence in microscopic charcoal values would tend to favour the latter interpretation, rather than a total cessation of activity. Furthermore, the soil micromorphological analysis suggests only a brief period occurred in between the ard tillage and the spade and ridge cultivation of BB1. Elevated *Betula* and *Corylus* values in the upper spectra of the BB2 profile may represent a resurgence of scrubland from the extra-local contribution to the pollen assemblage. It is noteworthy that *Alnus* percentages remain depressed, indicating that any regenerated scrubland was of a different ecotype to that recorded in the soil pollen spectra.

Pastoral and arable agricultural indicator pollen taxa are better represented in the BB1 soil section than in the BB2 soil section. This supports the macroscopic evidence that indicates cultivation occurred for longer at this location. Indeed, cereal pollen grains are present in the basal peat spectrum at BB1, suggesting that cultivation continued as peat began to accumulate. Similarly to the situation in BB2, the transition to blanket peat at the sampling site is accompanied by a change in pollen taphonomy and landscape component representation, and the local component, the blanket bog taxa *Calluna* and Poaceae, dominates the pollen assemblage. The BB1 profile ends before the resurgence of *Betula* and *Corylus* recorded in BB2-3.

Chapter 7

Interpretation: Significance of the results from Belderg Beg

7.1 Introduction

This chapter offers a comprehensive integration of the results assembled in the two previous chapters. Firstly, the on- and off-site results will be compared and combined to formulate a wider interpretation. The new information provided by this investigation is then used to assess previously held theories regarding the occupation and agricultural regime of the site. The evidence from Belderg Beg will then be compared to existing knowledge of prehistoric occupation and agriculture in the area. This will allow an assessment of the consequences of this additional evidence for our understanding of the prehistory of North Mayo. The site is placed in its broader regional context, by assessing it in comparison with western Irish evidence of prehistoric settlement and agriculture. Finally, the wider context is studied, by considering what this investigation has discovered about the marginality of later prehistoric societies of the Northern Atlantic fringe.

7.2 Integration of site results

7.2.1 Settlement history

7.2.1.1 Chronology

A major aim of this investigation was to refine existing knowledge of the sequence of prehistoric occupation at Belderg Beg (see Section 1.1.1). A linear age/depth profile (see Figure 5.8) has allowed secure interpolation of dates in order to estimate the internal chronology of the BEL profile. The palynological record is therefore used as a basis for identification of the phases of occupation and agriculture.

Due to the date of peat initiation, only limited new evidence pertaining to the chronology of the Neolithic occupation phase has been forthcoming. Peat accumulation did not commence early enough to palynologically recognise the start of activity. The date of abandonment has, however, been refined to c. 5375 cal. BP. Following this, human activity was much reduced for more than a millennium. The chronology of Bronze Age occupation is more complex. The three pollen profiles (BEL, BB1 and BB2) provide evidence of activity for almost the entire span of the Bronze Age, from c. 4100 cal. BP to the mid-third millennium cal. BP. Initial re-occupation commenced at c. 4100 cal. BP, with mixed agriculture recorded palynologically in the BEL profile (Figure 5.18). At c. 3400 cal. BP, the roundhouse was constructed and oak stakes used to extend Wall 3 (see Figure 3.4). This phase of activity is registered in the BEL profile until c. 3060 cal. BP. However, whilst the BEL profile records abandonment or a decline in human activity at c. 3060 cal. BP, the BB2 profile records cessation of arable agriculture at c. 2840 cal. BP, with pastoral activity continuing (Figure 6.9). In the BEL core, further evidence for agriculture is recorded again from c. 2775 cal. BP, lasting until c. 2600 cal. BP (Figure 5.18 & Section 5.4.5). The cultivation ridges in the BB1 section were apparently in use until they were overwhelmed by blanket peat in the mid-third millennium cal. BP (Figure 6.4). In addition, one particular taxon in the BEL core may be of use in deconstructing the phasing of settlement and agriculture. *Pteridium aquilinum* is considered indicative of the recolonisation of fallow land, hence it is used to identify both abandonment and agricultural phases which included fallow phases between cycles of arable cultivation (Behre 1981).

The chronological evidence from the three pollen profiles with regard to Bronze Age agricultural activity may be summarised as follows:

- The general signal of pastoral and arable/disturbance indicators in the BEL core identifies mixed agricultural phases between c. 4100 – 3060 cal. BP and c. 1935 – 1600 cal. BP
- Less definitively, pastoral and arable/disturbance pollen indicators in the BEL core suggest an additional phase of mixed agriculture at c. 2775 – 2600 cal. BP and pastoral agriculture from c. 2600 to c. 2400 cal. BP.
- In this context, the *Pteridium aquilinum* profile in the BEL core (Figure 5.18) clearly identifies three main phases of post-Neolithic, pre-modern agriculture: from c. 4100 – 3250 cal. BP, from c. 2775 – 2450 cal. BP and from c. 1940 – 1775 cal. BP.
- The BB2 section records a short-lived phase of mixed agriculture which ceased at this location at c. 2840 cal. BP. Agriculture continued elsewhere, as pastoral activity is recorded in the peat overlying the soil section.
- The BB1 section records cessation of a phase of mixed agriculture in the mid-third millennium cal. BP.

These results are displayed in Figure 7.1. This suggests that there were two main phases of activity within the Bronze Age. The general chronology of settlement is summarised thus:

1. Neolithic occupation, utilising the field system including Walls 1 and 2, which was abandoned at c. 5375 cal. BP
2. Bronze Age occupation from c. 4110 – 3060 cal. BP. This main period of occupation may have consisted of shorter, discrete phases of settlement and abandonment. This phase included the roundhouse construction and extension of Wall 3 with oak stakes, both at c. 3400 cal. BP.
3. Late Bronze Age occupation in the first half of the third millennium cal. BP. This period may have consisted of shorter sub-phases of occupation.
4. Iron Age activity from c. 1940 – 1600 cal. BP.

The question remains as to whether the area was totally abandoned between c. 3060 cal. BP and the start of the agricultural activity which ceased at c. 2840 cal. BP. Perhaps agricultural reorganisation occurred at c. 3060 cal. BP in response to a reduction in good quality soil availability (due to peat expansion) and cultivation was concentrated thereafter in the ard-marked area close to the roundhouse. Considering the poor dispersal of cereal pollen (see Section 4.4.2.3) cereal cultivation at such a distance from the BEL core (see Figure 5.1) might not necessarily be expected to register in the BEL palynological profile. However, continued representation of other palynological indications of agricultural activity *would* be expected, such as *Plantago lanceolata*, *Rumex* and *Pteridium aquilinum*. These taxa are all much reduced, occurring sporadically if at all between c. 3050 and c. 2850 cal. BP (136 to 124cm) in the BEL profile. Therefore, cessation of agricultural activity is suggested.

The brief phase of cultivation recorded in the BB2 profile at c. 2840 cal. BP (Section 6.3.5.2) is not particularly marked by palynological indications of agriculture in the BEL core. A cereal pollen grain is recorded at c. 2710 cal. BP, contemporary with the appearance of the arable/disturbance indicator *Plantago major/media* and a small peak of *P. lanceolata*. The BB2 pollen profile suggests that the intensity of arable agricultural activity was reduced for a brief period after c. 2840 cal. BP. However, considering poor dispersal rates of cereal pollen grains, cultivation did not necessarily cease at this time. There is no evidence for a significant hiatus between the ard tillage and ridge-and-furrow cultivation phases at BB1. Between the phases, pastoral indicators are at low levels, remaining so even during the phase associated with the reappearance of cereal pollen grains (see Figure 6.9).

These results are further discussed below (section 7.2.2) in the context of agricultural dynamics, in an attempt to uncover the nature of the agriculture that was undertaken. They are also discussed in Sections 7.3.1 and 7.3.2 in terms of the regional evidence of prehistoric settlement and agriculture.

7.2.1.2 Geochemical evidence

The geochemical record of the BEL profile (Figure 5.15) does not contain evidence of any periods of enhanced copper deposition onto the mire surface. This suggests that there was no prehistoric exploitation of the chalcopyrite seam at the Horse Island cliffs. Whilst this could be a false indication, as the sampling location is some 2 km distant from the copper vein, there is no other evidence of copper working in the palaeoenvironmental or archaeological record at Belderg Beg. Such evidence might be expected to consist of particularly high quantities of microscopic charcoal in the palaeoenvironmental record, reflecting increased burning from fire-setting at the ore face, or artefactual evidence of copper smelting or working. Despite the widespread blanket peat limiting the availability of agricultural land, it appears that Bronze Age occupation was not concerned with copper exploitation and therefore occurred for alternative reasons.

7.2.2 Agricultural dynamics

7.2.2.1 Pollen analysis

Neolithic agriculture

The herb taxa present in the basal levels of the BEL core (Figure 5.18) are indicative of a pastoral agricultural regime during the Neolithic occupation. High levels of Poaceae and moderate representation of *Plantago lanceolata*, with occasional *Rumex* grains, indicate that the fields in the vicinity of the BEL core (i.e. the land enclosed by Wall 1; see Figure 5.1) were used for stock grazing. The sporadic occurrence of disturbance indicators *Urtica* and *Polygonum aviculare* suggest that there may have been a minor arable component. However, cereal-type pollen grains, which would more definitively indicate arable agriculture, were not discovered. The economic position of cereals in the Neolithic of western Ireland, linked to the level of arable agriculture, has been debated using palynological evidence (e.g.

O'Connell & Molloy 2001). The economic importance of cereal cultivation in the Neolithic of the British Isles as a whole has been more widely discussed (e.g. Richmond 1999). This issue is returned to below in Sections 7.3.1.2, 7.2.4.2 and 7.4.1.

Bronze Age agriculture

The following appraisal of the chronology of Bronze Age agriculture is made with reference to Figure 7.1. There is firm evidence for cereal cultivation in the Bronze Age occupation. In the palynological record of the BEL core, the first cereal-type pollen grain is recorded at c. 4045 cal. BP, approximately at the start of the main Bronze Age phase of occupation and agriculture. This is followed by an apparent hiatus in arable evidence, and significant numbers of cereal-type grains and arable weed taxa are recorded from c. 3775 cal. BP. Mixed agriculture continues to be evidenced palynologically in the BEL profile until c. 3060 cal. BP.

Ideally, in a pollen profile from a buried agricultural soil certain features could be used to elicit further information pertaining to the nature of the arable regime. Cereal pollen grains can potentially be identified to type level (see Appendix C), to provide information on the main crop grown. However this is not always possible due to the preservation quality of the grain, or an inability to identify sufficient diagnostic features. The suite of herb taxa may also identify agricultural practices, such as the season in which crops were grown and harvested (Behre 1981). High percentages of *Urtica* pollen are commonly found in dung-heaps (Vorren 1981, 3). The use of animal dung or bedding as manure may be indicated by very high values of this taxon in a palaeosol. Similarly low percentages of cereal-type pollen to those in the BB sections are known in other buried soils which have been identified as formerly cultivated, and in such situations the herb flora have proved useful indicators of former agricultural regimes (e.g. Sageidet 2005).

The dimensions of, and notes on, each cereal-type pollen grain from the BEL core and BB1 and BB2 profiles are presented in Tables 5.5, 6.3 and 6.6. The cereal-type pollen grains from depths in the BEL core corresponding to the prehistoric settlement phases (196 – 92cm) are all of *Hordeum* (barley) type, with the exception of one probably *Avena-Triticum* (oat or wheat) type and one indeterminate grain. Cereal-type pollen grains in the lower levels of the BB2 core (2cm to -1cm), corresponding to the end of one phase of Bronze Age occupation are also of *Hordeum* type, with the exception of one indeterminate grain. This grain, found at

1cm below the peat/mineral soil interface, is larger than the average for *Hordeum* type grains mounted in silicone oil (Andersen 1979), but its annulus diameter and surface sculpturing are typical of *Hordeum* type pollen rather than *Avena-Triticum* type. The cereal-type pollen assemblage from the upper spectra of the BB2 profile (-7 to -10cm below the peat/mineral soil interface) is represented by two grains each of *Hordeum* and *Avena-Triticum* types. It is suggested above (Section 6.4) that these spectra are equivalent to the lowermost cereal grains recorded in the BB1 section (-1 to 9cm below peat/mineral soil interface). All of these grains in the BB1 section are classified into the *Hordeum* type. This suggests that barley was the sole or main crop. The presence of two *Avena-Triticum* type pollen grains in BB2 should not be taken to indicate the cultivation of wheat or oats as a secondary crop; occasional grains are likely to represent the presence of the taxon as a weed. In many prehistoric macrofossil assemblages, the occasional occurrence of unexpected cereal taxa (usually oat or rye) is explained as its presence as a weed (e.g. Boyd 1988, 104; Greig 1991, 305) and similar interpretations have been applied to isolated 'anomalous' cereal pollen types in assemblages located in or near agricultural soils (e.g. Sageidet 2005, 67).

The combined cereal-type pollen evidence from all three cores suggests that barley was the principal or sole arable crop cultivated at Belderg Beg in all prehistoric occupation phases. Relatively high percentages of *Plantago lanceolata* in the soil spectra of the BB1 profile might be taken to indicate ley agriculture, as this taxon characteristically colonises former agricultural land, and in pollen profiles is commonly identified as an indicator of ley farming (Behre 1981).

7.2.2.2 Soil micromorphology

Interpretations of the BB1 and BB2 sections in terms of pedogenesis and agriculture, based on the features noted in thin section soil micromorphological analysis (see Tables 6.4 and 6.8), are presented in Tables 6.5 and 6.9 respectively and discussed in Sections 6.2.5 and 6.3.5.

Repeated cultivation is evident and is most marked in the BB1 section. Use of an ard to work the soil is apparent both in plan (Caulfield pers. comm.) and in thin section (see Plate 6.13). Leaching and amendment suggests that significant efforts were made to work the soil. The macroscopic and microscopic features of Section BB1 suggest that two phases of agriculture are represented by this profile, separated chronologically by a brief intermission. Both phases are considered to have occurred in the Bronze Age, because the interlude was brief in comparison to the considerable gap evident between Neolithic and Bronze Age agriculture. In the latter case, abandonment lasted from c. 5375 to c. 4110 cal. BP.

The textural features identified as indicative of arable agricultural activity are the fines lenses and the dusty clay infills and coatings. The latter, occurring only in **1005**, are typical of disturbance, including that associated with cultivation activity (Courty *et al* 1989, 132; Macphail *et al* 1990, 56). The fines pans and lenses in **1005** and **1004** are a particularly interesting relic characteristic of ard tillage. Similar features have been noted in archaeological and experimental ard-worked soils (Lewis 1998). Evidence of amendment strategies employed to improve soil quality and thereby crop yields consists of the Calcium-Iron-Phosphate (Ca-Fe-P) infills (**1004**) and the rubified minerals evident in OIL (**1004** and to a lesser extent **1005**).

A generalised picture of changing agricultural strategies is thus formed. The first agricultural phase represented in the soil sections is one of ard tillage. It is recorded in both BB1 and BB2, but had a longer duration in the former than the latter. Barley was grown and it is possible that some ash was added to the soils to improve fertility, which was compromised as nutrients were leached. It is not evident from the soil profiles precisely when this phase was abandoned, as the only available radiocarbon age providing a *terminus ante quem* for cessation is from BB2, which was evidently tilled for a shorter period than BB1. It is therefore unclear when BB2 was abandoned relative to the abandonment of BB1. As discussed above (Section 7.2.1.1) comparison with the BEL palynological profile suggests that the BB2 tillage occurred during the final phase of ard tillage at BB1. This possibly represents a last attempt to increase arable production, ending just prior to c. 2840 cal. BP.

Pastoral activity and probably arable cultivation continued, and at some point the second phase of activity at BB1 commenced. This phase consisted of cultivation of the ridge-and-furrow plots which are evident in plan and in section in the vicinity of the roundhouse, reworked in different chronological stages. It is possible that a spade was used to till the ridge-and-furrow plots, but this is not definitively indicated by the soil micromorphological features. Again, barley was cultivated. This agricultural phase ended at some time during the radiocarbon calibration plateau in the mid-third millennium cal. BP.

7.2.3 The environment and occupation of Belderg Beg

Table 7.1 presents a schematic account, from the data obtained in this thesis and in previous studies, of the chronology, palaeoenvironment, occupation and agricultural dynamics at Belderg Beg from c. 5500 cal. BP until present. This section describes how the landscape at and around Belderg Beg looked, as reconstructed from the analyses of this thesis and previous investigations.

7.2.3.1 The Neolithic (c. 6000 – 4300 cal. BP)

Agriculture and landscape

In line with other Neolithic agricultural sites in the North Mayo region, farming is assumed to have commenced at Belderg Beg in the centuries following the *Ulmus* decline of c. 5800-5900 cal. BP. The largest-scale fields known at present (Walls 1 and 2: see Figure 5.1) relate to this period of agriculture. It was evidently primarily pastoral in nature, although there was probably a minor arable component to the economy (see Sections 7.2.4.2 and 7.3.1.2). This agriculture took place within a disturbed landscape, although full woodland clearance beyond the extent of the field system did not occur. The wider landscape around the Belderg Beg farm in the Neolithic occupation phase was highly differentiated. The sub-peat walls on the Belderg Mór hill (see Figure 2.6 for location) have been assigned to the Neolithic by Caulfield *et al* (1998, 639), on the basis of subfossil *Pinus* stumps in blanket peat overlying the walls and the soils upon which they were constructed. The Belderg Valley therefore contained at least two stone-walled field systems. Whether those field systems could be described as individual farmsteads is unknown, due to the absence of sufficient landscape-scale surveying of sub-peat field walls. The presence of a court tomb on the Belderg Mór hill (see Figure 3.1) suggests a substantial Neolithic population (see Cooney & Grogan 1999, 53). The interpretation is that the Belderg Valley was a differentiated landscape home to communities occupying discrete farmsteads, but which were linked to one another in other ways.

Vegetation

Damp organic sediments were present on the lower valley slopes. In areas with sufficiently developed sediment, fen carr communities were present, whereas damp-loving tall-herb communities and marshland existed in areas of thinner soils. Blanket peat was already accumulating on the upper plateaux (Caulfield *et al* 1998, 638). Woodland patches existed in edaphically suitable locations which had not been subject to anthropogenic clearance.

An organic detrital sediment began to accumulate at the location of the BEL core at c. 5525 cal. BP, chiefly a natural development of acidified soils, but perhaps accelerated by increasing runoff from the open agricultural land upslope. Soil within the fields was subjected to erosion and sediment banked up against the terminal downslope field walls. In the continuingly relatively dry climatic regime, the sandy soils became droughty and easily leached. Soils from below the field system were removed to supplement soil profiles within the fields. Edaphic conditions became increasingly marginal for the agricultural regime, and at c. 5375 the field system was abandoned. After abandonment, erosion may have continued for some time, due to the absence of management techniques (see Lewis 1988, 46). Woodland became rapidly re-established, consisting of *Alnus* carr in the area of wetter soils downslope of the fields, and mixed woodland with *Betula*, *Corylus*, *Quercus* and *Pinus* elsewhere in the valley, on drier soils.

Hydrology and climate

There are two main phases of hydrological and climatic change recognised within this period, at c. 5170 – 4850 cal. BP and c. 4550 – 4495 cal. BP. As well as climatically-induced rainfall fluctuations (temperature induced reductions in evaporation as well as increasing precipitation rates), the ecological and hydrological status of a mire, its topographical location and its vegetation may significantly affect its surface wetness and post-depositional internal dynamics (see above, section 3.4.4.2). In this study, the pollen and geochemical profiles provide a check on the humification signal.

The c. 5170-4850 cal. BP wet shift was characterised by a change from an organic sediment developing into a fen peat capable of supporting trees (section 5.2.3). The hydrophilic tree *Alnus* was the main beneficiary of these ecological changes and would have grown on the fen surface. This shift is likely to have been inevitable as soil acidification is suggested to have been commenced in the early Holocene in Ireland, causing the development of blanket peat in vulnerable locations. However, the precise timing of pedogenic change varied from location to location and at Belderg Beg there were apparently two driving forces which caused the development of fen peat at this particular time. The first factor was climate; as discussed above, the period from c. 6000-5000 cal. BP was relatively dry in the North Atlantic, with a more continental climatic regime (Section 2.3.4.1) and the transition to presumably averagely wet climatic conditions at c. 5000 cal. BP coincides with increased surface wetness at Belderg Beg. The beginning of farming at Belderg may have accelerated this pedogenic process *via* increased run-off from agricultural fields upslope.

The wet phase at Belderg Beg at c. 4550-4495 cal. BP coincides with generally well-recognised regional indications of climatic wetness. It is expressed in lesser magnitude in the Belderg Beg humification curve than the preceding wet phase. This wet period is associated with a pronounced change in the sedimentary environment at c. 4450 cal. BP when the fen carr below the (by then disused) field system experienced a major change in floristic composition. *Alnus* was replaced by *Betula* as the chief mire-dwelling species, with open ground represented by the increasing Poaceae and Cyperaceae pollen curves. At c. 4370 cal. BP *Betula* increased in representation, becoming dominant on the mire surface. Vegetational change in the wider landscape is evident also, in the form of general woodland decline indicated by decreases in all non-mire-dwelling woodland taxa to background representation only. Human activity is not registered in the palynological record at this point. Climatic change, also causing the *Pinus* decline (Section 2.2.3.4), is interpreted as the trigger.

7.2.3.2 The Early Bronze Age (c. 4300 – 3700 cal. BP)

Agriculture and landscape

Secondary clearance aided by fire occurred between c. 4100 and c. 4000 cal. BP, affecting the mire-dwelling *Betula*. This clearance took place in the context of reoccupation for agriculture. Following clearance, there was a temporary re-establishment of *Betula* on the mire surfaces, but the taxon commenced its final decline at c. 3945 cal. BP. Agriculture practiced from this date onwards was primarily pastoral, but the presence of cereal-type pollen grains and arable weed taxa indicate that a minor arable element was present in the economy. In PAZ BEL-5a (c. 3950 - 3700 cal. BP), Poaceae pollen percentages are at their highest levels in the profile. This suggests that pastoral farming was at its most spatially extensive during that phase of time. This is interpreted as a local phenomenon, relating to the Belderg Beg farmstead. There are no other known farmsteads of an equivalent age in the Belderg Valley, although the presence of a wedge tomb on the apex of the Belderg Mór hill (see Figure 3.1) indicates a significant human population existed at the time of its construction. The earliest wedge tombs date to the Late Neolithic, but their construction continued well into the Bronze Age (Cooney & Grogan 1999, 53). The Belderg Valley was abandoned during the Late Neolithic (see Section 7.2.1.1); therefore a Bronze Age construction date can be suggested for the Belderg Mór wedge tomb.

Vegetation

The low AP percentages, including the decline in *Betula*, suggest that the coverage of scrubland in the wider landscape progressively declined, probably due to blanket peat expansion. Maintenance of open landscapes by Early Bronze Age farmers has been identified as the chief causal factor in Atlantic blanket bog expansion (O'Connell 1990a). Peat had expanded upslope to roughly the altitude of the modern road. The local presence of *Calluna vulgaris* at the BEL location is highlighted by the commencement of a constant curve in the pollen profile as herb peat began to replace wood peat.

Hydrology and climate

The geochemical and humification records both suggest that the climate was more than averagely wet during the Early Bronze Age. The complicating factor of increased run-off *via* woodland clearance from c. 4100 cal. BP could cause the humification curve to record increased surface wetness. The change in BEL sediment stratigraphy from wood to herb peat further complicates interpretation of its humification signal. The Early Bronze Age was evidently a pivotal point in landscape history as blanket peat rapidly expanded over the hillslope and the nature of vegetation drastically changed from carr and scrub to blanket bog taxa.

7.2.3.3 The Middle Bronze Age (c. 3700 – 3200 cal. BP)

Agriculture and landscape

Construction of the roundhouse and the extension of Wall 3 with oak stakes occurred at c. 3400 cal. BP, in this phase of activity. A continuation of the mixed agriculture throughout subzone BEL-5b (c. 3725-3460 cal. BP) is seen in the pastoral and disturbance indicator curves. Cereal-type pollen are better represented in this phase than the Early Bronze Age, suggesting that the farmstead reorganisation associated with Wall 3 extension and roundhouse construction may have been part of a general agricultural reorganisation centred upon the intensification of arable cultivation.

Vegetation

The increases in *Sphagnum* and *Calluna vulgaris* at c. 3725 cal. BP (180 cm in BEL), when taken in conjunction with the sedimentological transition from wood peat to herbaceous peat, signalled a shift from fen peat to blanket bog in the vicinity of the sampling area in the Early Bronze Age. By c. 3725 cal. BP, blanket bog had expanded upslope to approximately the altitude of the modern road; the basal peat at W21 is assayed to c. 4040 cal. BP (see Figure 5.1 and Table 5.1). The modification or re-organisation of the farmstead (see above) occurred within a changing landscape that was being covered by blanket peat. However, there was a significant delay between peat development below the modern road and above it, which is highlighted by comparing the age of basal peat at W21 with that at N10 (see Figure 5.1 and Table 5.1). This may indicate that the farmers in the intervening timespan took measures to retard peat expansion. Such strategies may have consisted of drainage ditch construction, removal of peaty turves (which may have then been burnt as fuel), or amendment by addition of manures to increase fertility or mineral matter to inhibit paludification.

Hydrology and climate

In the Middle Bronze Age the proxies at Belderg give conflicting palaeoclimatic indications. The geochemical record indicates maximum oceanic influence, whilst the humification record suggests a shift to relatively dry surface conditions. This suggests that there was minimal groundwater influence in this phase, and that rainfall supplied the vast majority of water to (at least the lower slopes of) the bog. Surface run-off may have declined as a consequence of strategies to inhibit peat spread, possibly linked to land management techniques associated with agricultural reorganisation (see above).

7.2.3.4 The Late Bronze Age (c. 3200 – 2550 cal. BP)

Agriculture and landscape

In the BB2 core, cessation of agricultural activity is dated to just above the basal peat layer, at c. 2840 cal. BP. The 2σ range, 2930 - 2750 cal. BP, correlates to around 124cm in the BEL core. In the BB1 core, similar cessation is dated to the boundary between the rig-and-furrow horizon and the earliest overlying peat, at c. 2540 cal. BP, with a 2σ range of 2725 - 2355 cal. BP. These ranges are considerably later than the estimate of agricultural cessation in the vicinity of the BEL core. A contraction of agricultural activity is perhaps signified. At c. 3060 cal. BP, when cultivation ceased to be recorded in the BEL profile, blanket peat was already established upslope at the W21P coring location (see Figure 5.1). The only peat-free areas appeared to be those at approximately the altitude of the roundhouse (i.e. the BB1 and BB2 sections and the N10P coring location: see Figure 5.1). Cultivation is less likely to be recorded in the highly localised pollen source area represented in the BEL profile at this point as the blanket bog was well established.

Vegetation

Although blanket peat covered most of the landscape by the Late Bronze Age, the significant proportions of tree pollen in the BB soil profiles indicates that limited stands of woodland survived in the area until c. 2800 cal. BP. The evidence of final woodland demise, added to that of contemporary severe erosion (below) is suggestive of landscape deterioration in terms of suitability for agriculture.

Hydrology and climate

Soil profiles BB1 and BB2 consist of relatively nutrient-poor, sandy soils that were only capable of sustaining repeated cultivation with significant amendment techniques employed. The agricultural soils were easily eroded at Belderg Beg in the Neolithic, and the multiple layers of inwashed mineral grains evident in the Transect 1 sediment-stratigraphic record (see Appendix D) indicates that this was the case in later agricultural phases also. One particularly clear inwash layer was assayed to c. 2860 cal. BP, showing that erosion was especially severe at that date. As this corresponds to abandonment of tillage and peat development at BB2, an interpretation of severely unfavourable edaphic conditions is made.

The increase in erosion is interpreted as resulting from a phase of extreme climatic storminess. Such storminess episodes have been associated with phases of rapid climatic flux (e.g. Dawson *et al* 2003, 391; Caseldine *et al* 2005) and the Later Bronze Age, particularly the century centred on c. 2850 cal. BP, is identified as such a period of rapid climate change and northern hemisphere atmospheric reorganisation (see Section 2.3.4.3; Kilian *et al* 1995; van Geel *et al* 1998) recognised in many peat-based palaeoclimatic reconstructions (e.g. Mauquoy & Barber 1999a; Barber *et al* 2003; Langdon *et al* 2003).

7.2.4 Comparison with previous landscape narratives

The following sections summarise current assumptions or theories based on existing data pertaining to the archaeological and palaeoenvironmental history of Belderg Beg, and provide a discussion of how the results obtained in this investigation compare with those conclusions.

7.2.4.1 Earliest occupation

Initial occupation at Belderg Beg has never been satisfactorily dated, owing to the nature of material selected for dating in previous studies. Although Mitchell & Ryan (2001, 206) preferred a Later Neolithic date of c. 4500 cal BP for the first recognisable human activity, absolute dates have suggested otherwise. A *terminus ante quem* of c. 5145 cal. BP from a sub-peat pine rooted in mineral soil near a supposedly Neolithic wall (see Figure 5.1) has hitherto been the most precise dating evidence (Caulfield *et al* 1998, 633-634).

Due to the absence of peat growth at a sufficiently early stage the current investigation has failed to provide any firm evidence pinpointing when Neolithic agricultural activity began. Although it is impossible to ascertain that there is no earlier blanket peat located on the Belderg Beg hillslope, an extensive programme of probing and Eijelkamp coring located the deepest peat known within the vicinity of the archaeological remains and, crucially, the location with the most complete sediment stratigraphy including till, sand, thin organic detrital sediment and various layers of peat. The combinations of stratigraphic complexity and greatest depth suggest that this location (the BEL core) should contain the earliest peat sufficiently close to the archaeological remains to have received any palynological signals of human activity. The BEL pollen profile starts with an open environment including pastoral, and probably some arable, agriculture. The dating of the opening of the BEL profile to c.

5525 cal. BP provides an earlier *terminus ante quem* for the beginning of Neolithic agriculture at Belderg Beg than that which was obtained from the pine stump upslope (see Caulfield *et al* 1998). A date for initial activity within the Early Neolithic (6000 – 5500 cal. BP: see Section 2.2.2) is suggested.

The absence of indications of peat growth before this significant period of agricultural activity is in itself interesting and informative. Increasing erosion and run-off from agricultural activity is concluded to have triggered or enhanced peat development (see Section 7.2.3.1 above). The regional significance of the timing of peat initiation is discussed further in Section 7.3.1.1 below.

7.2.4.2 Nature of Neolithic agriculture

Prior to this investigation, all that was known about the nature of Neolithic agriculture at Belderg Beg was that stone walls had been constructed around irregularly shaped fields, forming a field system of unknown size. The individual fields were demonstrably smaller than those at Céide Fields, and the layout was apparently less regular (Molloy & O'Connell 1995, 190). The former extent of the field system is unknown due to modern construction, but was assumed to have been much smaller than Céide Fields (ibid.; Caulfield 1978, 140). As this study did not involve excavation or probing large areas, further estimations that can be made regarding the spatial extent of the agriculture can only be derived from the degree of landscape openness indicated in the pollen record. Walls 1 and 2 (see Figure 5.1) are argued to have acted as field walls in the Neolithic agricultural phase. The BEL pollen profile during this time records significant percentages of tree pollen (Figures 5.16 – 5.18). This suggests that the surrounding landscape was not completely open and that significant areas of woodland remained within the extra-local as well as the regional pollen source area.

Percentages of AP in the levels of the BEL core corresponding to Neolithic agriculture (PAZ BEL-1), c. 60% TLP (see Figure 5.16), are higher than those in the most intensive phase of Neolithic agriculture at Céide Fields (c. 20%: see Figure 2.3). As the environment at Céide Fields is considered to have been very open over a wide geographical area at that time (see Molloy & O'Connell 1995; Caulfield *et al* 1998), the comparisons of AP content suggest that the Belderg Beg field system must have been much smaller than that at Céide Fields in the Neolithic phase of activity. However, if the swamping effect of *Alnus* is removed from the BEL calculations, AP contributes 20% to the TLP total at that time (see Figure 5.17), a figure comparable to the Céide Fields percentages. As *Alnus* is likely to have been present in the wider landscape and not just at the locality of the BEL core, perhaps the interpretation of an open landscape comparable to that at Céide Fields is an unrealistic assumption. Nevertheless, the presence of a field system on the other side of the Belderg Valley at Belderg Mór suggests that a reasonably large farmed landscape existed in the Neolithic. This issue is considered further in Section 7.3.1.2.

Although no firm stratigraphic evidence relating to the ard-marked layer of soil near the roundhouse was forthcoming *via* excavation (Caulfield 1978), these features (see Figure 5.1) have previously been tentatively assumed to date to the Neolithic occupation (Molloy & O'Connell 1995, 191; Caulfield pers. comm.). The main supporting evidence for this hypothesis is stratigraphic: the ard-marks are present not only beneath the area covered by cultivation ridges but also outside it (see Figure 5.1). This has been assumed to indicate that the ard-marks and cultivation ridges relate to different agricultural phases (Caulfield 1974: see Appendix B).

Thin section soil micromorphological analysis does not support this hypothesis. Firstly, in the BB1 section, there is no evidence of a significant distinction between the ard-marked soil and the overlying ridged layer which would signal a considerable intervening period of abandonment. If such a period of agricultural inactivity were present, certain features would be expected in the thin sections at the boundary between the layers; principally evidence for grassland with increased vegetation cover, perhaps indicated by an increased concentration of phytoliths. No such features were identified. The conclusion is that there was no significant break in activity associated with the change in cultivation technique from ard to ridge-and-furrow tillage.

Neolithic agriculture at Céide Fields (and elsewhere in North Mayo) has been described as predominantly pastoral with a small but significant cereal component (see Molloy & O'Connell 1995; O'Connell & Molloy 2001). An arable component to the productive economy at Belderg Beg is signified by the ard-marked soil layer (Caulfield 1978, 140) but the present investigator considers that layer to represent Bronze Age activity. The palynological profile at BEL produced by this investigation is limited in terms of the Neolithic agricultural phase, and although no cereal-type pollen grains were counted in the few slides pertaining to that phase, several taxa in the group classed as herbs typical of arable land or disturbed habitats were recorded (see Figure 5.18). This might suggest that arable agriculture did indeed take place but at some distance from the sampling site. This is credible, as the BEL core is located downslope from the Neolithic fields and arable cultivation would presumably be located further upslope on drier ground. The scrubby nature of the vegetation outwith the fields (*Corylus* and *Betula* are well-represented palynologically, with high indeterminate Pteropsida [monolete] spore percentages suggestive of significant tree cover) might have acted as a filter, reducing the probability of pollen from a distance reaching the sampling location.

7.2.4.3 Abandonment of Neolithic agriculture

Peat initiation in the Neolithic fields has hitherto been assumed to have acted as a *terminus ante quem* for the abandonment of agriculture therein. As dating evidence pertaining to the site is limited to *Pinus* macrofossils, estimates as to the date of abandonment have been made by reference to dates from the outer rings of pines rooted in the sub-peat mineral soil. Two such indirect dates, c. 4725 cal. BP and c. 5145 cal. BP (see Appendix A) are imprecise, as they do not record events associated with human activity. The current investigation has provided a much more precise date for the abandonment of c. 5375 cal. BP, in the Middle Neolithic (see above, section 5.4 and Table 5.4).

The context of abandonment remained hypothetical until this investigation. Whether or not the Neolithic fields were abandoned because peat began to cover the mineral soil is critical to an assessment of the environmental marginality of the site. Long-term maintenance of open ground undoubtedly promoted blanket peat expansion (see O'Connell 1990a). However, the presence of blanket peat in the early- and mid-Holocene in North Mayo, including locations close to the Belderg Valley, indicates that early human impact (i.e. Neolithic agriculture) was not responsible for its spread (see Caulfield *et al* 1998, 637). That those locations subject to early blanket peat coverage are apparently lacking in archaeological evidence for mid-Holocene occupation is taken to suggest that the best, peat-free areas were selected for settlement and agriculture (ibid.). This study supports these conclusions: the Belderg Beg hillslope was indeed free of peat before the Neolithic farming commenced. Furthermore, abandonment of the Neolithic field system occurred some four centuries prior to, and thus entirely independently of, peat initiation within the fields. At the time the fields were abandoned, peat was apparently confined to altitudes some 40m downslope of the terminal field walls (i.e. the section of Wall 1 running roughly north-south: see Figure 5.1). The fact that peat began to accumulate on either side of that part of Wall 1 (see Figure 5.1) at the same time, supports the conclusion that Neolithic agriculture was not abandoned because of peat spread. The evidence for lynchet formation, illustrated by increasing depths of minerogenic soil banking up against the terminal field wall 1 (see Figures 5.1 and 5.2), suggests that significant soil erosion occurred prior to peat initiation within the field; this may have been a causative factor in land abandonment (see Section 7.3.2.2. below).

7.2.4.4 Reoccupation

The secondary occupation of Belderg Beg is firmly associated with construction of the roundhouse and the oak stakes in Wall 3 (see Figure 5.1) at c. 3400 cal. BP (see Caulfield 1978, 140; Molloy & O'Connell 190-192). Mitchell & Ryan (2001, 206) raised the possibility of an interim phase of activity marked by the cultivation ridges, occurring at some indeterminate time prior to the roundhouse construction, based on their interpretation of the stratigraphical relationships between these features (*contra* Caulfield 1978; Molloy & O'Connell 1995; Caulfield pers. comm.).

The palynological record examined in this investigation has dated the anthropogenic clearance of the secondary woodland to c. 4100-4000 cal. BP, with further clearance and mixed agriculture commencing at c. 3950 cal. BP. Although this is significantly earlier than previously believed, evidence from the cultivation ridges themselves does not support the aforementioned hypothesis of Mitchell & Ryan (2001). This places initial reoccupation in the Early Bronze Age, continuing through to the Late Bronze Age.

Whilst this thesis has no new archaeological evidence to put forward, a critique can be made of some previously held hypotheses. Wall 3 (see Figures 3.4 and 3.5b) has been firmly interpreted as a single-phase structure acting as a boundary in the Bronze Age occupation (Caulfield 1978, 140; Molloy & O'Connell 1995, 191). That the wall is extended at its western extremity by stakes into gradually encroaching peat has been presumed to result from the greater availability of timber than stone. Support for a single phase of construction for the entire boundary was given by the statistically inseparable dates of two of the oak stakes (Caulfield pers. comm.). However it has been noted that the dated stakes were adjacent to each other, and located at the point where the stone wall began to be supplemented by stakes (Byrne pers. comm.). It is thus proposed that two adjacent oak stakes cannot be used to date the entire length of the stone and timber wall. An alternative hypothesis would be that the stone wall was constructed during an earlier phase, and was extended by oak stakes at the time of roundhouse construction.

As the landscape at Belderg Beg was largely covered in blanket peat by the time the secondary occupation commenced, previous interpretations have suggested that the motive for settlement must have outweighed the restrictions resulting from the limited quality and availability of agricultural soils. Interest in the seam of chalcopyrite at the cliffs in Horse Island (see Figure 3.1) was considered the most likely motivation for settlement (Caulfield 1978, 140; Mitchell & Ryan 2001, 205). On balance, the geochemical evidence presented in this investigation makes it clear that such an interpretation cannot be upheld.

7.2.4.5 The cultivation ridges

The cultivation ridges have been assumed to relate to the roundhouse (Caulfield 1978, 140; Molloy & O'Connell 1995, 191) or alternatively to be older than it, belonging to a phase between the Neolithic occupation of the site its construction (Mitchell & Ryan 2001, 206).

The soil forming these ridges evidently supported repeated agriculture, as it was leached and acidified, and amendment strategies had been employed to some degree. The absence of cultivation ridges over the entire area occupied by the ard-marks resulted from agricultural reorganisation, perhaps a consequence of the contraction of the area put under cultivation and a change in crop husbandry practices. Support for this hypothesis comes from the retardation of peat spread between the BB2 and BB1 sections. Despite the large errors associated with the radiocarbon assays, a delay is apparent between abandonment of the area at BB2 (ard-marks only) and BB1 (ard-marks under cultivation ridges). A period of agricultural reorganisation is postulated, whereby ard tillage was abandoned and cultivation resumed under a ridge-and-furrow regime.

There is a certain disjuncture between the dating of the roundhouse and the cultivation ridges. An oak timber (presumed to be structural) from the house was dated to c. 3400 cal. BP (with a wide error of ±240 cal. years: see Appendix A) whilst basal peat covering the cultivation ridges in the BB1 section was dated nearly a millennium later, at c. 2540 cal. BP (with a wide error of ±185 cal. years: see Table 5.1). The 2σ ranges, 3640 – 3160 cal. BP and 2720 – 2350 cal. BP respectively, do not overlap. The 2σ range of the basal peat date in the BB2 section, 2930 – 2750 cal. BP, does not overlap with that of the roundhouse either. The lifespan of a Neolithic or Bronze Age stone and timber roundhouse has been estimated at c. 20-25 years (Cooney & Grogan 1999, 48), so it is evident that without significant rebuilding and structural modification the house could not have been in use when either of the BB sections became buried by blanket peat. As is discussed above in Section 6.4, cereal cultivation is recorded in the BB2 profile c. 100-150 years after peat initiation at that location, which is considerably later than the range indicated for roundhouse construction, but potentially relates to cultivation of the ridges. Peat initiation at BB1 is furthermore not believed to have been delayed after its agricultural abandonment. It is therefore concluded that agricultural activity, including cultivation of the ridge plots, persisted for some centuries subsequent to the roundhouse falling into disrepair.

7.2.4.6 Anomalies

Two bulk samples of charcoal from the roundhouse hearth, radiocarbon dated to the mid third and the late fourth/early third millennium cal. BP (see Appendix A) have been described as 'impossible to reconcile with either the archaeological material or the radiocarbon dates from the site' (Caulfield 1978, 142). Notwithstanding the problems associated with radiocarbon dating samples from bulk charcoal contexts, the potential old wood effect and the large error ranges associated with the calibrated dates (see Section 1.1.2), it may not be necessary to discard these results as anomalous. The refined chronology provided by the current investigation confirms activity on the site during the earlier, and at least some of the later, spans of time bounded by these date ranges. Although construction of the roundhouse is placed at a much earlier time than either of these charcoal dates, and the building would almost certainly have fallen into disrepair by the opening of the third millennium cal. BP, the ruined building may have been used by the inhabitants of the later phase of activity.

7.3 Integration into regional datasets

7.3.1 The Neolithic

7.3.1.1 Environmental history

Palaeoclimate

In order to integrate the palaeoenvironmental proxy signals from Belderg Beg within the mid- and late Holocene climatic scheme from wider north-west Britain and Ireland, the summarised accounts of these proxies (see Table 7.1) must be compared with existing data. Table 7.2 displays the sequence of occupation, agriculture and main palaeoenvironmental signals from sites in North Mayo.

The palaeoclimatic sequence indicated by the Belderg Beg proxy record suggests climatic forcing of the observed sedimentological changes in the Neolithic period. The outline scheme is of wetness between c. 5200 – 4900 cal. BP, forced by switching from a relatively dry to a relatively damp climatic regime, followed by a phase of relative surface dryness from c. 4850 to c. 4520 cal. BP. This sequence of wet/dry shifts is in accord with the generalised scheme recognised in British and Irish palaeoenvironmental proxy records outlined in Section 1.4.2.3. The Crag Cave stalagmite records cool phases in the early sixth and early fifth millennia cal. BP (McDermott et al 2001, see Figure 2.21).

Increasing oceanicity and a brief peak in surface wetness are indicated at c. 4500 cal. BP at Belderg Beg, coincidentally with the *Pinus* decline. This lasted until the early fourth millennium cal. BP and is in accordance with the wet phase lasting most of the fifth millennium cal. BP at Achill Island (Caseldine *et al* 2005). The scheme is also in agreement with the generalised British and Irish sequence. A phase of increased wetness is recognised from Northern Scotland at c. 4500 cal. BP in humification profiles (Anderson *et al* 1998; Tipping *et al* 2003, 42) and is supported by the sub-fossil pine dating programme by Gear & Huntley (1991).

There is no palynological evidence of the primary (pre-Neolithic disturbance) woodland at Belderg Beg, due to the relatively late date of peat accumulation. Only limited evidence is available for the disturbed woodland which existed during the Neolithic occupation. As the extra-local landscape was open in nature, due to the presence of the pastoral field system, Poaceae dominates the pollen assemblage (if *Alnus* is removed from the TLP count: see Figure 5.18). Of the woodland taxa, *Alnus* is dominant, with *Corylus*, *Betula* and *Pinus* secondary. The *Alnus* component has been interpreted as locally dominant on incipient peat at the base of the hillslope.

Although the Belderg Beg pollen profile opens during a period of agriculture and is thus dominated by Poaceae, the arboreal pollen components of the lowermost few spectra (equivalent to the final part of the agricultural phase) provide information on the nature of the woodland which surrounded the field system. In PAZ BEL-1, at c. 5465 cal. BP, the AP assemblage is dominated by *Alnus*, with *Corylus* and *Betula*, and smaller percentages of *Pinus*. By reference to Section 2.4.2 the similarity of the Belderg Beg woodland to typical western Irish pollen profiles of that period is seen. *Alnus* dominated lake margins and areas of wetter soils. Despite its low altitude, Belderg Beg seems to have had a more typically upland vegetation cover, characterised by the relatively high proportions of *Betula* and *Pinus*. *Corylus* is typically well-represented in western Irish pollen diagrams (see Section 2.4.2.1) and has been suggested as an indicator taxon of disturbed landscapes, owing to its fire-resistance and tendency to colonise recently burned open ground (Huntley 1993, 214). Some typical lowland taxa are present in lesser proportions at PAZ BEL-1, for instance *Ilex*, *Quercus*, *Ulmus*, *Taxus*, *Salix* and *Hedera* (see Section 2.4.2.1 and Figure 5.17). In general, however, these lowland taxa are better represented palynologically in PAZ BEL-2, suggesting that the wooded part of the landscape represented in BEL-1 was characterised by typical upland trees. That *Alnus* dominated at this early stage suggests that low-altitude soils were damp and waterlogged. The woodland assemblage may have been more typically upland than lowland in composition because it was disturbed, or because it was originally more upland in character, possibly because of the exposed position of the site and its susceptibility to Atlantic storms.

The similarity of the AP assemblages of Belderg Beg (mostly below 50m OD) and Céide Fields (mostly above 150m OD) highlights the more characteristically upland nature of the

Belderg Beg woodland, with the Belderg Beg AP suite otherwise more typical of damp soils. The pre-Landnám woodlands at Céide Fields were dominated by *Corylus* and *Pinus*, with *Betula* and *Quercus* at lesser levels and *Alnus* poorly represented at c. 5%TLP (Molloy & O'Connell 1995). Most of the *Pinus* was probably localised (O'Connell & Molloy 2001, 103). *Corylus* and *Pinus* also dominated at Garrynagran, with a similar woodland suite to that at Céide Fields, albeit with *Ulmus* of greater importance than *Quercus* (ibid., 108; see Figure 2.26).

The perceived upland-lowland divide in woodland composition is increasingly evident when the pollen assemblages from western Ireland (Counties Clare, Donegal and Galway) are considered. *Corylus* generally declines in representation in disturbed woodlands (e.g. Lough Maumeen, Co. Galway: Huang 2002; An Loch Mór, Inis Oírr, Aran Islands: Molloy & O'Connell 2004; Lough Mullaghlahan and Altar Lough, Co. Donegal: Fossitt 1994; Lough Sheeauns, Co. Galway: Molloy & O'Connell 1987). Other than that, no further generalisations are apparent.

Comparison of the other western Irish datasets with those from North Mayo suggests that woodland disturbance associated with post-*Ulmus* decline Neolithic agriculture was less than total clearance, but one which resulted in shifting woodland dynamics with regards to composition. The precise nature of the shifts in composition varied according to the nature of the pre-existing woodland, itself evidently largely a function of location, with topography and edaphic factors apparently constituting the controlling factors. O'Connell & Molloy (2001, 118) suggested that at sites where *Ulmus* was previously unimportant in the landscape, substantial Neolithic woodland clearances were marked by decreases in the canopy formers *Pinus* and *Quercus* and especially the understorey shrub *Corylus*. Several factors suggest that this may have been the case at Belderg Beg. Whilst the Belderg Beg disturbed woodland cannot be compared with its precursor, the resurgence of those taxa after abandonment suggests they may have been important in the landscape. That *Alnus* responded to abandonment more markedly with sharp increases, suggests that it was a local, mire-dwelling taxon (cf. Section 5.4.2). The response of *Betula* was also rapid, but less so than that of *Alnus*, suggesting that, with the light-demanding shrub *Corylus*, it rapidly expanded into newly abandoned areas.

By the Neolithic, peat had been growing for considerable lengths of time at various locations in the North Mayo region. At the plateau at the apex of the Belderg Beg hillslope itself

(Geevraun townland), numerous pine stumps are preserved in peat well above the mineral soil. There, a bulk peat sample from 5cm above the transition between mineral soil and peat was dated to c. 6510 cal. BP (Caulfield *et al* 1998, 633; see Appendix A). Peat began to accumulate in the early Holocene in the small basin used by Molloy & O'Connell (1995) for their palynological investigations at Céide Fields. Peat initiation occurred on the lower flatter areas of Achill Island between 10000 and 9000 cal. BP, with large areas of the island covered by peat by c. 6000 cal. BP (Caseldine *et al* 2005, 172). At Garrynagran, peat accumulation started in the early Holocene, before 6500 cal. BP (see Figure 2.26; O'Connell & Molloy 2001, 108-9 & 115) and the bog was considered to have been 'extensive' by the time of Neolithic Landnám (ibid., 110).

A vital factor is that there is a likely hiatus in peat growth in the early- and mid-Holocene in the Céide Fields sampling basin; the precise chronology has not been explored but the authors concluded that peat accumulation re-commenced at c. 5900 cal. BP, shortly before the *Ulmus* Decline (Molloy & O'Connell 1995, 198). A case can perhaps be made for an externally-forced environmental change in the first half of the sixth millennium cal. BP, causing peat initiation or renewed accumulation in sensitive locations as and when particular edaphic thresholds were crossed.

Secondary woodland

At Belderg Beg, *Alnus* formed the main mire-dwelling canopy, and outside that area *Betula*, *Pinus* and *Quercus* expanded, forming a canopy to the detriment of *Corylus*. That *Ulmus* did not feature particularly strongly in the secondary woodland at Belderg supports the suggestion that it had not been an important component in primary (pre-*Ulmus* Decline) woodland (cf. O'Connell & Molloy 2001, 120). Again, the nature and species composition of woodland regeneration in the Middle and Late Neolithic post-abandonment contexts of western Ireland appears to vary largely in response to local topographic and edaphic controls. At the island site of An Loch Mór, the secondary woodland resurgence was characterised by increases in *Pinus*, *Corylus* and *Ulmus* and declining percentages of *Quercus* and *Alnus* (Molloy & O'Connell 2004, 47 & 53). At the upland site of Lough Maumeen, *Quercus* became dominant over *Pinus*; *Betula*, *Corylus* and *Alnus* stabilised, *Fraxinus* formed a continuous curve and *Taxus* peaked (Huang 2002, 160). At the lowland sheltered site of Lough Sheeauns, the woodland regeneration saw values of *Quercus* and *Ulmus* recover, and percentages of *Betula*, *Corylus* and *Alnus* stabilise (Molloy & O'Connell

1987, 210-214). Although site-specific factors govern the general composition of regenerated woodland, a number of recurring phenomena are identifiable.

1. *Fraxinus* increase

Fraxinus was fairly well-represented in the secondary woodland at Belderg Beg, which is typical of its pattern of expansion in post-*Ulmus* decline woodlands of western Ireland (O'Connell & Molloy 2001, 120). *Fraxinus* expanded in post-abandonment secondary woodland from the Middle Neolithic at An Loch Mór (Molloy & O'Connell 2004, 53), Lough Maumeen (Huang 2002), Altar Lough and Lough Mullaghlahan (Fossitt 1994, 10 & 17), Céide Fields (Molloy & O'Connell 1995; see Figure 2.3) and Garrynagran (O'Connell & Molloy 2001, 109). Its increase is apparent but was less marked at Lough Sheeauns (Molloy & O'Connell 1987, 215) and at Church Lough, Inishbofin (O'Connell & Ní Ghráinne 1994, 74). At sites with little or no evidence of Neolithic farming activity, *Fraxinus* did not expand so markedly in the Middle and Late Neolithic, such as Lough Nabraddan, Co. Donegal (Fossitt 1994, 10-14) and Mooghaun, Co. Clare (O'Connell *et al* 2001).

The *Fraxinus* expansion occurred later in Ireland than England, where it expanded first in the Atlantic period, several centuries before its main expansion in the Sub-Boreal (O'Connell & Molloy 2001, 120; cf. Godwin 1975). The causal factor behind the *Fraxinus* increase is likely to have been that the taxon (which is relatively light-demanding) opportunistically colonised newly abandoned areas. The similar expansion of *Quercus* in the Late Neolithic at Belderg Beg is also a common characteristic of north-west Irish pollen diagrams (O'Connell & Molloy 2001, 120) such as Lough Sheeauns (Molloy & O'Connell 1987) and Lough Maumeen (Huang 2002).

2. *Taxus* representation

The status of *Taxus* is particularly interesting. In keeping with many western and south-western Irish pollen profiles (see O'Connell & Molloy 2001, 120), *Taxus* shows a marked expansion in the Late Neolithic at Belderg Beg.

Both human activity and a climatic shift have been postulated as causal factors in the Late Neolithic *Taxus* expansion. The former hypothesis, that yew took advantage of woodland disturbance by Neolithic farmers, is countered by its concurrent expansion at locations where Neolithic human impact was absent or minimal, e.g. Mooghaun (O'Connell *et al* 2001), Lough Namackanbeg, Co. Galway (O'Connell *et al* 1988, 279), Lough Doo (O'Connell *et al* 1987, 154-155) and Lough Nabraddan (Fossitt 1994, 14). O'Connell & Molloy (2001, 121) consider the general synchroneity of the *Taxus* expansion to support a climatic cause; highlighting that it occurred coincidentally with the colonisation of bog surfaces by *Pinus*; a phenomenon considered to have been mediated by a climatic shift (see Section 2.2.3.4).

3. *Pinus* decline

From Figure 7.2 it is seen that all the interpolated palynologically recognised *Pinus* decline dates in North Mayo, including that from Belderg Beg, occurred within the 2σ ranges where the decline was directly dated (Céide Fields: Molloy & O'Connell 1995 and Bunnyconnellan East: O'Connell 1990b).

In Connemara the *Pinus* decline is apparently more complex. A distinct *Pinus* decline occurred at c. 4650 cal. BP at Loch an Chorcail (interpolated: see O'Connell & Molloy 2001), which is in line with the majority of the North Mayo dates. However at certain other sites there is no apparent decline, such as Lough Namackanbeg (O'Connell *et al* 1988), or *Pinus* declined much later, such as at Letterfrack, Connemara National Park (ibid.; see Figure 6.1). At Lough Sheeauns, the earlier Holocene (c. 7500 cal. BP) *Pinus* decline, in the context of the *Alnus* expansion, is well registered (a feature also seen at Céide Fields: Molloy & O'Connell 1995), but subsequently there was only a slow mid-Holocene decline of *Pinus* from c. 5150 cal. BP, lasting a few centuries (O'Connell *et al* 1988). In the karstic environment at Inis Oírr, Aran Islands, *Pinus* declined at c. 5100 cal. BP, but pollen percentages indicate it persisted in the region, and percentage representation increased briefly before a further decline at c. 4700 cal. BP (Molloy & O'Connell 2003, 53).

In County Donegal, the accumulated evidence points to an expansion of *Pinus* between c. 5700 and 5150 cal. BP, followed by a general, but not markedly synchronous decline (Fossitt 1994, 26-27). The complexity of this situation is seen by comparing sites: at Lough Mullaghlahan, *Pinus* began a slow decline from already low percentage values at c. 5700 cal. BP; whereas at Lough Nabraddan, the taxon expanded at c. 5400 cal. BP and declined gradually between c. 5150 and c. 3760 cal. BP; and at Altar Lough, a short-lived *Pinus* decline at c. 4000-3630 cal. BP is the only marked event within the generally steady percentage representations of the taxon which occurred between c. 5550 and c. 2340 cal. BP, when a marked decline got under way (ibid.).

The available radiocarbon-dated *Pinus* declines from northern Scottish pollen profiles range from c. 4600 to c. 3500 cal. BP (see Figure 6.3). Nevertheless, in that region, pine stumps ceased to be preserved in peat after c. 4200 cal. BP, although there is the potential problem of absence of preservation conditions (see Section 2.2.3.4). It is difficult to avoid making the general conclusion that the *Pinus* declines of northern Scotland occurred slightly later than those of western Ireland.

From assessment of this accumulation of data, it can be argued that the *Pinus* decline was indeed a response to externally forced climatic changes, which were characterised by the extinction or near-extinction of a taxon from its range limits (see Section 2.2.3.4). However, the situation was probably more complex than that statement would suggest. It would appear that local conditions played a significant part in determining the timing of the decline; indicating that whilst external forcing was the ultimate cause, the timing of the resultant effect was influenced by local conditions, such as topography, vegetation dynamics, edaphic conditions, and human activity; the consequence being that thresholds were crossed at any particular location according to the authigenic response to the external forcing.

7.3.1.2 Settlement and agriculture

The chronology of settlement at Belderg Beg is comparable with the sequence of occupation at other sites in North Mayo. Figure 7.3 shows a comparative chronology of occupation of the major Neolithic and Bronze Age sites of settlement and agriculture in Counties Galway and Mayo. Similarly to the other sites where Neolithic agriculture is evidenced in North Mayo, Céide Fields and Garrynagran, initial agricultural activity occurred in the Early Neolithic and the first half of the Middle Neolithic periods (see Table 7.2). It remains unknown whether farming at Belderg Beg (and indeed Belderg Mór on the other side of the valley) began at a similar time to that at Céide Fields and Garrynagran, that is to say just a century or so later than the *Ulmus* Decline (see O'Connell & Molloy 2001).

Whilst stone-walled field systems are absolutely dated to the Neolithic in the Belderrig valley (Belderg Beg and Belderg Mór) and at Céide Fields, the remainder of the pre-bog stone walls and other features in North Mayo recorded by Herity and Caulfield in the 1970s must be described as just that: pre-bog stone features. There does not appear to be any adherence to a particular typology in field system design when the only surveyed examples - Céide Fields and Belderg Beg – are compared. Both the individual fields within the Céide Fields and the overall system are much more regularly shaped than the known parts of the system at Belderg Beg. Nevertheless, a predominantly pastoral economy with a minor arable growing component appears to be in evidence at the three North Mayo sites with evidence of Neolithic agriculture: Céide Fields, Garrynagran and Belderg Beg (Table 7.2).

Although settled agriculture is established as a recurring feature of western Ireland in the Early and Middle Neolithic, unequivocal evidence for coaxial field systems seems to be limited to North Mayo. Whilst several stretches of pre-bog stone walls have been recorded in Connemara (Gosling 1993; M. Gibbons pers. comm.), no organised field systems have been found to date, even in regions where subsequent blanket bog development and non-intensive human activity have provided suitable preservation conditions (O'Connell & Molloy 2001, 122). Arguments have been made for assigning some of the field boundaries on the Burren to the Early/Middle Neolithic, although the dating is not secure (ibid.). Reasonable conclusions may be that Early and Middle Neolithic settled agriculture was a robust feature of western Ireland, and that it was unusual in terms of its wider geographical context, but that strong sub-regional identities were present which were expressed in the physical organisation of the agricultural landscapes. The pre-bog stone wall features of Connemara and Mayo which have been recorded but not fully explored may be contemporary with the Early and Middle Neolithic agriculture and may perhaps represent a different strategy of landscape utilisation to those employed in the coaxial field systems. There is perhaps an undiscovered typological continuum of stone boundary features from that period, encompassing the discrete, obscure lengths of pre-bog wall in Mayo and Connemara, the small, patchy fields at Belderg Beg and the large coaxial system at Céide Fields, which is related to the regional agricultural sedentism of the time.

The relatively small size, irregular layout and earlier abandonment of Belderg Beg in comparison to Céide Fields could reflect the marginal status of the former site. Perhaps sites such as Belderg Beg and Belderg Mór were peripheral to the core, Céide Fields. If the economy at Belderg Beg was unable to maintain the population, amalgamation with the Céide Fields community (i.e. the core absorbing the periphery), or relocation elsewhere, might have been the only options available.

The question of arable agriculture in the Neolithic is difficult to answer at Belderg Beg. The regional (North Mayo) Neolithic economy has been described as primarily pastoral, with a minor arable element present at most sites, in the first few centuries after the *Ulmus* Decline (O'Connell & Molloy 2001, 123). This occurred within a settled rather than mobile agricultural landscape (ibid.) although field systems were not a ubiquitous characteristic. There are interesting parallels in the Neolithic of Atlantic Scotland which may be applicable to western Ireland. Site-based archaeological investigations with intensive geoarchaeological sampling strategies (soil micromorphology, phosphate analysis, magnetic susceptibility, loss-on-ignition and microscopic charcoal analysis) have suggested midden cultivation occurred at Old Scatness, Shetland (Guttmann *et al* 2004, 61) and Northton, Harris, where a pre-existing Mesolithic midden was cultivated (Gregory *et al* 2005, 947). Guttmann (2005) has argued for Neolithic midden cultivation at other sites in Atlantic Scotland: Knap of Howar, Papa Westray (Ritchie 1983); Links of Noltland, Westray (Clarke *et al* 1978), and possibly also in England: Hazleton North, Gloucestershire (Macphail 1990). Evidence shows that this practice continued into the Bronze and Iron Ages at Cill Donain (Gilbertson *et al* 1999) and Hornish Point (Barber 2003), both on South Uist, and Old Scatness, Shetland (Guttmann *et al* 2004, 61). Research strategies have obviously influenced these discoveries; site-based integrated archaeological investigations have resulted in the wealth of detailed evidence for Scottish prehistoric agriculture, whereas western Irish evidence for Neolithic agriculture has exclusively derived from pollen profiles and landscape-scale surveys (see O'Connell & Molloy 2001) with little intensive site-based excavation.

It is evident from the soil micromorphological investigation in this study that the Bronze Age arable agriculture at Belderg (as evidenced in the BB1 section) was not carried out in the context of midden heap cultivation. Soil horizonation was evident and only the later tillage phase displayed minor indications of amendment by domestic refuse addition. There is, however, a possibility that the Neolithic farming phase at Belderg (and indeed the other Early/Middle Neolithic settled agricultural sites) employed midden cultivation techniques. With most Neolithic agricultural sites in Ireland being preserved under peat and therefore not extensively or intensively excavated, the chance of discovery of any tillage sites, whatever their form, has been largely unrealised.

7.3.1.3 Abandonment

The field system at Belderg Beg was abandoned around 200 – 250 years before Céide Fields and Garrynagran. Although doubts have been expressed above as to whether the entire Céide Fields system as seen in plan represents a single phase of occupation, the palynological evidence does support agricultural cessation within the pollen source area of the GLU IV core (see Molloy & O'Connell 1995).

The evidence from Belderg adds to the corpus of data accumulated by O'Connell & Molloy (2001), which indicates a distinct pattern to regional (Co. Galway and Co. Mayo) Neolithic occupation (see Figure 7.2). Agriculture typically began immediately after the *Ulmus* decline and peaked in intensity at the end of the Early Neolithic. Sites were then abandoned from the second half of the Middle Neolithic until the end of the Late Neolithic, i.e. from c. 5100 – 4300 cal. BP, although reoccupation commenced later at many locations. This is particularly interesting and worthy of further investigation. Why did human activity cease or decline in intensity in much of western Ireland at this time? Did the model of sedentism described in Section 2.2.2, apparently so uncharacteristic of most of mainland Britain, apply to the Early and Middle Neolithic only in this region, with the Late Neolithic characterised by mobility? A decline in overall population rather than a geographical shift within the region has been postulated as a causal factor for the woodland regeneration (ibid., 120).

Although environmentally deterministic causes of population dynamics are unfashionable, the contemporary environmental and climatic conditions must be considered when seeking a possible cause for the apparent abandonment of much of the region. By reference to Figure 2.1 and Section 2.3.4.1 it can be seen that the Irish palaeoclimatic indicators suggest the period 5400 – 5100 cal. BP was one of climatic fluctuations, with a regionally significant shift in North Atlantic climatic regimes evidenced. Cool conditions were signified by the GISP2 glacio-chemical index (O'Brien *et al* 1995). Few terrestrial records are available because peat initiation generally occurred later at sites which have been hitherto analysed for palaeoclimatic proxies (see Section 2.3.4.1), but the Crag Cave stalagmite (O'Donnell *et al* 2001) indicates a cooling phase within the appropriate time period. The Achill Island peat humification record suggests that surface conditions remained relatively dry until c. 5000 cal. BP (Caseldine *et al* 2005) and the Céide Fields pollen record suggests a drier mire surface between c. 5200 and 4900 cal. BP (O'Connell & Molloy 2001, 115). The episode of extreme storminess registered at Achill Island at c. 5200-5100 cal. BP (Caseldine *et al* 2005) may be a representation of a short-lived climatic fluctuation. Regardless of causality, the period in which much of the west of Ireland was apparently largely depopulated seems to have occurred in the interlude between two phases of climatic deterioration: those at c. 6000 – c. 5000 and c. 4500 – c. 4000 cal. BP (see Section 2.3.4).

Although peat initiation commenced shortly before agricultural abandonment at Belderg Beg, which in itself indicates increasingly wet surface conditions, the humification record suggests the initial detrital peat was relatively dry. Relatively dry surfaces at three sites – Belderg Beg, Céide Fields and Achill Island – indicate a significant regional trend. Furthermore, this trend is coincident with land abandonment. Causal connections can be postulated, requiring a rethinking of common assumptions regarding the nature of environmental marginality.

The theory proposed here rests on pastoral agriculture being the mainstay of the economy, with cereals playing a minor role. It has been suggested that pioneer Neolithic agriculturalists selected the best areas to colonise based on edaphic factors, and that increased climatic dryness at c. 6000 cal. BP permitted arable cultivation on soils that were at that time drier than they would subsequently be (see Bonsall *et al* 2001). Pastorally-based economies with a minor arable component were established in North Mayo, in the areas with better soils, as peat was already widely spread. A spectrum of stone wall field system typologies developed, characterising the agricultural economies. Céide Fields, the largest such site, was a core area, with outlying peripheral communities including Belderg Beg and Belderg Mór. This economy was successful for a time but soils gradually became exhausted as a result of long-term agriculture, perhaps even overgrazing; a situation amplified by the continuing climatic regime of relative dryness in the sixth millennium cal. BP. Water shortage could have been a problem, in terms of both soil moisture and finding sufficient water to maintain cattle populations. Droughty soils would decline in productivity and the resulting reduction in vegetation cover would increase susceptibility to erosion. Meanwhile, downslope of the barriers formed by the stone walls, peat growth commenced in suitable initiation *foci*. By c. 5375 cal. BP the situation was such that there was insufficient vegetation available to maintain grazing requirements, and the required level of agriculture could not be sustained. Extensification of the field system was inhibited by peat spread in the vicinity. Environmental marginality – with soil quality and water availability the limiting factors – ultimately had a climatic cause – increased dryness. Relocation of settlement must have been necessary.

A similar situation occurred approximately two centuries later at Céide Fields (Molloy & O'Connell 1995; O'Connell & Molloy 2001) and at Achill Island also, where palaeoenvironmental records suggest that extreme storminess accompanied the transition from phase of climatic dryness to one of wetter conditions at c. 5100-5000 cal. BP (Caseldine *et al* 2005). The effects of this regionally significant climatic shift on rates of peat spread varied at different locations according to local edaphic and topographic influences.

Societal factors would have been involved in the shift in settlement patterns and locations. That western Ireland was more or less abandoned as populations migrated elsewhere, or adopted a less sedentary lifestyle, seems logically more probable than catastrophic population decline in that region alone. Grogan (2004) interprets changing house structural typology in the Middle Neolithic to express changing societal relationships and dynamics; with a reduction in size and therefore number of inhabitants, and longer-term occupation by smaller groups, as the main traits that can be inferred (see Section 2.2.2.1). Although the houses he makes these inferences from are not located in western Ireland, there may be a wider significance betrayed by changing social networks and domestic arrangements noted elsewhere in Ireland.

There is some evidence that the Middle and Late Neolithic agricultural decline so apparent in western Irish pollen profiles was part of a pan-regional (Atlantic fringe) phenomenon. A reduction in agricultural intensity was interpreted in the Neolithic occupation of Scord of Brouster, Shetland, registered palynologically in several cores by a short phase of scrub regeneration ending just prior to c. 4700 cal. BP. This was ascribed to a decline in population levels (Keith-Lucas 1986, 116-117). At that stage, comparisons were drawn to similar regenerative phases in Northern Ireland commencing between c. 5380 and c. 5150 cal. BP, namely Ballynagilly, Ballyscullion and Beaghmore (Pilcher *et al* 1971) and Gortcorbies (Smith 1975). As more detailed studies have become available and comparisons possible (e.g. Bradley 1978; Whittle 1978; Edwards 1993), suggestions have been made that the Later Neolithic of Britain was generally characterised by woodland regeneration, prior to a progressive woodland reduction continuing thereafter to the present, a pattern most commonly identified and palpable in upland and peripheral areas (Edwards 2004, 63). The possibility of any relationship between Middle and Late Neolithic woodland regeneration and climatic change has not been explored, arguably due to the prevalent interpretation of settlement continuity (Tipping & Tisdall 2004, 76; see Thomas 1999).

7.3.2 The Early and Middle Bronze Age

7.3.2.1 Environmental history

Palaeoclimate

After c. 3500 cal. BP the palaeoclimatic indicators at Belderg Beg appear to give largely inconclusive, indeed contrary, signals. The humification curve records increasing dryness, whilst geochemistry indicates an absolute increase in oceanically-derived elements, suggesting climatic oceanicity at its maximum level for the profile. The general scheme outlined in Section 2.3.4.3 shows an increase in climatic wetness commencing at c. 3200 cal. BP and lasting until c. 2300 cal. BP, although sub-phases characterised by short-lived fluctuations undoubtedly occurred within this timespan. Comparison to other sites in western Ireland is also inconclusive. A relatively dry mire surface is also recorded at Céide Fields at this time (see Table 7.2), but a brief spell of cool wet conditions is recorded in the late fourth millennium cal. BP at Abbeyknockmoy, Co. Galway (Barber *et al* 2003, see Figure 2.20).

Vegetation

The post-Neolithic regenerated woodland at Belderg was again characteristic of damp soils, with elements typical of both upland and lowland assemblages. The over-representation of *Alnus*, due to its presence on the mire surface, somewhat masks the nature of the wider woodland regeneration. With the exception of the occasional *Pinus* tree, this secondary woodland apparently did not extend to the previously farmed fields (as evidenced by the peat stratigraphy). When compared to the post-Neolithic secondary woodland at Garrynagran and Céide Fields (see Figures 2.26 and 2.11), the dominance of *Alnus* at Belderg Beg seems anomalous, but is probably a factor of hydrology. The high representation of *Corylus* at Belderg Beg is in keeping with its dominance at contemporary levels at both the aforementioned sites. Perhaps due to their somewhat more exposed locations, Belderg Beg and Céide Fields have higher percentages of *Betula* than *Quercus*, a situation which is reversed at Garrynagran, where *Pinus* is also of greater importance than at the other sites. The expansion of the minor woodland taxa, *Fraxinus* and *Taxus*, is characteristic of north-west Ireland (see Section 7.3.1.1 above). The commencement of a continuous curve for *Salix* is seen at both Belderg Beg and Céide Fields in the secondary woodland, as is the regeneration of *Ulmus*, which is also seen at Garrynagran. *Ilex* is better-represented at Belderg Beg than at either Céide Fields or Garrynagran. Indeed, other typically light-demanding woodland and woodland-edge taxa, such as *Salix*, *Fraxinus*, *Taxus* and *Sorbus*, appear to be best represented at Belderg Beg (if *Alnus* is removed from the TLP sum).

It is particularly interesting that the *Taxus* expansion at Belderg Beg persisted beyond the renewed clearance and agricultural activity, decreasing in percentage representation at c. 2775 cal. BP. In most profiles it was apparently cleared in the context of renewed anthropogenic impact of the Early Bronze Age (O'Connell & Molloy 2001, 121), such as Lough Maumeen (Huang 2002, 158-160), Church Lough, Inishbofin (O'Connell & Ní Ghráinne 1994, 74), Gortlecka, the Burren, Co. Clare (Watts 1994, 52), An Loch Mór (Molloy & O'Connell 2004, 53), Lough Doo (O'Connell *et al* 1987, 155). Only occasionally did it persist until modern times (Mitchell 1990). The level of grazing seems to have been a controlling factor in the success of *Taxus* expansion throughout prehistory (O'Connell & Molloy 2001, 121). Interestingly, in contrast to the situation with *Fraxinus*, *Taxus* showed a characteristic peak in the Late Neolithic at Mooghaun (O'Connell *et al* 2001, 170-171), which perhaps supports a climatic driver in its population dynamics.

With regards to the non-arboreal pollen component of the North Mayo assemblages, it is apparent that even though bog taxa had been eliminated from the TLP count at Céide Fields, *Calluna* was less important at Belderg Beg. This could be a function of hydrology, or of pollen source areas. *Calluna* has a low dispersal rate and the sampling site at Belderg Beg was at that time vegetated by fen woodland species, whilst at Céide Fields the sampling location, a small basin mire, was in all probability dominated by Ericaceae. Poaceae are slightly better represented at Belderg Beg than Céide Fields. Overall, the woodland at Belderg Beg following abandonment of the Neolithic field system apparently regenerated in a similar way to that at proximal sites in the region (Céide Fields and Garrynagran) albeit in accordance with the particular edaphic and topographical conditions – its damp soils and exposed conditions limiting the expansion of deciduous woodland.

Peat accumulation appears to have started later in the areas of base-rich Carboniferous limestone bedrock than in those areas of acidic bedrock geologies further to the west. Peat initiation in localised areas within the Carrownaglogh area has been estimated to have begun at c. 4500-4400 cal. BP, principally caused by increased climatic wetness (O'Connell 1986, 171). At Bunnyconnellan East townland, peat accumulated over mineral soils slightly earlier, at c. 4630 cal. BP, at a higher altitude (O'Connell 1990b, 270-271). At Lough Doo, the main expansion of bog and heath pollen taxa was underway at c. 3750 cal. BP (ibid., 275), and the absence of prior agricultural activity has been argued as a causal factor in the delayed blanket bog spread (O'Connell *et al* 1987; see Section 2.4.2.2). At

In his appraisal of the timing of blanket bog initiation in western Ireland, O'Connell (1990a, 64) considered that synchroneity or clustering of dates of peat initiation and expansion would suggest control by factors operating at a regional level, such as climate, or the introduction of a new element such as Neolithic farming. In contrast, a wide range of dates and an absence of clustering would indicate that local factors were probably responsible, such as edaphic conditions, which are mainly determined by solid and drift geology (ibid.). On this basis, it is suggested that the mid-fifth millennium cal. BP cluster of peat initiation dates in the Carrownaglogh area was primarily caused by climatic factors, and that acceleration of bog expansion at individual sites may have been triggered by human activities, as evidenced at Lough Doo. Further west along the North Mayo coastline, human activity in the first half of the sixth millennium cal. BP evidently triggered peat initiation at Belderg Beg and renewed accumulation in the Céide Fields basin (cf. Molloy & O'Connell 1995, 198). Similar sequences occurred in Connemara at susceptible sites also, supporting the causal connections. For instance, at Lough Maumeen, blanket bog became established in the context of Neolithic farming and had replaced woodland by the Late Neolithic, but the major blanket bog expansion commenced as a consequence of Early Bronze Age agriculture (Huang 2002, 162). Early and Middle Bronze Age human activity, including clearance by fire, was considered to have been the causal factor in blanket bog expansion at Lough Namackanbeg and probably also Lough Sheeauns, (O'Connell *et al* 1988, 285).

7.3.2.2 Settlement and agriculture

Reoccupation occurred later at Belderg Beg than at Céide Fields and Garrynagran. The secondary occupation at Belderg Beg occurred at a point when agriculture apparently contracted at Céide Fields. The main phase of agriculture at Lough Doo, and the activity at Bunnyconnellan East, both started approximately two centuries after reoccupation at Belderg began (see Figure 7.2). Although it is unclear from the archaeological record or this investigation whether the Bronze Age occupation at Belderg was continuous throughout the entire timespan indicated (c. 4000 cal. BP to the mid-third millennium cal. BP), or whether activity occurred in discrete shorter periods not recognisable as such in the palaeoenvironmental record, the end of this phase is roughly contemporaneous with abandonment of agriculture at Carrownaglogh and Lough Doo (see Figure 7.2). Sustained activity is seen in the Céide Fields palaeoenvironmental record, although again, the continuity or otherwise of occupation through the span is unknown.

Bronze Age agriculture at Belderg Beg is in a curious position of having good archaeological evidence for intensive cultivation and pastoralism, but poor chronological resolution. The latter has been discussed above and it is likely that the distance between the agricultural land and the pollen sampling location, as well as the prevailing wind direction, are causal factors. Sustained agriculture throughout most of the Bronze Age is typical for the western Irish pollen profiles; suggesting that long-term occupation at Belderg Beg would not have been regionally anomalous. In particular, the entire fourth millennium cal. BP seems to have been a phase of particularly intensive agriculture.

The inferred cultivation of barley as the sole cereal crop during the Bronze Age at Belderg Beg is typical of Bronze Age Ireland, where barley is the most common cereal crop identified macroscopically (see Section 2.2.3). Occasional finds of wheat species have been made, such as *Triticum*-type pollen grains in Late Bronze Age levels of a lake sediment profile at Mayo Abbey, central Co. Mayo (Fuller 2002, 21). Oat cultivation is signalled at Mannin 2, Co. Galway, at c. 2875 cal. BP (Weir 1996b). Both of these are roughly coincident with a phase of agriculture at Belderg Beg, but on a widespread scale, barley is the most common identified crop.

7.3.3 The Late Bronze Age

7.3.3.1 Environmental history

Palaeoclimate

The third millennium cal. BP, most of which is commonly considered to have been dominated by cool, wet conditions in north-west Europe, especially from c. 2800 cal. BP onwards (see Section 1.4.3.4) is not highlighted as such in the Belderg Beg humification or geochemical indices, although deteriorating edaphic conditions are suggested by the presence of AMS-dated mineral inwash layers. Several peat-based records of Northern Britain and Ireland, including that from Abbeyknockmoy, Co. Galway (Barber *et al* 2003) have identified cool or wet phases in the early third millennium cal. BP. The geochemical and humification records from Belderg Beg do not appear to exhibit sensitivity to known climatic fluctuations in this phase. Hydrology and land management techniques may be the cause of this insensitivity (see Section 7.2.3.4), as storminess resulting from the climatic shift evidently caused erosive episodes upslope.

Vegetation

By the Late Bronze Age, blanket peat dominated the landscape of Belderg Beg and the last woodland stands had disappeared. AP percentages remain negligible, reflecting background regional pollen input. The extremely sporadic representation of *Pinus* pollen from the Late Bronze Age onwards in the Belderg Beg profile is characteristic of western Ireland (cf. Céide Fields: Molloy & O'Connell 1995, 204; Lough Doo: O'Connell *et al* 1987, 160). Extensive bog growth in all areas of North Mayo by the Late Bronze Age has been indicated (O'Connell *et al* 1987, 162) and general data from Ireland suggest that blanket bog growth was well established in the Atlantic fringe of Ireland by the middle of the third millennium cal. BP (see O'Connell 1990a, 50-51). The evidence of small-scale woodland survival at Belderg Beg is limited to the *Betula*, *Corylus* and *Fraxinus* curves, which persisted beyond the Late Bronze Age. Wider ranges of AP taxa persisted at Céide Fields (Molloy & O'Connell 1995), Carrownaglogh (O'Connell 1986) and Lough Doo (O'Connell *et al* 1987). Late Bronze Age human impact upon woodland was particularly marked in the western Irish sites of Mooghaun Lough (O'Connell *et al* 2001) and An Loch Mór (Molloy & O'Connell 2004), but clearance was not permanent, and regeneration of open woodland followed the abandonment or reduction in intensity of agricultural activity at both sites.

The patterns of blanket bog development in relation to human impact in western Ireland suggest that topography, solid geology and edaphic factors were strongly involved in determining landscape evolution. For instance, peat spread most readily as a consequence of Neolithic human impact in upland or exposed locations (Lough Maumeen, Céide Fields, Belderg Beg, most of Co. Donegal). Early and Middle Bronze Age human impact is most strongly associated with large-scale blanket bog spread in most Connemara sites. In particular locations, such as the karstic locations An Loch Mór and Mooghaun Lough, where Carboniferous limestone will have provided preferable edaphic conditions, even sustained and severe human activity in the Late Bronze Age did not prevent woodland regeneration.

7.3.3.2 Settlement and agriculture

The chronology of Late Bronze Age agricultural activity in western Ireland is as site-specific as that of the Early and Middle Bronze Age, therefore the potential to identify recurring patterns is limited. Reference to Figure 7.3 allows the construction of certain hypotheses. Several sites showing apparent abandonment or reduction in activity in the Middle Bronze Age, feature reoccupation in the opening centuries of the third millennium cal. BP, lasting for only a few centuries at most. This is seen at Belderg Beg, Carrownaglogh (O'Connell 1986), Derryinver (Molloy & O'Connell 1993) and An Loch Mór (Molloy & O'Connell 2004). Late Bronze Age agricultural abandonment also occurred at Lough Doo (O'Connell *et al* 1987). However, agriculture commenced or persisted at other sites past c. 2500 cal. BP, e.g. Céide Fields (Molloy & O'Connell 1995) and Lough Sheeauns (O'Connell *et al* 1988), and the break or reduction in activity at Derryinver was brief (Molloy & O'Connell 1993). Based on this evidence, the conclusion is that certain vulnerable sites became marginalised for agriculture by Late Bronze Age climatic fluctuations. That abandonment was not as wide-spread as that seen in the Middle Neolithic, suggests that either the climatic fluctuations were less severe, or that sufficient buffering mechanisms had been developed to offset the stresses in some locations.

Agricultural practices in the Late Bronze Age at Belderg Beg appear to be directly comparable to those recognised in other regions within the Atlantic fringe. Soil micromorphology has been particularly informative in this respect. Bronze Age ard cultivation has been noted at many British sites, particularly those in the Atlantic fringe, such as Old Scatness Broch, Shetland (Simpson *et al* 1998b), South Nesting, Shetland (Dockrill & Simpson 1994) and Tofts Ness, Orkney (ibid.). Bronze Age examples from the European Atlantic fringe are known also, such as at Bjerre, Denmark (Lewis 1998). Sites from mainland Britain containing ard-marks datable to the Bronze Age are Phoenix Wharf, London (Macphail *et al* 1990, 63), Strathallan, Perthshire (ibid.; Romans & Robertson 1983), Fengate, Cambridgeshire (Lewis 1998) and Ashcombe Bottom, Sussex (Macphail *et al* 1990, 64). At this stage it appears that there is insufficient chronological detail available to chart any temporal patterning to the spread of agricultural practices and technology within the British Isles.

Soil amendment strategies in Bronze Age Atlantic fringe sites typically involve the addition of organic manures or composts, such as domestic wastes. This practice was apparently more intensive later in the Bronze Age than earlier, as evidenced by differences between primary and secondary Bronze Age soils at Old Scatness Broch (Simpson *et al* 1998b, 116), a situation directly comparable to that at Belderg Beg. Cultivation of barley as the primary cereal crop is typical of the Bronze Age of Atlantic sites, with barley being the dominant crop in most Atlantic Scottish archaeobotanical assemblages from that period, e.g. Ardnave, Islay (Ritchie & Welfare 1983), Machrie Moor, Arran (Barber 1998), Rosinish, Benbecula (Shepherd & Tuckwell 1979), Buckquoy, Orkney (Donaldson *et al* 1981), Tofts Ness, Orkney (Dockrill *et al* 1994) and Ness of Gruting, Shetland (Milles 1986).

7.3.4 The Iron Age

7.3.4.1 Environmental history

Similarly to the Late Bronze Age, the second millennium cal. BP climatic fluctuations commonly seen in Atlantic British and Irish terrestrial proxy records are not marked in the Belderg Beg palaeoenvironmental proxy records. The BEL humification profile records continuing relatively dry surface conditions, suggesting that this location remained insensitive to changes in climatic wetness. Humification was not tested after 80cm (c. 2100 cal. BP). Although *Betula* and *Corylus* experienced short-lived minor expansions between c. 2275 and 2100 cal. BP, woodland regeneration in the Late Iron Age was not evident at Belderg Beg, in contrast to many other sites.

7.3.4.2 Settlement and agriculture

The typical lull in farming activity in the Late Iron Age (c. 1950 – 1600 cal. BP) noted in many pollen profiles from western Ireland (O'Connell *et al* 2001) is not particularly recognisable in the North Mayo sites, with the exception of Céide Fields (see Figure 7.2). The Belderg Beg main pollen profile suggests that pastoral and possibly arable agriculture occurred between c. 1950 and c. 1600 cal. BP. Indeed, a resurgence of pastoral agriculture is seen not just at Belderg Beg but also at Carrownaglogh and Lough Doo (see Figure 7.3). Research strategies and poor chronological resolution can be identified as a factor in the relative absence of detailed knowledge regarding the Late Bronze Age and Iron Age of North Mayo, and to some extent Connemara as well. To date, the Neolithic and Bronze Age have been the primary research targets of palaeoenvironmental and archaeological investigations. Palaeoenvironmental sampling has occurred at fine temporal resolution in

Neolithic levels of cores, and sampling in Iron Age levels has tended to be at a rather coarse resolution. A further consideration has been that of dating. Not only does the mid-third millennium cal. BP calibration plateau cause problems with calibrating Late Bronze Age and Iron Age radiocarbon assays, but most studies to date have utilised conventional rather than AMS radiocarbon technology, necessitating thicker samples from cores and thereby reducing the precision of resultant assays. The introduction of sophisticated tephra chronologies has improved precision in recent years, e.g. at An Loch Mór (Chambers *et al* 2004; Molloy & O'Connell 2004).

7.4 Environmental marginality of prehistoric societies of the British and Irish Atlantic fringe

7.4.1 Neolithic environmental marginality

With the evidence for arable cultivation at Belderg Beg being so scant and indirect, the possibility of a phase of activity without cereal cultivation must be addressed. If conditions were climatically or edaphically marginal for arable cultivation in the Neolithic occupation phase, the opportunity may have existed to supplement the pastoral economy by importing cereal grain. Cereal-importing has been suggested in certain sites considered marginal for agriculture. The most cogently argued interpretations are based on multiple lines of evidence, for instance in the Early Bronze Age occupation at Lairg, Sutherland, based on the near-absence of cereal pollen and the absences of chaff in archaeological deposits and of querns in the archaeological record (Tipping & McCullagh 1998, 207). The producer-consumer model based on southern English sites would identify the absence of chaff, a common northern British phenomenon (van der Veen 1992) as indicative of consumer sites, though the evidence is equivocal (cf. Hillman 1980; Jones 1985) and this has not frequently been discussed in terms of self-sufficiency (Tipping & McCullagh 1998, 207). Therefore, too little is known to speculate upon regional patterns, and to extend speculations to sites with no pertinent archaeobotanical evidence. The regional picture may be more informative. The Neolithic occupation phases at Garrynagran and Céide Fields, and indeed most sites in the western Irish region, have been described as primarily pastoral, with a minor arable component (cf. O'Connell & Molloy 2001, 123). From this description, and from the levels of cereal-type grains in pollen profiles, it is difficult to imagine any of the known sites within the region producing a cereal grain surplus sufficient to supply to other sites. Whilst Belderg

Beg has been interpreted as peripheral to the Céide Fields core, it seems unlikely that any trade between the sites included the movement of grain.

As has been discussed above, the abandonment of agriculture and settlement at Belderg Beg in the Middle and Late Neolithic period is a characteristic and recurring feature of many palynological profiles of that time. This phenomenon is well-recognised not just extra-locally (i.e. in North Mayo) but regionally (in western Ireland) and potentially pan-regionally (in Atlantic Britain). The causal factors behind this phenomenon are largely unknown, and whilst individual site-based theories have been mooted (such as soil quality in the present investigation), there is no identified common trigger.

This investigation may aid interpretation of causality of Middle and Late Neolithic declining human activity in the North Mayo region. Deteriorating soil quality caused by erosion, facilitated by a relatively dry climatic regime, has been postulated as a causal factor in the abandonment of agriculture at Belderg Beg (see Section 7.2.4.2). A relatively dry climate was also interpreted to have prevailed at the time Neolithic agriculture was abandoned at Céide Fields, whilst Neolithic settlement and agriculture on Achill Island was seen to decline in intensity at c. 5200-5100 cal. BP, associated with extreme storminess and resultant severe erosive episodes at the transition between relatively dry and a relatively wet climatic regimes (see Section 7.3.2.2). There are no indications of severe erosion associated with Neolithic agricultural phases at Lough Maumeen (Huang 2002), Lough Sheeauns (O'Connell *et al* 1988), or An Loch Mór (Molloy & O'Connell 2004).

Based on the proxies shown in Figures 2.20, 2.22 and 2.23, climatic conditions in Ireland, and the North Atlantic region as a whole, at the critical period in question (c. 5400-5100 cal. BP) can generally be categorised as cool and dry. Coolness is indicated by the Crag Cave stalagmite (McDermott *et al* 2001) and the GISP2 glaciochemical index (O'Brien *et al* 1995), whilst dryness is indicated by the Achill Island humification record (Caseldine *et al* 2005), tree-ring records from Southern Germany (Mayr *et al* 2003) and the Cairngorms (Dubois & Ferguson 1985), and lake levels in Northern Britain (Yu & Harrison 1995) and Sweden (Digerfeldt 1988). There is less regional evidence to corroborate the shift to wetter conditions at c. 5000 cal. BP which was implied at Achill Island (Caseldine *et al* 2005), although in the early fifth millennium cal. BP the Cairngorms tree-ring evidence suggests a shift to increased wetness (Dubois & Ferguson 1988) and a die-off event is signalled by Irish tree-ring widths (Leuschner *et al* 2003).

The conclusion reached, therefore, is that the trend towards increasing dryness, which commenced at c. 6100 cal. BP (see Section 2.2.1.2), allowed the adoption of mixed agriculture in Britain and Ireland. The climatic conditions of the second half of the sixth millennium cal. BP, of persistent dryness and increasing storminess, facilitated acceleration of soil erosion on agricultural sites in susceptible locations. In some locations it is known that relatively sophisticated arable cultivation techniques had been developed, such as midden cultivation and manuring. Edaphic pressures associated with overgrazing may have been prevalent at sites such as Belderg Beg, where it is suggested that a significant proportion of the landscape was already covered by blanket peat. Eventually, soils became so exhausted that the sites could be described as environmentally marginal for the agricultural regimes in place. This scheme appears to apply well to North Mayo, but is evidently not applicable to Connemara, where there is less evidence for soil erosion. The pivotal threshold in that region, and others within the North Atlantic fringe, has yet to be ascertained.

7.4.2 Bronze Age environmental marginality

At Belderg Beg, it is evident that peat expansion was underway during the Bronze Age occupation phase. This was also displayed at Céide Fields and Carrownaglogh by analysis of multiple pollen profiles (O'Connell 1986, 171-172; Molloy & O'Connell 1995, 221). Soil acidification and blanket peat expansion continuing from the Middle and Late Neolithic period, in which edaphic conditions were already marginal for agriculture, might be expected to seriously impede the success of settled farming societies.

However, the edaphic pressures on Bronze Age farmers as a result of the increasing expanse of blanket peat did not prevent long-lasting agriculture from occurring, and cereal cultivation is also evident. The general picture from Co. Mayo is that Bronze Age agriculture was of a similar nature to that practised in the Neolithic, i.e. mainly pastoral but with a minor arable component. Belderg Beg, Céide Fields and Carrownaglogh contain evidence of relatively intensive arable agriculture on a small scale, as exemplified by the small ridge-and-furrow plots at Belderg Beg and Carrownaglogh (O'Connell 1986), and the apparent restructuring of former Neolithic walls forming smaller cultivated fields at Céide Fields (Molloy & O'Connell 1995, 221). Soil micromorphological study of the tillage plots at Belderg Beg has revealed that adaptive strategies including manuring were developed in order to maintain cereal crop yields, and that tillage strategies changed over time. Turf stripping or 'scalping' is interpreted to have occurred during both the Neolithic and Bronze Age occupation phases at Belderg, based on soil micromorphological and sediment-stratigraphical evidence. This adaptive strategy suggests that the society was subjected to edaphic stresses, and that without such actions, the site would have been marginal for agriculture. The importance of adaptive strategies during times of climatic or environmental stress has arguably been under-emphasised, perhaps because of archaeological invisibility (see Davies *et al* 2004, 8).

The development of peat whilst cultivation was occurring at BB1, as evidenced by the highly organic nature of the upper part of the ridge-and-furrow layer and the preservation of fresh plant material (see Section 6.2.4), indicates that any attempts to retard or inhibit peat expansion were ultimately unsuccessful. Whether or not this peat spread was a causal factor in the mid-third millennium cal. BP abandonment of agriculture at Belderg Beg is obviously unknown, but it is certainly a possibility. A further factor to be considered is that of the climatic conditions, which obviously may have affected the edaphic and pedogenic processes operating at Belderg.

The early- and mid-third millennium cal. BP has been identified as a period of climatic change, in that most proxies signal wet or cool conditions in the North Atlantic region (see Figures 2.19 & 2.22). An IRD event occurred at c. 2800 cal. BP (Bond *et al* 1997; see Figures 2.19 & 2.22). Cool conditions are registered by the GISP2 glaciochemical record (O'Brien *et al* 1995). Tree-ring records from Southern Germany and Ireland indicate cool and/or wet conditions, at c. 2900 cal. BP (Leuschner *et al* 2003; Mayr *et al* 2003). Lake levels are interpreted to have transgressed (indicating higher precipitation/evaporation ratios) during the third millennium cal. BP in Northern Britain (Yu & Harrison 1995), Sweden (Digerfeldt 1988) and Jura (Magny 1992). The Irish palaeoclimatic data are less definitive during this period; only the Abbeyknockmoy plant macrofossil record indicates cooler, wetter conditions occurring at c. 2800 cal. BP (Barber *et al* 2003). Referring back to Section 2.3.4.3, the accumulating evidence for a shift to an increasingly oceanic climatic regime at c. 2800 cal. BP might be taken as an indication of increasing rates of peat expansion. The generally variable climatic regime indicated during the early third millennium cal. BP might be characterised by frequent climatic shifts at amplitudes perceptible to human communities. These may be expressed by increased uncertainty regarding agricultural success or failure, which has been suggested as the primary factor in land occupation or abandonment. Assuming that the Belderg Beg economy was substantially self-sufficient, the increased likelihood of agricultural failure may have forced abandonment of the site.

Chapter 8

Summary and conclusions

8.1 Introduction

This study has attempted to reconstruct the environmental conditions and dynamics of settlement and economy at Belderg Beg during later prehistory, with the aim of establishing any links between landscape evolution, climatic and environmental changes or stresses, and responses or adaptations by the human communities. Prior investigations at this site have been limited and there has been no palaeoenvironmental assessment. A second aim of this investigation was therefore to assess some of the assumptions that have underlain discussions of the site. Use of this site as a case study has allowed its results to be added to the corpus of regional evidence, and has furthered knowledge of the degree to which prehistoric agricultural settlements in North Mayo were vulnerable to particular environmental stresses. This final chapter summarises and concludes the findings from this investigation.

8.2 Summary

8.2.1 Summary of site findings

The sedimentary sequence opens in the Middle Neolithic at c. 5525 cal. BP when intensive agriculture was underway, in a disturbed landscape. The farming was evidently primarily pastoral, there being no direct evidence of arable cultivation in the palynological record. The field walls running downslope were assumed in previous investigations to be part of a field system constructed during the Neolithic, and this investigation corroborates that assumption, as well as placing a chronological framework upon their occupancy. The sedimentary sequence along the hillslope suggests that soil erosion occurred within the field system. This evidently caused significant stress upon the agriculture, because the sediment stratigraphy of the lower hillslope also indicates that turf stripping occurred, presumably in order to supplement the soils within the field system. That phase of farming came to an end at c. 5375 cal. BP and the palaeoenvironmental record suggests that continuing relative climatic dryness may have been a factor in abandonment, *via* the incremental effects of soil erosion and edaphic stress.

Following abandonment, the palynological record shows that woodland regeneration was rapid. The hillslope sediment stratigraphy suggests that woodland did not regenerate within the former fields. Outwith the fields, the increasing area covered by mire deposits was rapidly colonised by *Alnus*, and elsewhere on drier soils the main taxa were *Betula*, *Corylus*, *Quercus* and *Pinus*. Coincidentally with the *Pinus* decline at c. 4520 cal. BP, the humification record signals a peak in climatic wetness.

Secondary clearance commenced at c. 4100-4000 cal. BP, probably aided by fire. Mixed agriculture is in evidence palynologically from c. 3950 cal. BP. This farming phase continued until c. 3060 cal. BP, when there was either a temporary cessation of agriculture, or a reorganisation and spatial contraction of agricultural land. Many of the visible archaeological features were constructed during that long phase of agriculture, such as the timber extension to Wall 3 and the roundhouse.

On-site palaeoenvironmental study provided most of the information regarding the final phases of Late Bronze Age agriculture. Ard cultivation was fairly intensive, and although leaching and nutrient loss are in evidence, significant effort was made to cultivate the soils in the vicinity of the roundhouse. It is evident that midway through this farming phase, at c. 2840 cal. BP, the area under ard tillage was reduced in spatial extent. At some point, potentially the same time, the tillage method changed. The ard was no longer employed, and ridge-and-furrow cultivation was instead performed, probably using the spade. Soil erosion was occurring downslope from the cultivation plots at the time of this reorganisation, therefore it is possible that the change in tillage method was an adaptive response to deteriorating edaphic conditions. During the time that the ridges were cultivated, domestic wastes, including ash and kitchen refuse, were used as fertiliser, although this form of manuring was not employed intensively. This agricultural phase finished in the mid-third millennium cal. BP. Cultivation had been continuing in the face of peat encroachment for some time, and it is possible that a cooler wetter climate accelerated blanket bog expansion, tipping the balance of agricultural risk associated with settlement at the site.

8.2.2 Regional significance

The vegetation sequence and settlement chronology during the Neolithic occupation phase at Belderg were typical when considered in a regional context. Although there is no direct evidence of cereal cultivation during the Neolithic, palaeoenvironmental analysis of other sites in North Mayo suggests that self-sufficient economies were the norm, based on pastoral agriculture with small-scale arable cultivation. As it is unlikely that any of the identified locations might have been used to produce significant cereal surpluses, it is concluded that the Neolithic farmers at Belderg Beg probably practiced a similar agricultural production economy to those at the other known sites. There is significant evidence on a regional scale (North Mayo and Connemara) that substantial agricultural settlement occurred in the centuries after the *Ulmus* decline of c. 5800-5900 cal. BP, and that widespread abandonment ensued during the Middle Neolithic. The cause of this phenomenon is elusive, but the incremented results from Belderg Beg and Céide Fields suggest that relative climatic dryness may have compounded soil erosion in North Mayo.

Bronze Age occupation in North Mayo and in western Ireland as a whole is less well chronologically defined. However, the economy in North Mayo was apparently little changed from the Neolithic, in that pastoral agriculture with a minor arable element prevailed. Later in the Bronze Age, arable tillage techniques became more refined and cultivation intensified, although still on a small scale. The area under agriculture at Belderg Beg may have been reduced in comparison to the Neolithic, similarly to the situation at Céide Fields. Self-sufficient communities, possibly with lower population levels than the Neolithic, are interpreted to have inhabited sites such as Belderg Beg, Céide Fields and Carrownaglogh. Peat spread and soil erosion during the Bronze Age occupation of Belderg Beg may have been a causal factor in its abandonment in the mid-third millennium cal. BP. The regional evidence suggests that this was not such a marked common feature at that time, in contrast to the Middle Neolithic abandonment.

8.3 Importance of the site and the results

8.3.1 Importance of the findings

The investigations at Belderg Beg have proved the site to be of great importance in terms of its local and regional archaeological and palaeoenvironmental contexts. The findings go some way to identifying a likely common causal factor in the Middle Neolithic abandonment of agriculture in North Mayo – soil erosion and associated edaphic stress in a relatively dry climatic regime. Furthermore, the findings confirm that Belderg Beg was a relatively small field system. Its size and irregularity, along with its earlier date of abandonment, suggests that, along with Belderg Mór, it was perhaps a peripheral site, where Céide Fields was a regional core.

The findings of this investigation regarding Bronze Age occupation of Belderg Beg are important in terms of the site economy. Long-term occupation is indicated, and is mirrored at Céide Fields, although Bronze Age occupation and agriculture is less well chronologically defined on a regional scale than those of the Neolithic. Contrary to previous suggestions, this investigation concludes that the Bronze Age occupation was not concerned with exploitation of copper ore at Horse Island. The increasing intensity of arable cultivation in the Bronze Age and the changing techniques used to cultivate the deteriorating soils are of significance to characterisations of the region's prehistory.

8.3.2 Methodology and sampling strategies

This study has successfully realised its aims of reconstructing prehistoric agriculture and settlement chronology at Belderg Beg and relating the settlement dynamics to environmental conditions where appropriate. The sampling strategy may therefore be of relevance in influencing research design of investigations at other sites within the North Atlantic fringe. Although on-site investigation of ploughsoils depends on fortuitous excavation, the sampling strategy on a field system scale which may be recommended can be summarised.

- The use of sediment-stratigraphic characterisation on a landscape scale, i.e. across and outwith fields.
- Identification of off-site basins from which to reconstruct palaeoenvironmental conditions.
- Palaeoenvironmental analysis and AMS dating from objectively identified locations within fields, for comparison with the main palaeoenvironmental sequence.
- Soil micromorphological analysis of cultivation traces.

The use of soil micromorphological analysis has been of critical importance in the study and characterisation of Bronze Age agriculture at Belderg Beg. The soil micromorphological results from the ard-marked layer in particular are of great significance, not just to the site interpretation but to methodological research also. The characteristic features of ard cultivation exhibited in the BB1 profile have only recently been realised due to experimental work and detailed sampling strategies (Lewis 1998).

8.4 Opportunities and recommendations

8.4.1 Opportunities at Belderg Beg

There are several opportunities for further research at Belderg Beg to supplement the information incremented by previous excavations and this thesis. Although knowledge regarding the spatial extent of the Neolithic field system is hampered by modern buildings to the north and east of the site (see Figures 3.1 and 3.2), extensive probing and surveying to the west and south of the known extent of the field system may inform on the scale of agricultural settlement. Excavation of some sections of field walls (e.g. the downslope terminal of Wall 1: see Figure 5.1), with pollen and thin section micromorphological analysis of the soils and sediments contained by them, would further inform as to the nature and chronology of agricultural processes. This could operate by a targeted system of test pitting. Differentiation of functions across the field system could potentially be identified.

Extending the soil micromorphological investigation of the formerly cultivated soils would offer an opportunity to further knowledge of the length of time the soils were cultivated, and perhaps allow a fuller analysis of the ard-marks in the region of the BB2 section than was possible in the current investigation. A detailed, thorough sampling strategy incorporating all features of the ard-marks and the cultivation ridges would be required. This would benefit knowledge not just of this particular site, but also the general recognition of archaeological arable cultivation. Soil micromorphology could also be employed within the roundhouse and other enclosures within the site to identify functionality.

8.4.2 Recommendations based upon sampling strategy

There has been no soil micromorphological work in an archaeological context in Ireland published to date; a situation in contrast to that in mainland Britain and North West Europe. This study has shown how soil micromorphology can be a valuable technique to identify and characterise former agricultural practices. Soil micromorphological analysis in conjunction with soil pollen analysis and AMS dating of discrete locations within identified former agricultural sites would considerably add to the collective knowledge regarding prehistoric agriculture in western Ireland, bringing knowledge in line with that from mainland Britain and the Scottish islands. For instance, knowledge of agricultural practices such as manuring is hitherto unavailable, and soil micromorphology could readily rectify this information gap. More detailed site-based investigation, including excavation, to locate precise activity areas would be ideal, in order to bring the Irish prehistoric settlement data in line with that from, for instance, Atlantic Scotland.

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Figure 2.1: Irish Neolithic houses and settlement sites. From Grogan 2004, 106.

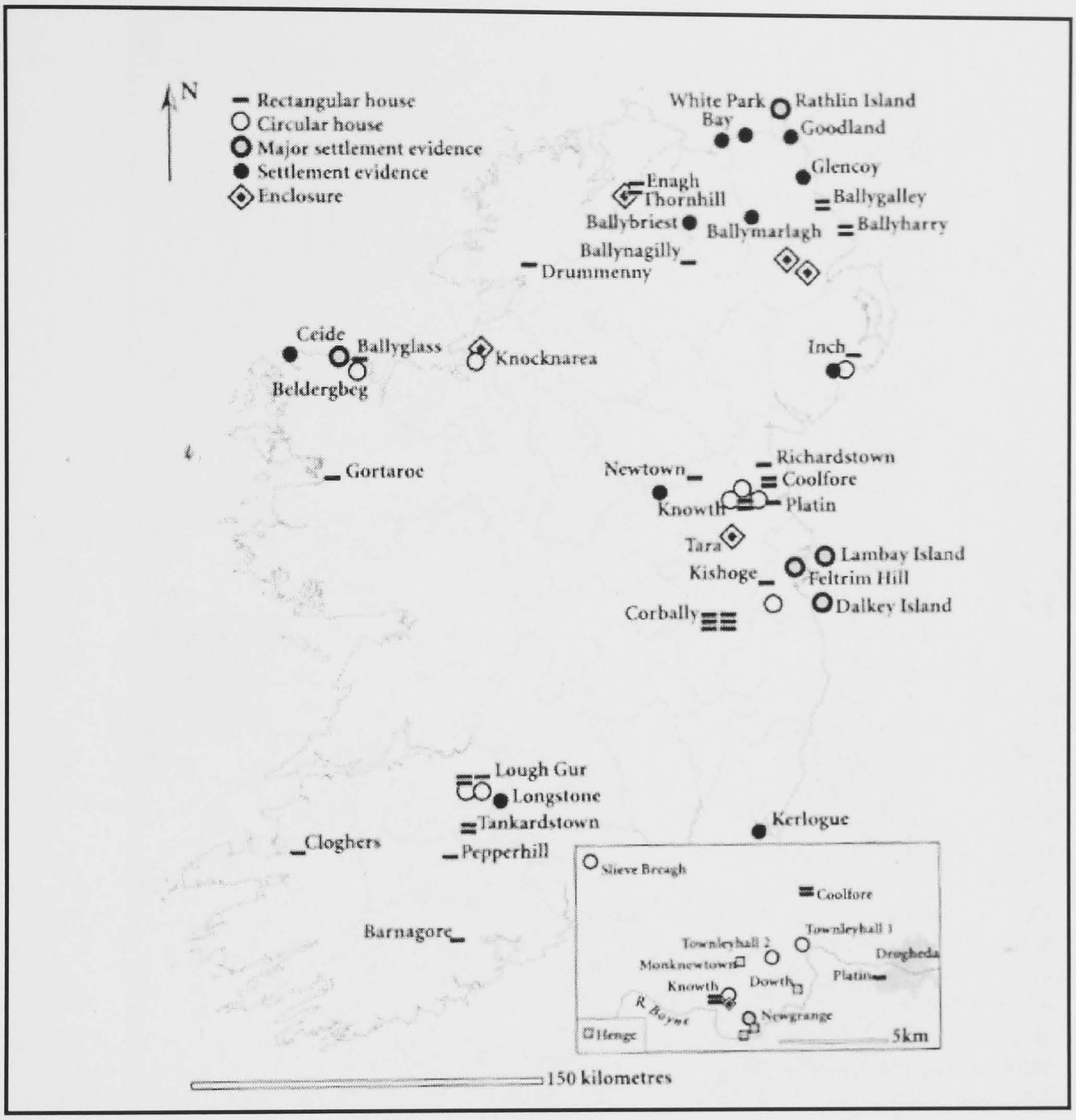
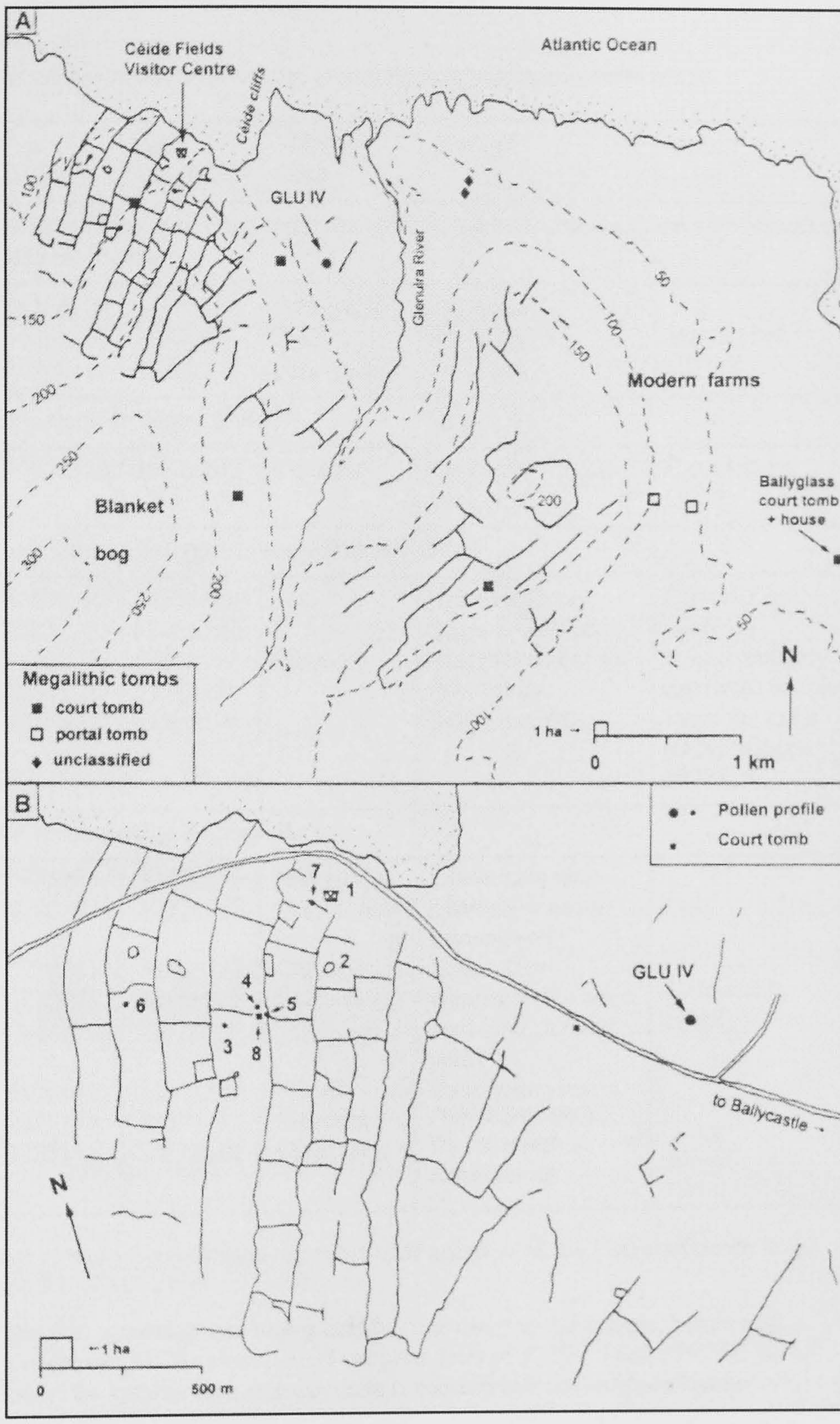


Figure 2.2: Plan of Céide Fields. From Molloy & O'Connell 1995, 191.



A: Field boundaries (solid lines) based on known extent of system in 1991. Megalithic tombs and contours in metres are also shown. Most of the area to the east of the Glenulra river and below the 150m contour is modern farmland, so that it is not possible to distinguish early field boundaries.

B: Detail of Céide Fields showing location of pollen profiles and court tombs. 1=Visitor Centre; 2=Glenulra Enclosure; 3=BHY III; 4=BHY IV; 5=BHY V; 6=BHY VI; 7=CF Ib and III; 8=Behy megalithic court tomb.

Figure 2.3: Céide Fields (GLU IV) pollen percentage diagram. From Molloy & O'Connell 1995.

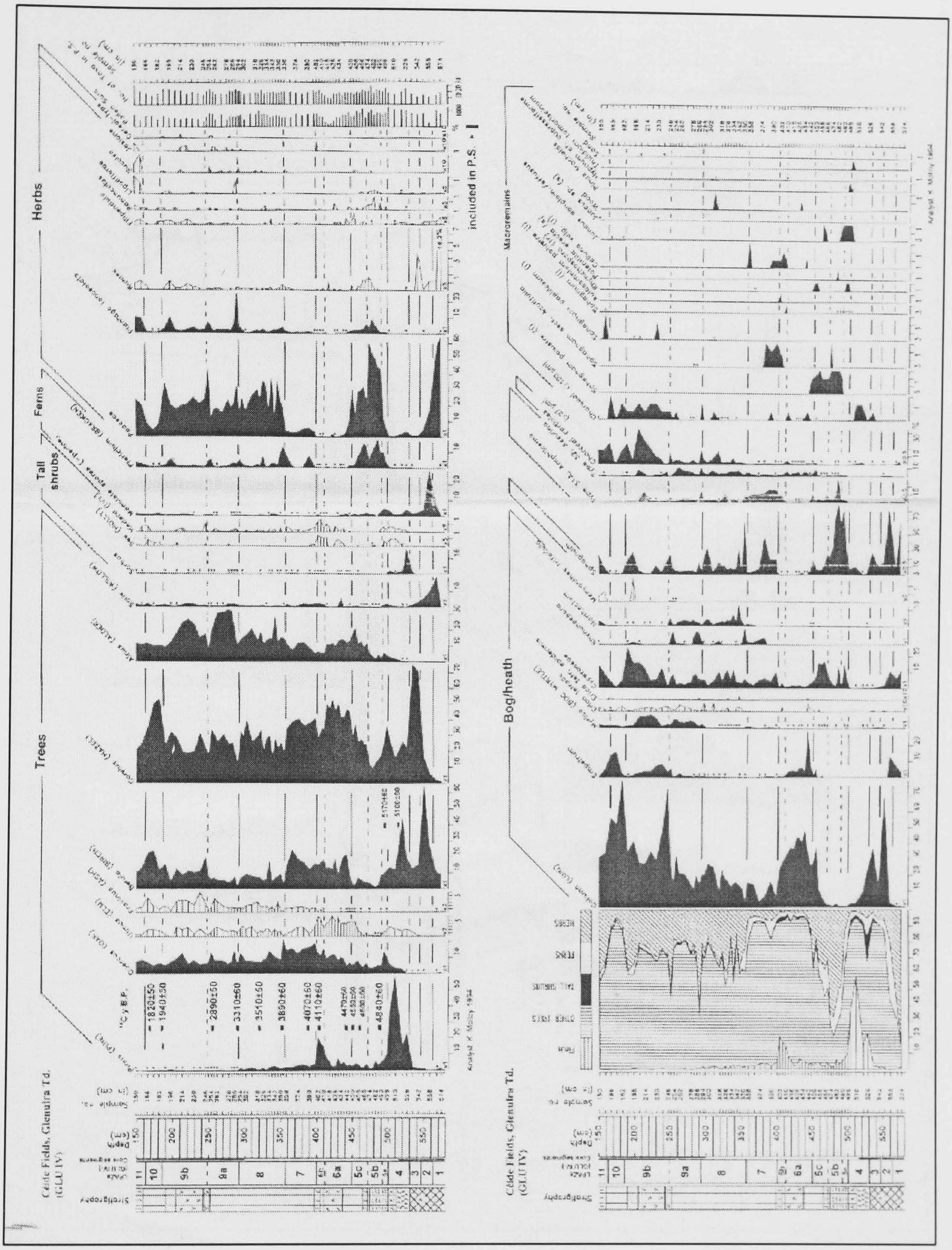


Figure 2.4: Plan of Rathlackan prehistoric landscape. From G. Byrne (unpublished).

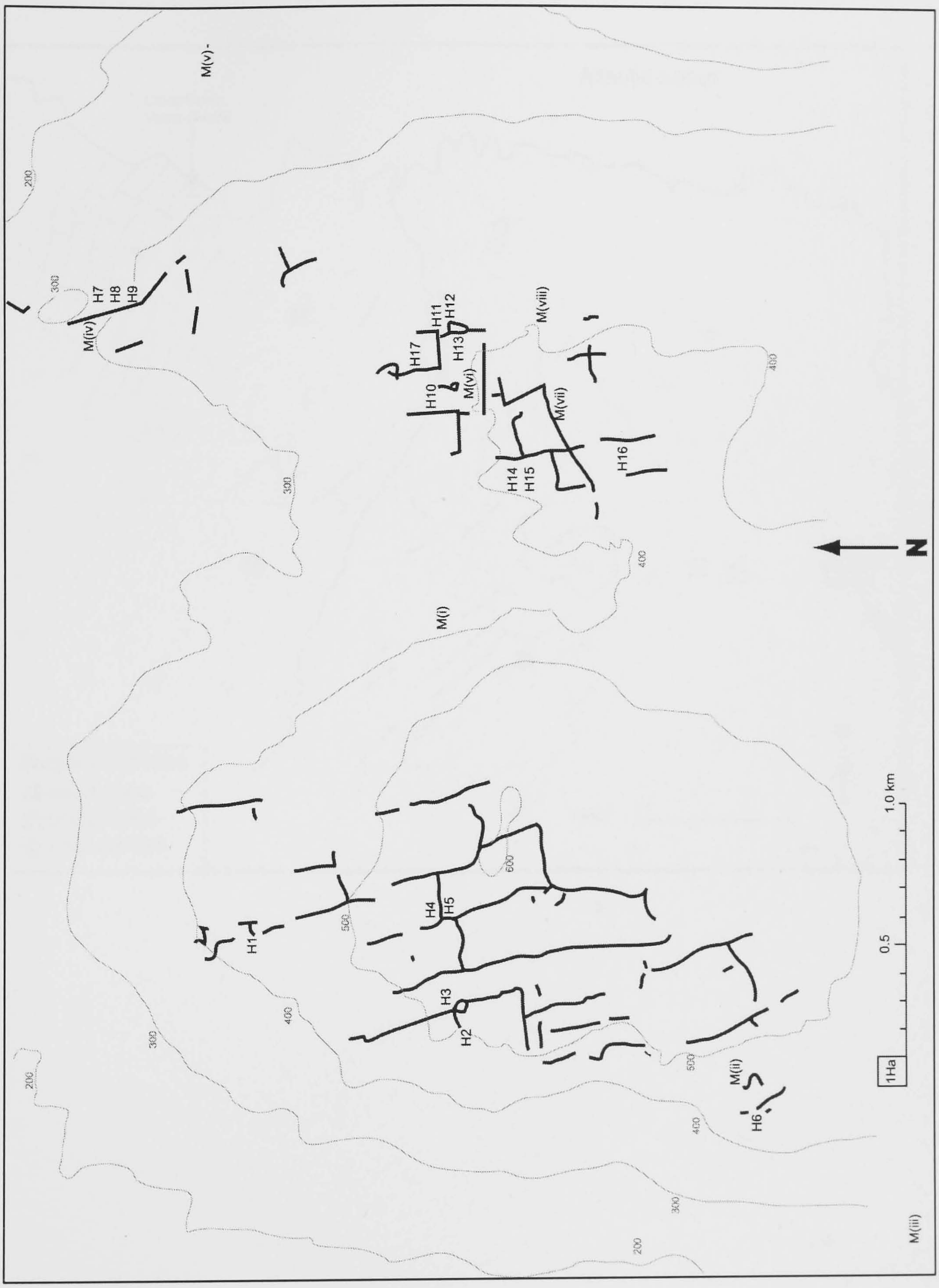


Figure 2.5: Plan of Céide Fields showing locations of megalithic tombs. Adapted from Molloy & O'Connell 1995, 191.

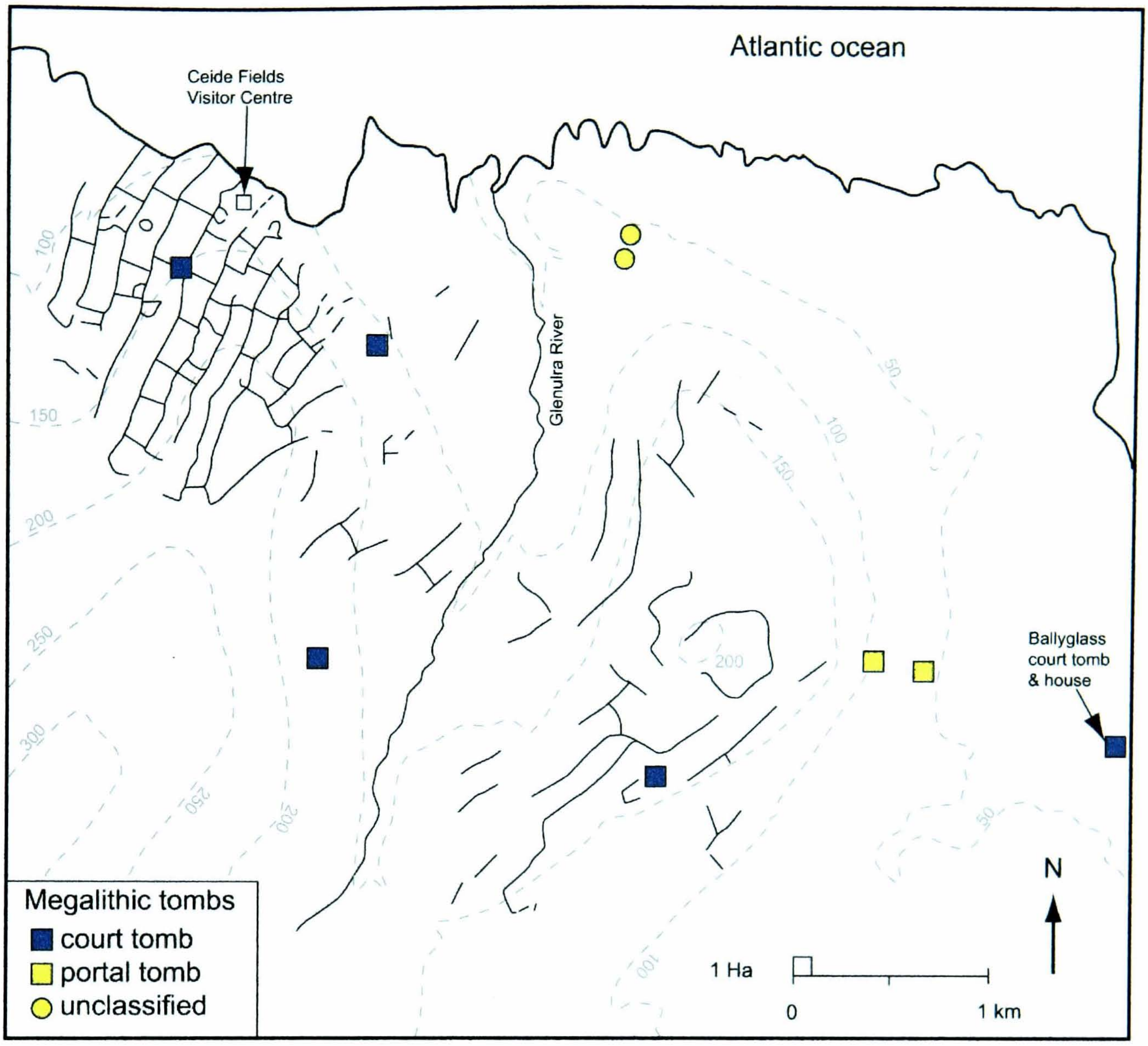
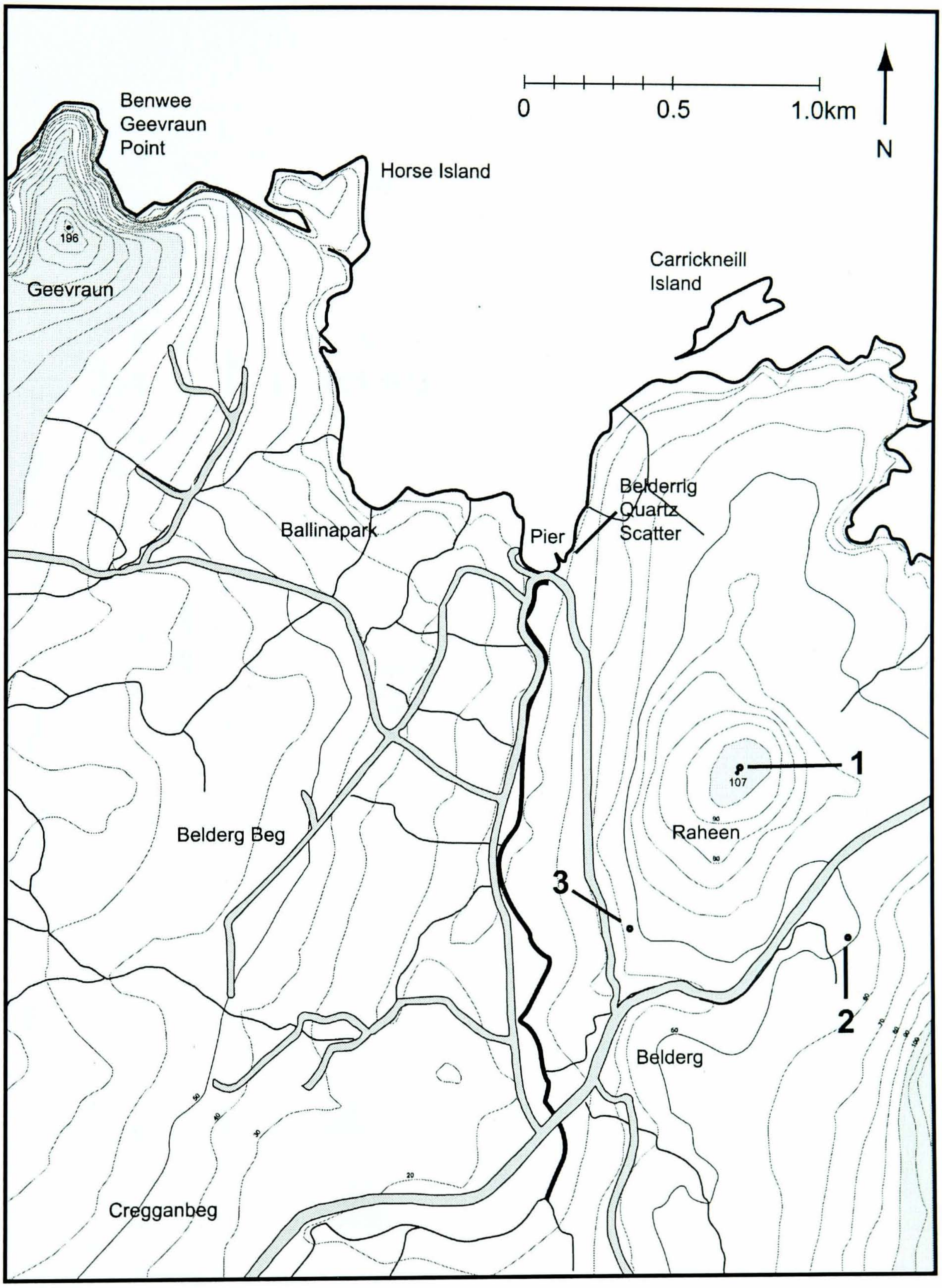


Figure 2.6: Plan of Belderrig area showing locations of megalithic tombs in the vicinity of the Belderg Mór pre-peat field walls



Shaded contours represent areas over 100m O.D.

Cross-reference megalithic tombs to Figure 3.1

Figure 2.7: Céide Fields pollen percentage diagrams (BHY III and IV). From Molloy & O'Connell 1995.

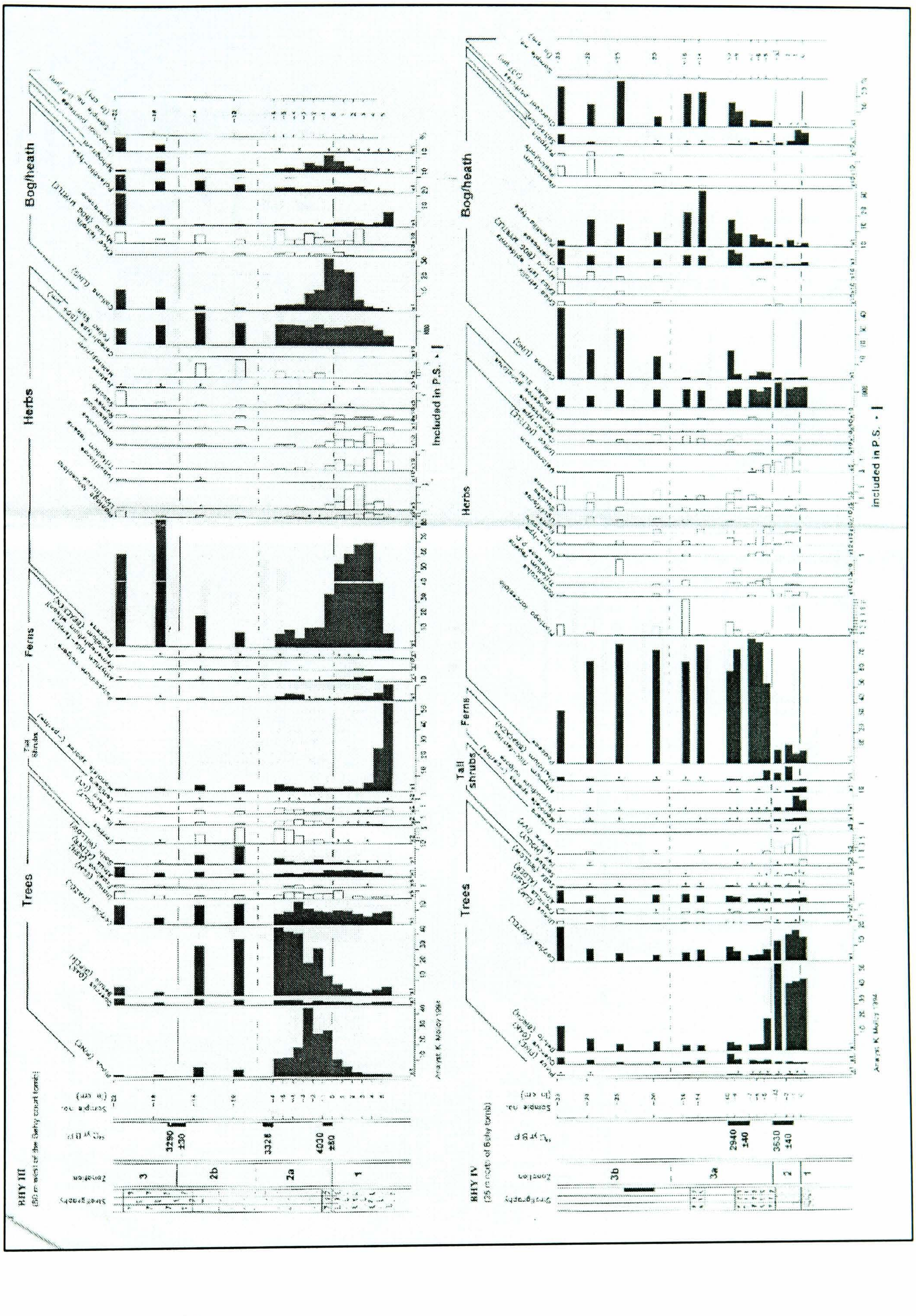


Figure 2.8: Céide Fields pollen percentage diagram (BHY V). From Molloy & O'Connell 1995.

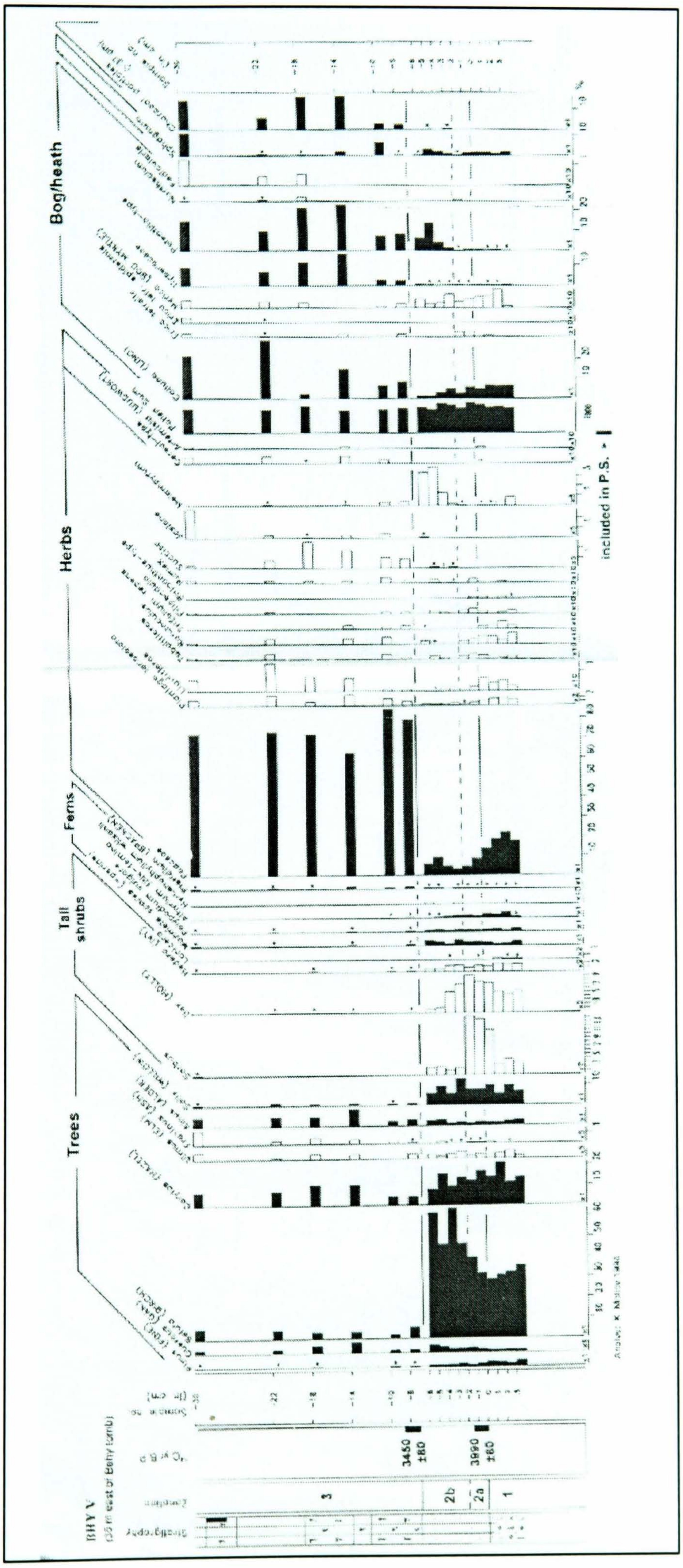


Figure 2.9: Céide Fields pollen percentage diagram (BHY VI). From Molloy & O'Connell 1995.

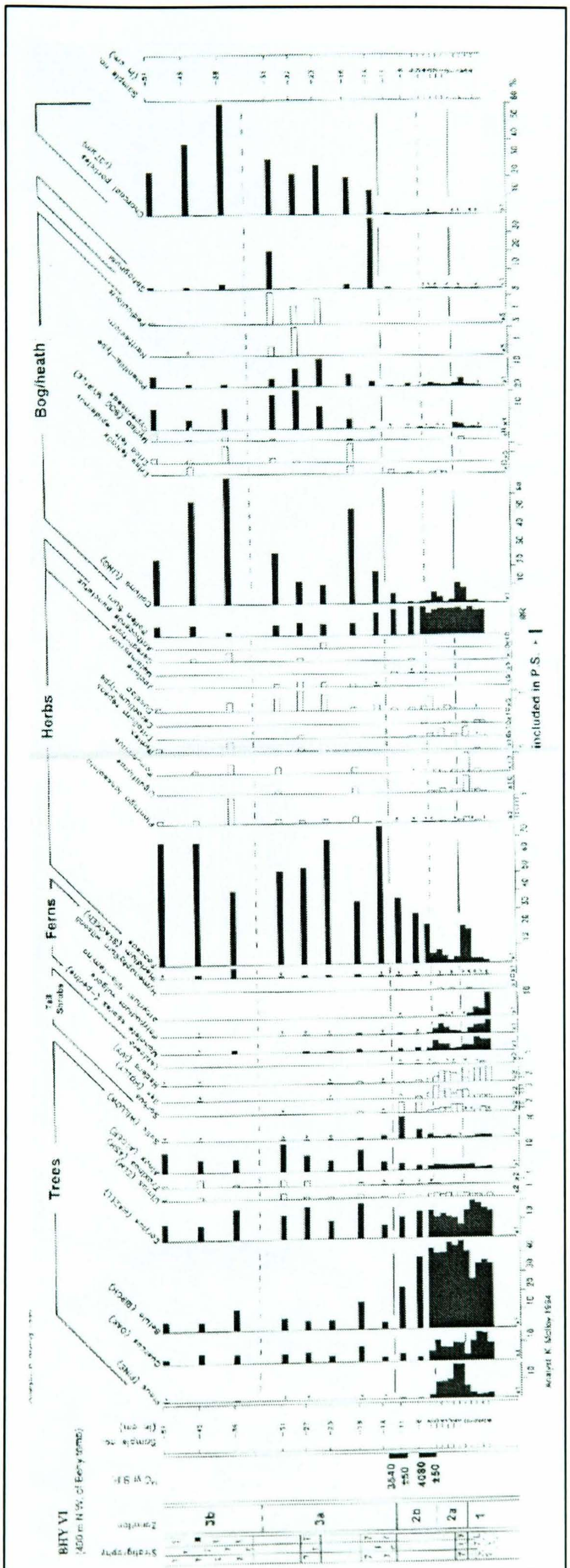


Figure 2.10: Céide Fields pollen percentage diagrams (CF Ib and CF III). From Molloy & O'Connell 1995.

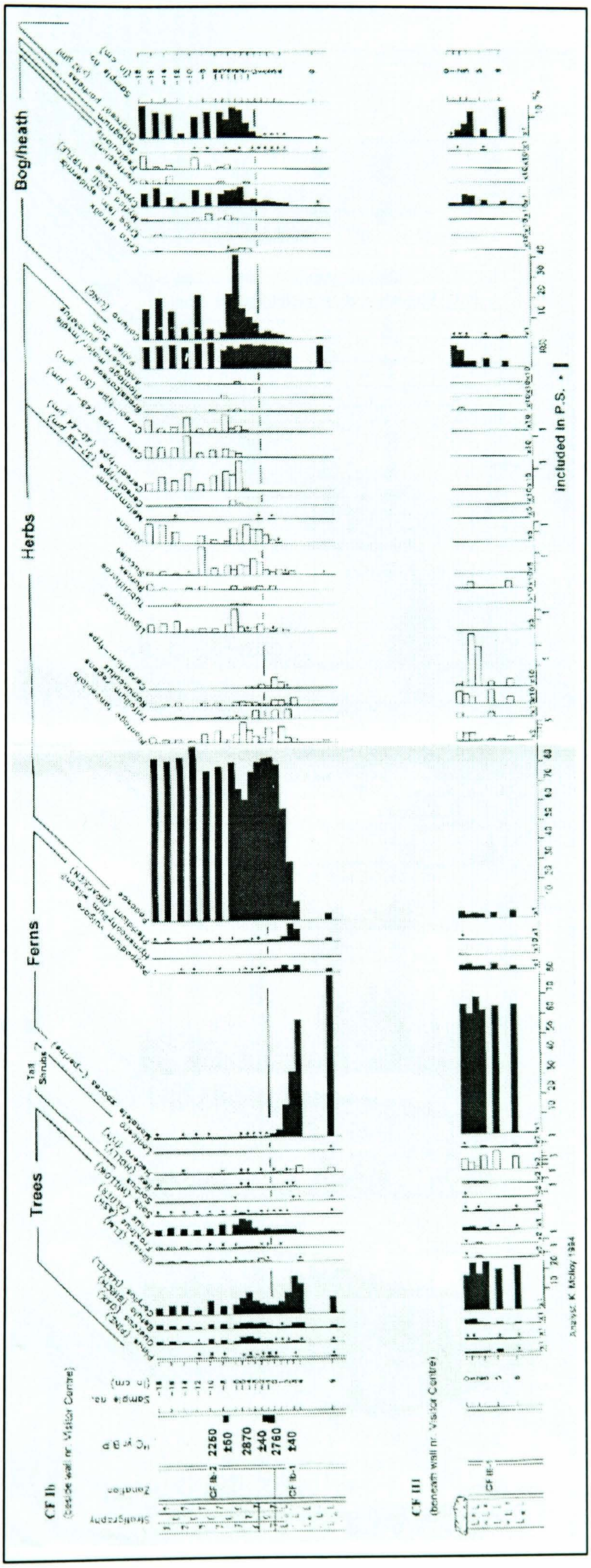


Figure 2.11: Céide Fields pollen percentage diagram (ploughmark infills). From Molloy & O'Connell 1995.

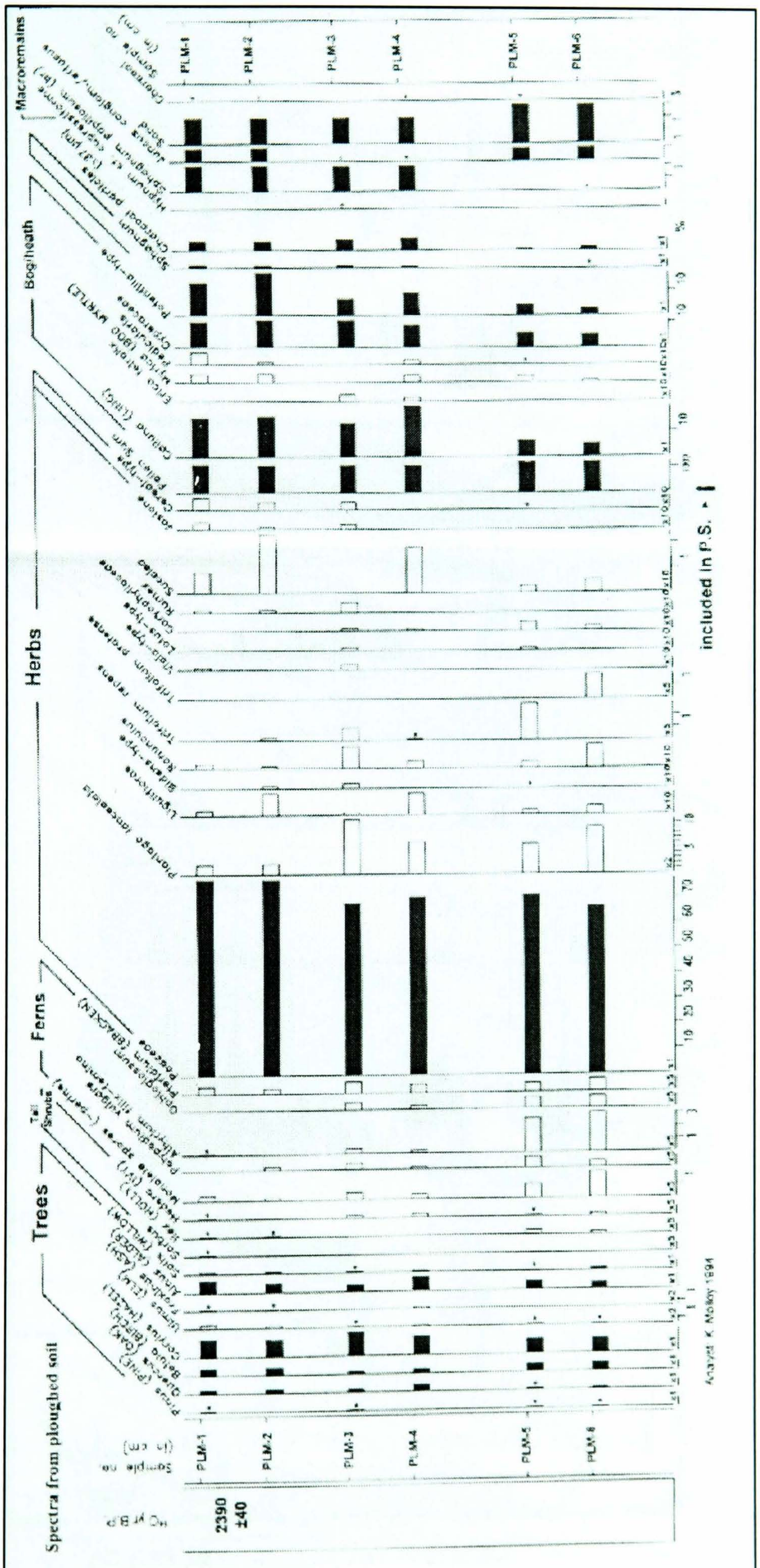


Figure 2.12: Solid geology of North Mayo. Adapted from Coxon 1991, 5.

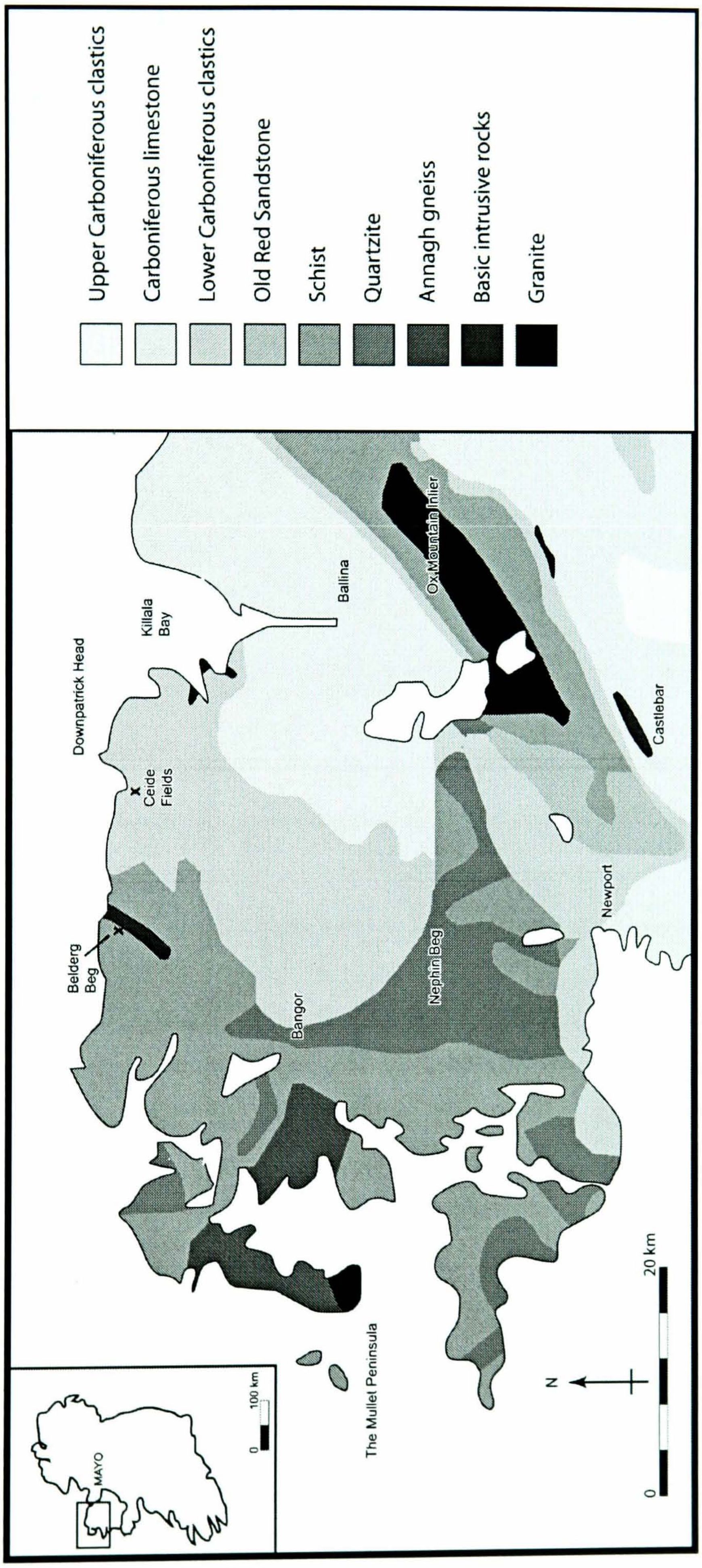
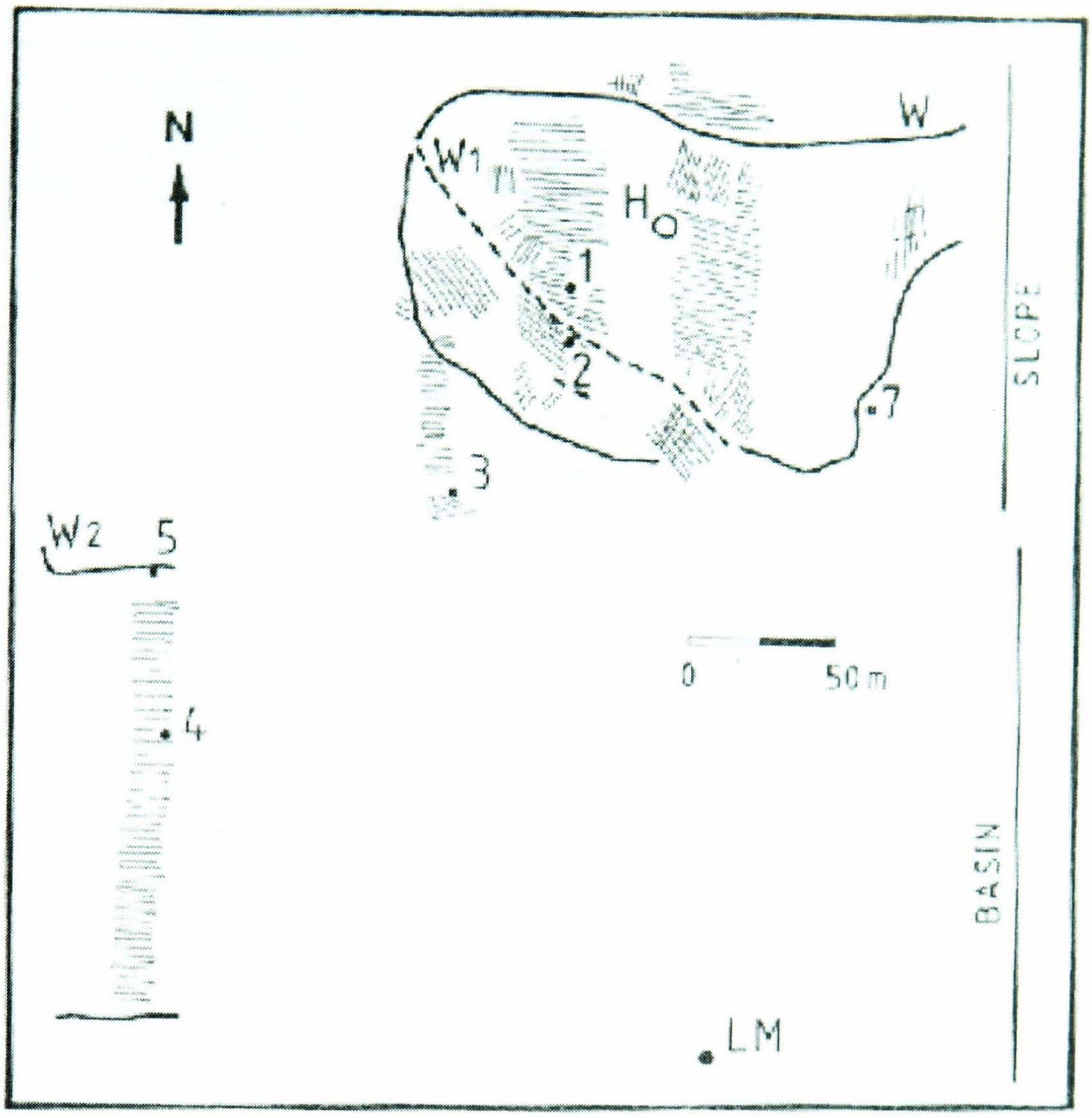
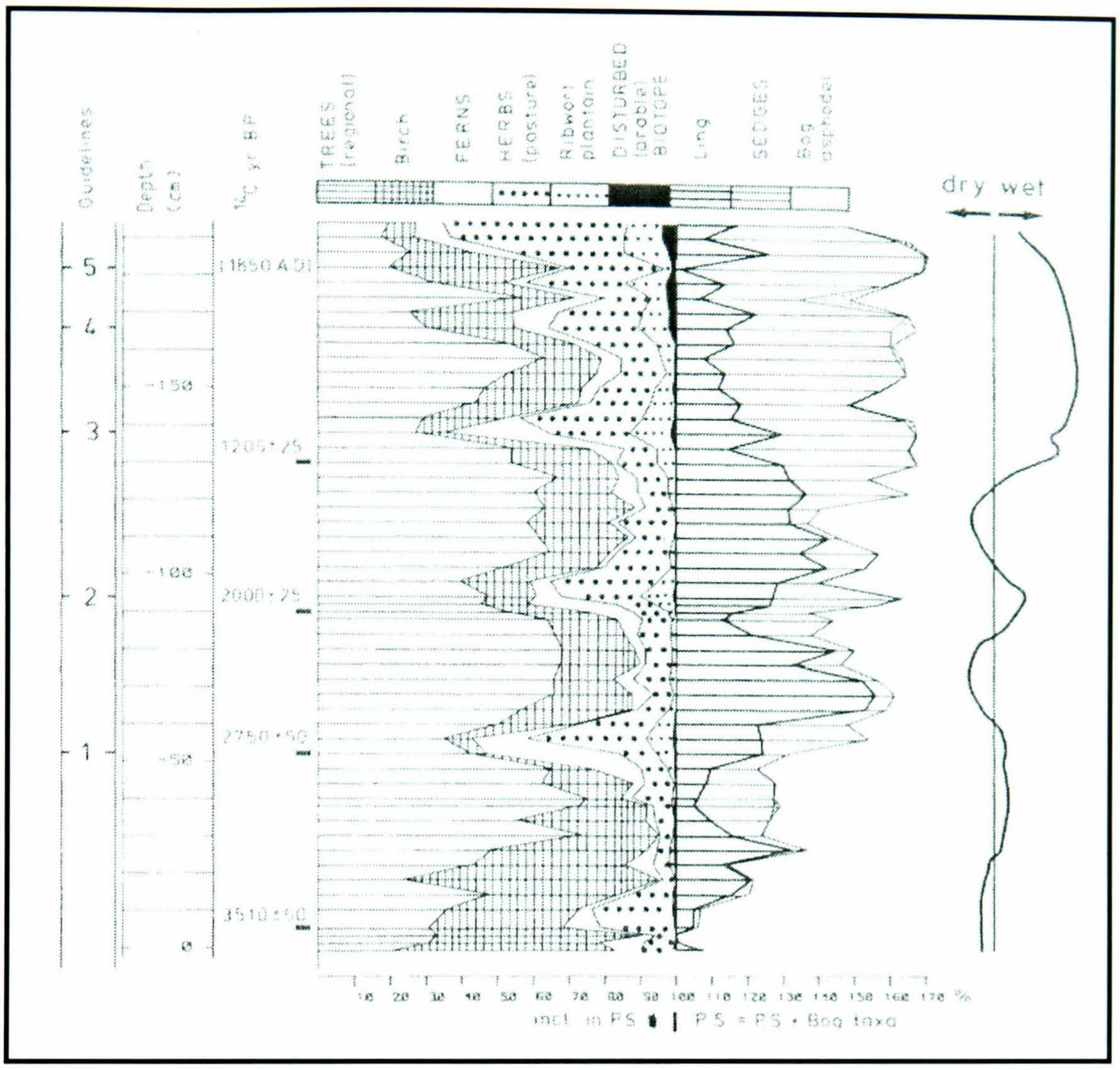


Figure 2.13: Plan of Carrownaglogh prehistoric site. From O'Connell 1990b, 261.



Stone walls are indicated by thick lines; thick broken lines indicate robbed stone walls. W=main enclosure wall; W1=primary robbed wall; W2=wall partly on peat. The ridges and their orientation in parts of the site cleared of peat during the course of the archaeological excavation are schematically represented. Sampling locations (1-5 and 7 and LM: Long Monolith) are indicated by closed circles. H= hut site, a low circular enclosure with hearth.

Figure 2.14: Pollen percentage profile from Carrownaglogh (Long Monolith). From O'Connell 1990b, 262.



Composite curves shown. Taxa of predominantly local bog origin were excluded from the pollen sum to avoid distortion of the other curves, which represent mainly vegetation of the surrounding mineral soil ground.

Figure 2.15: Pollen percentage profiles from Carrownaglogh (short profiles). From O'Connell 1990b, 265.

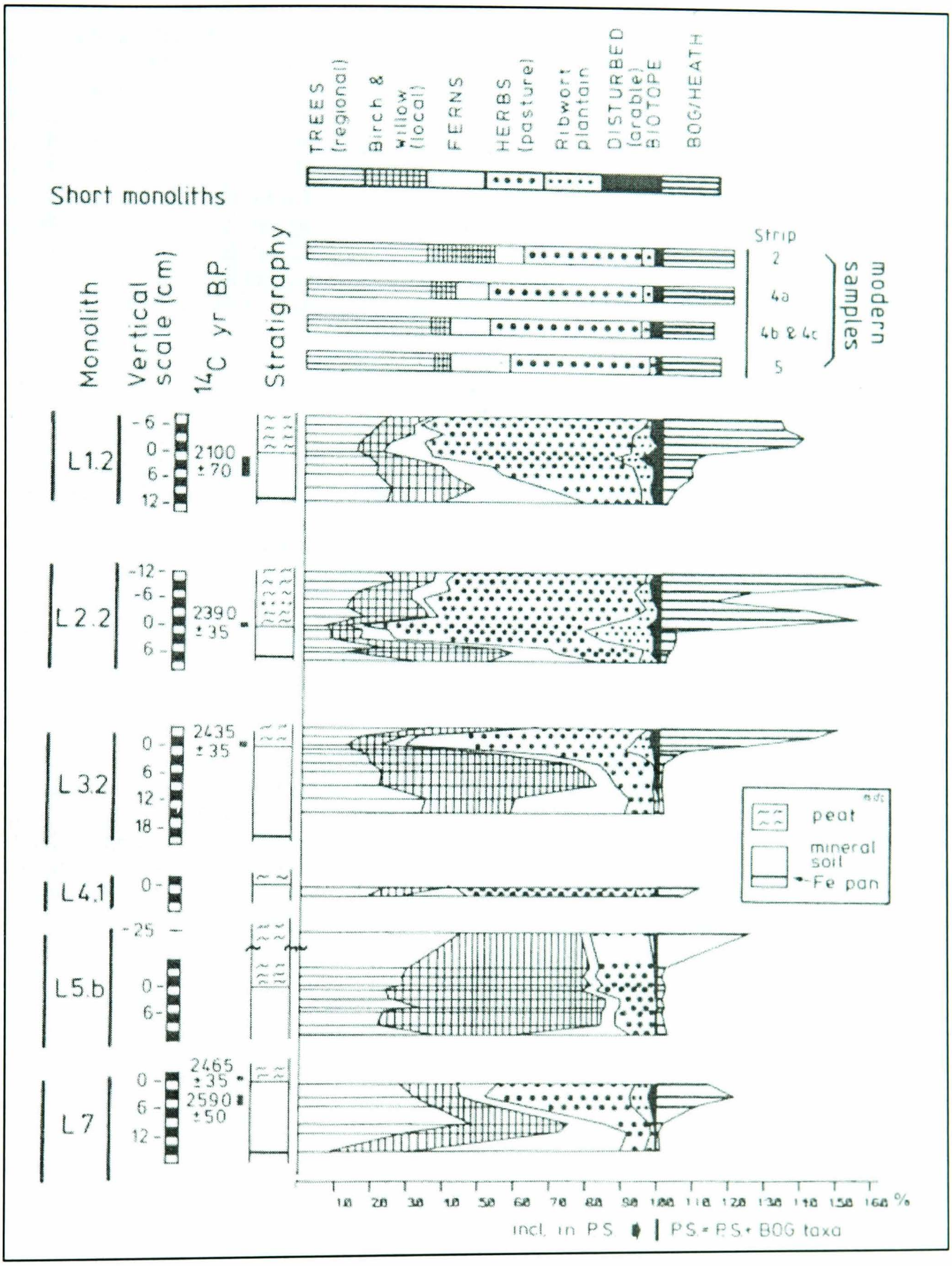


Figure 2.16: Subfossil pine dates in North Mayo. Redrawn from Caulfield *et al* 1998, 636.

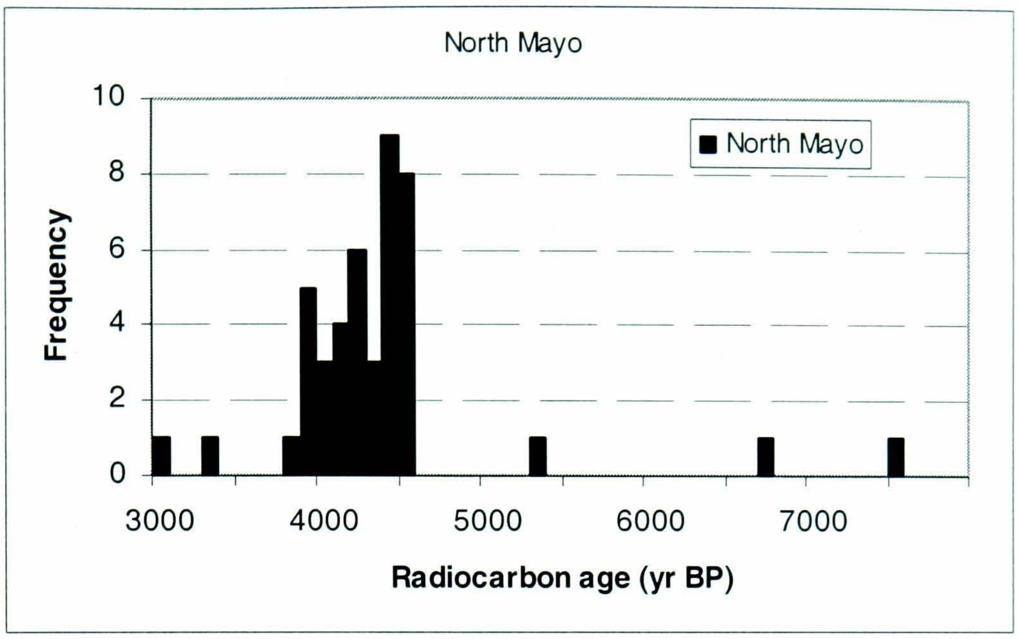


Figure 2.17: Subfossil pine dates in northern Scotland. Redrawn from Caulfield *et al* 1998, 636.

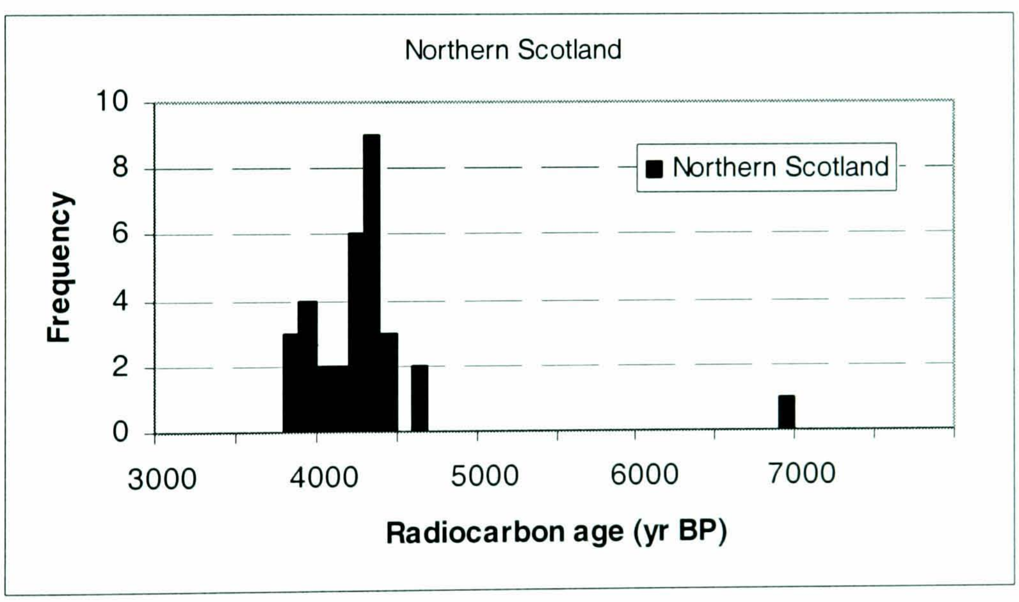
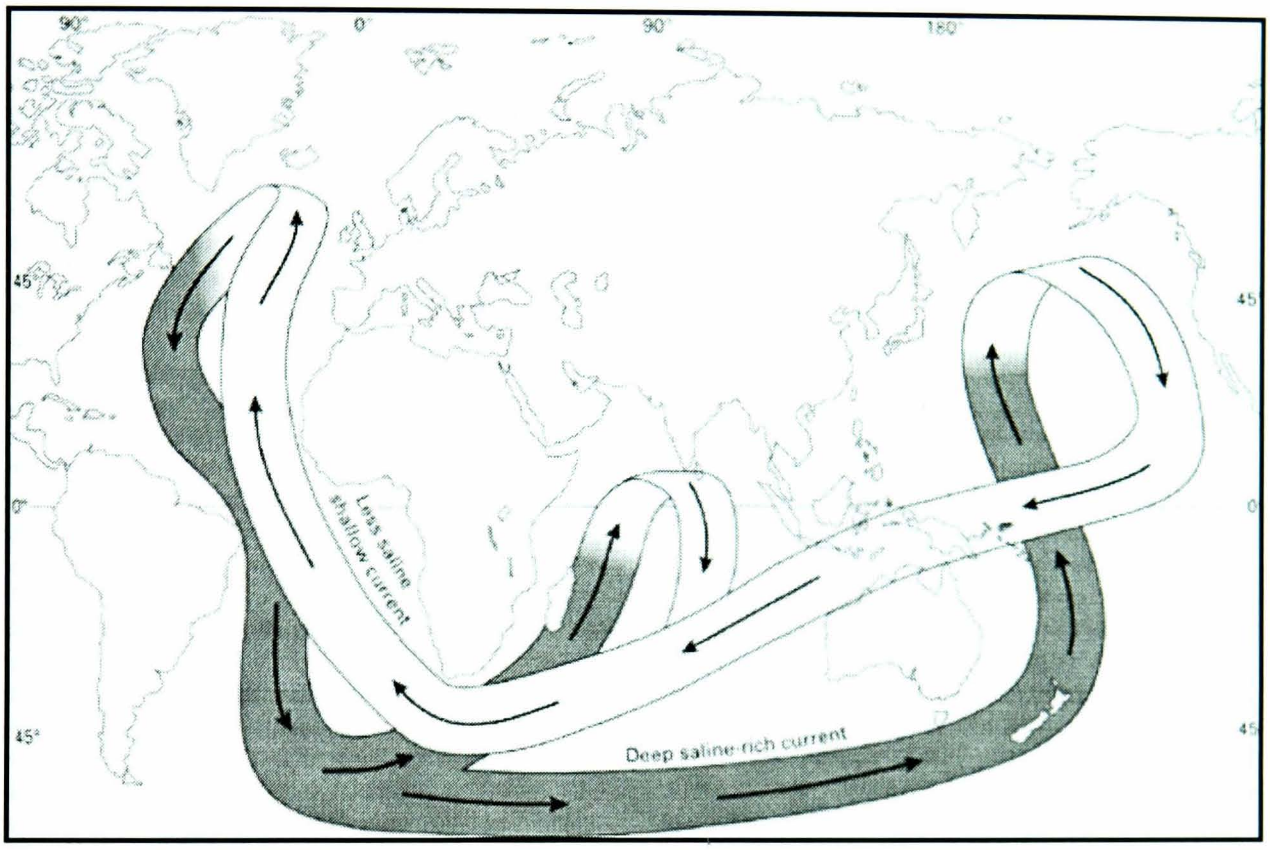


Figure 2.18: Thermohaline oceanic circulation.

The oceanic conveyor compensates for water transported as vapour from the Atlantic to the Pacific Ocean through the atmosphere. Dense salty deep water formed in the northern Atlantic flows down the length of the Atlantic and eventually northwards into the deep Pacific. Some of this water upwells in the northern Pacific, bringing with it the salt remaining in the Atlantic due to vapour transport. From Lowe & Walker 1997, 363; after original in Broecker & Denton 1990.



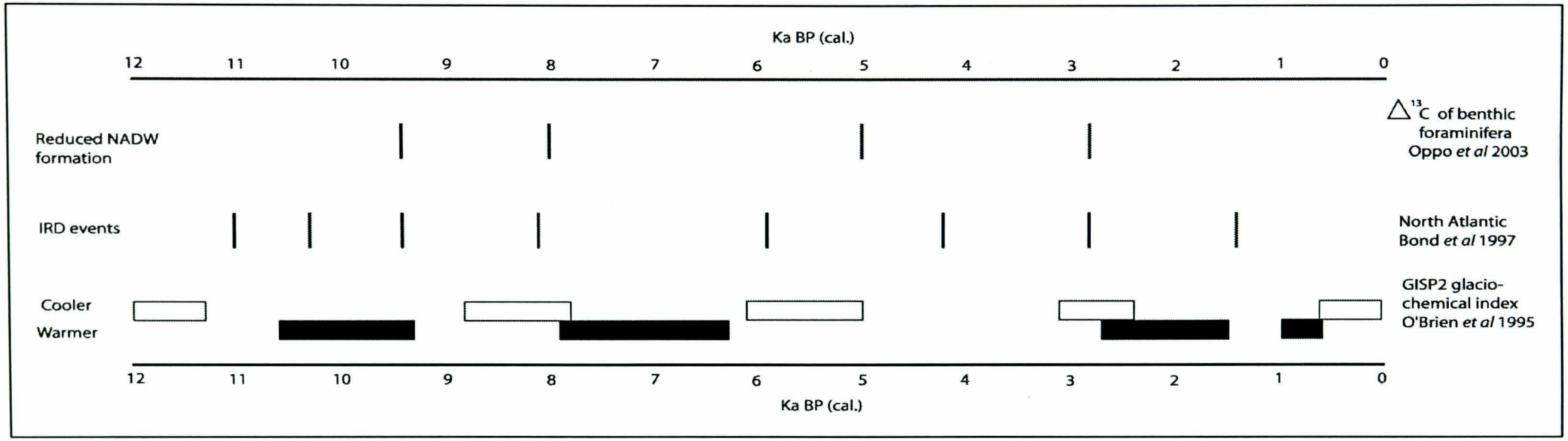


Figure 2.19: North Atlantic marine and ice-core records of Holocene climatic fluctuations

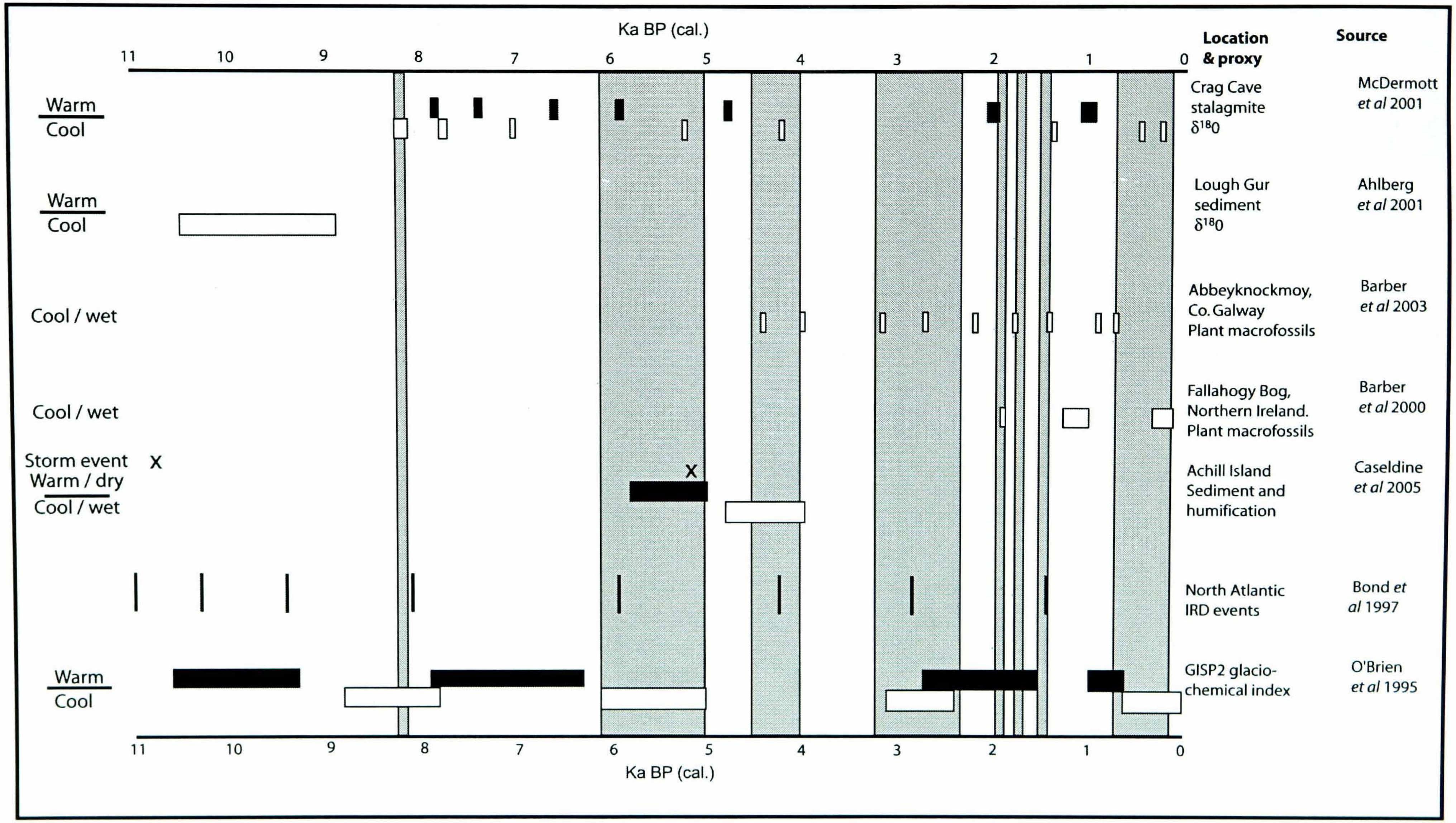
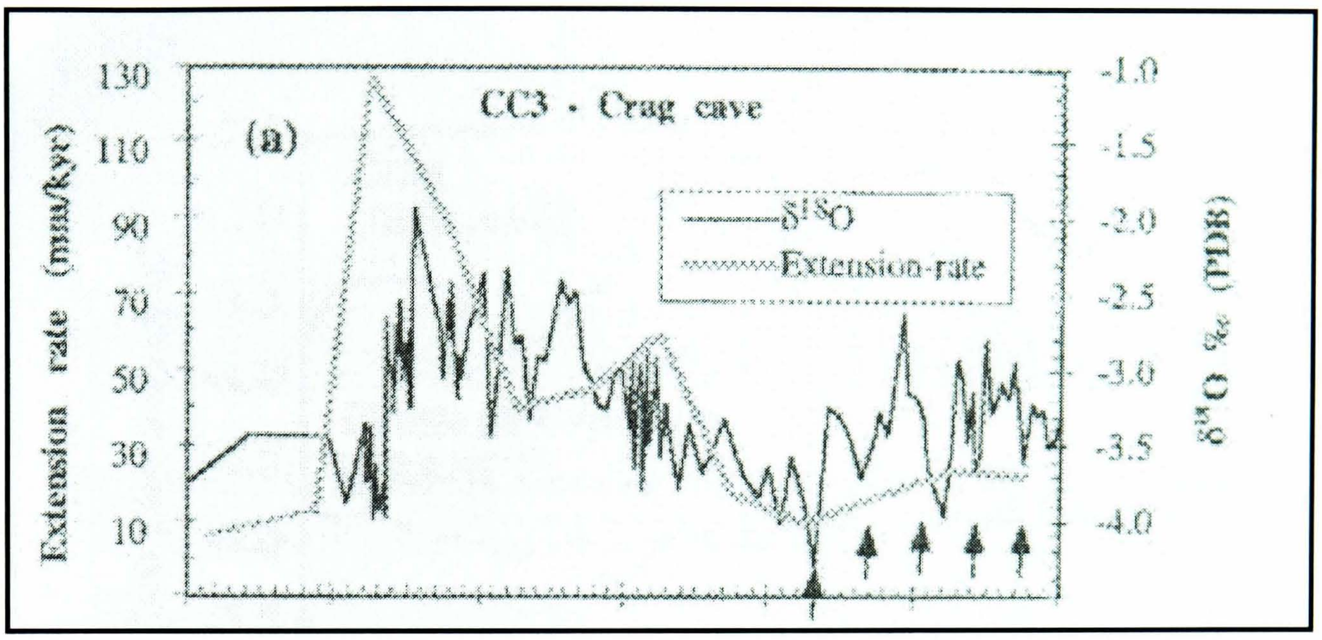


Figure 2.20: Holocene palaeoclimatic and palaeoenvironmental indicators from Ireland

Figure 2.21: Extension rate and $\delta^{18}O$ values for Crag Cave stalagmite, Co. Kerry. Arrows denote the timing of wet shifts recorded in Scottish mires (Chambers *et al* 1997), many of which appear to coincide with second-order troughs in the $\delta^{18}O$ curve. From McDermott *et al* 1999, 1028.



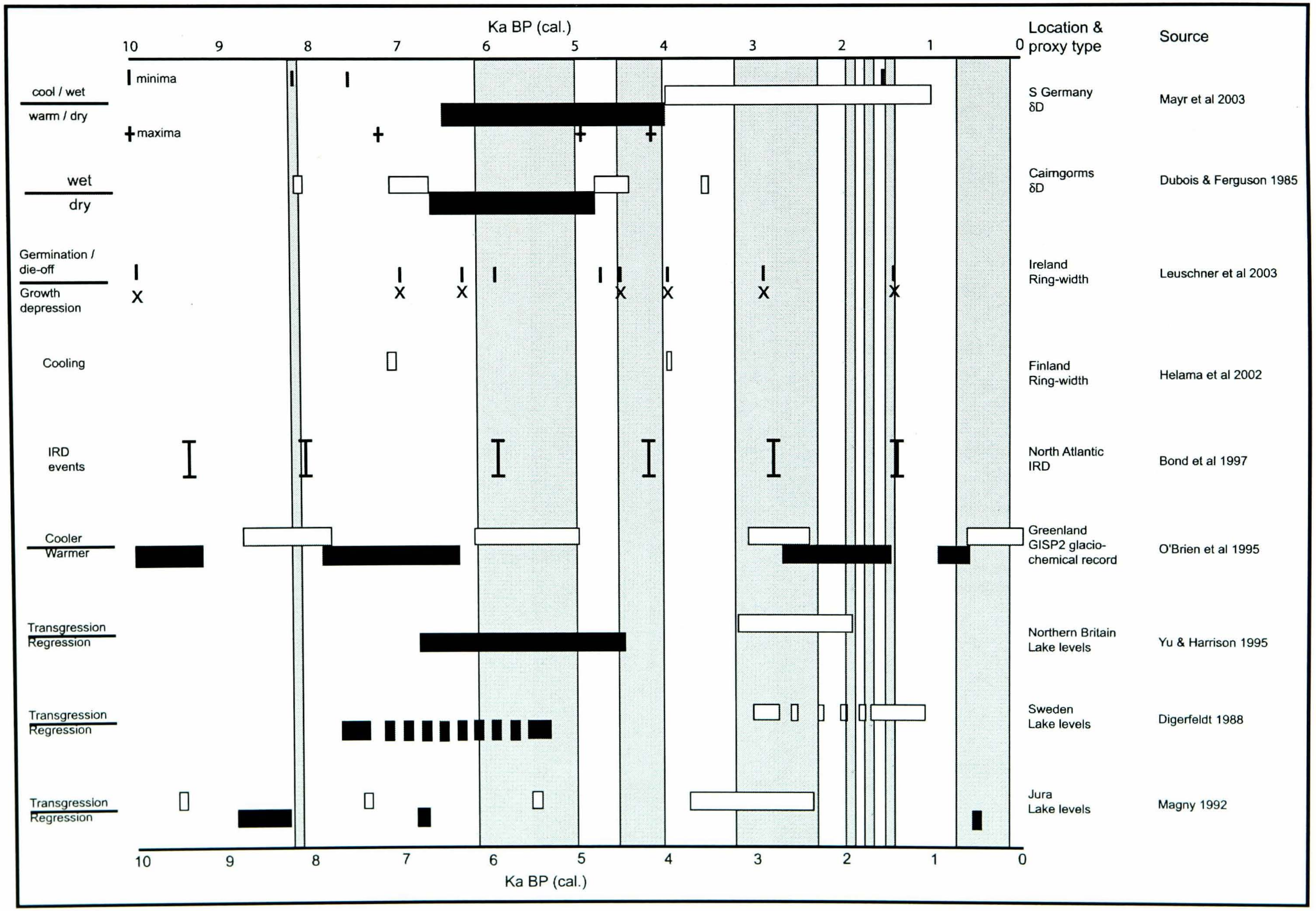


Figure 2.22: North-west European tree-ring and lake-level records of Holocene climatic fluctuations

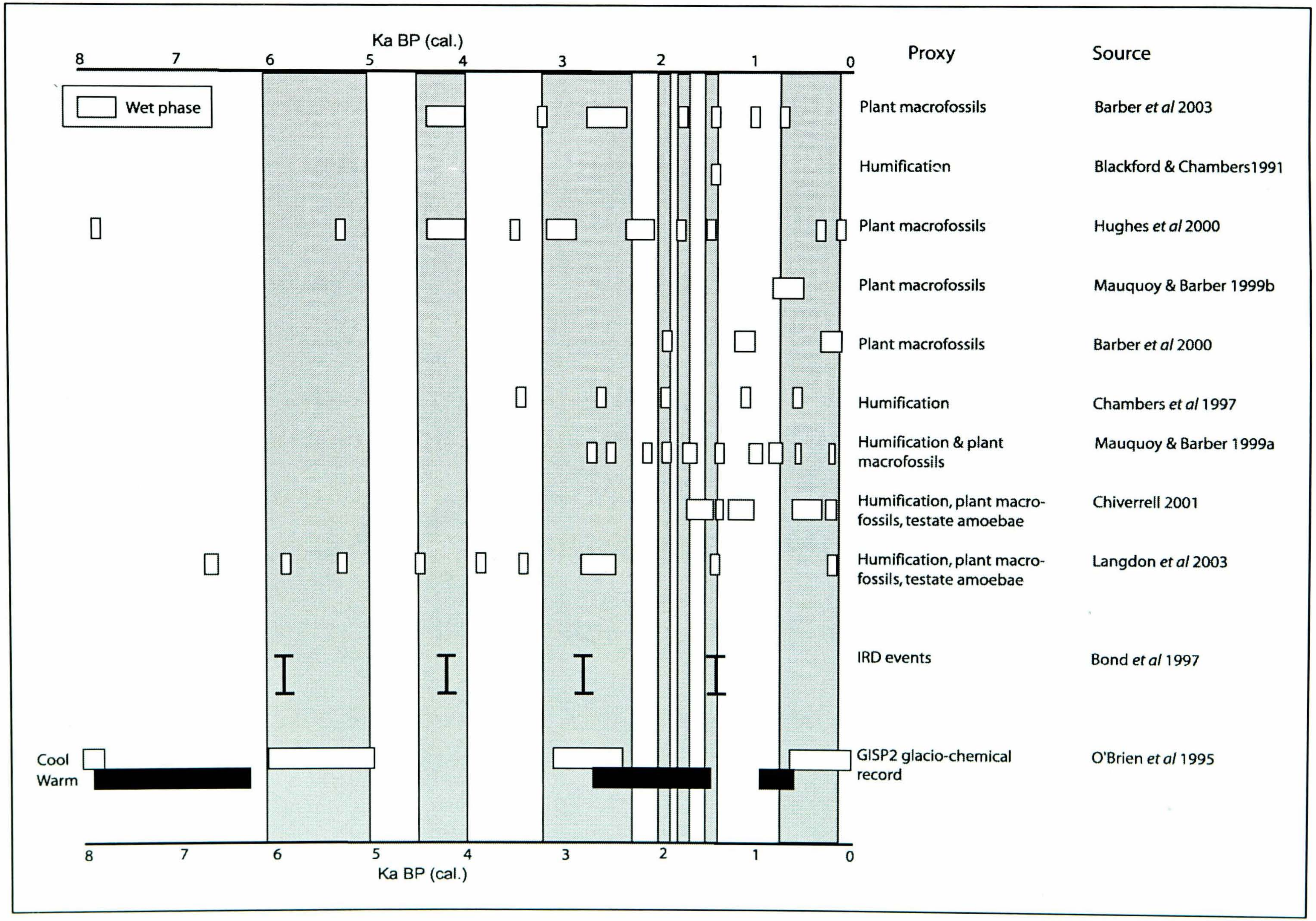


Figure 2.23: Records of Holocene climatic fluctuation from British and Irish ombrotrophic mires

Figure 2.24: Soil map of Ireland. From Agmet, 1980.

http://www.ucd.ie/agmet/Publications/Atlas/Soils_colour.html, accessed 09/01/06

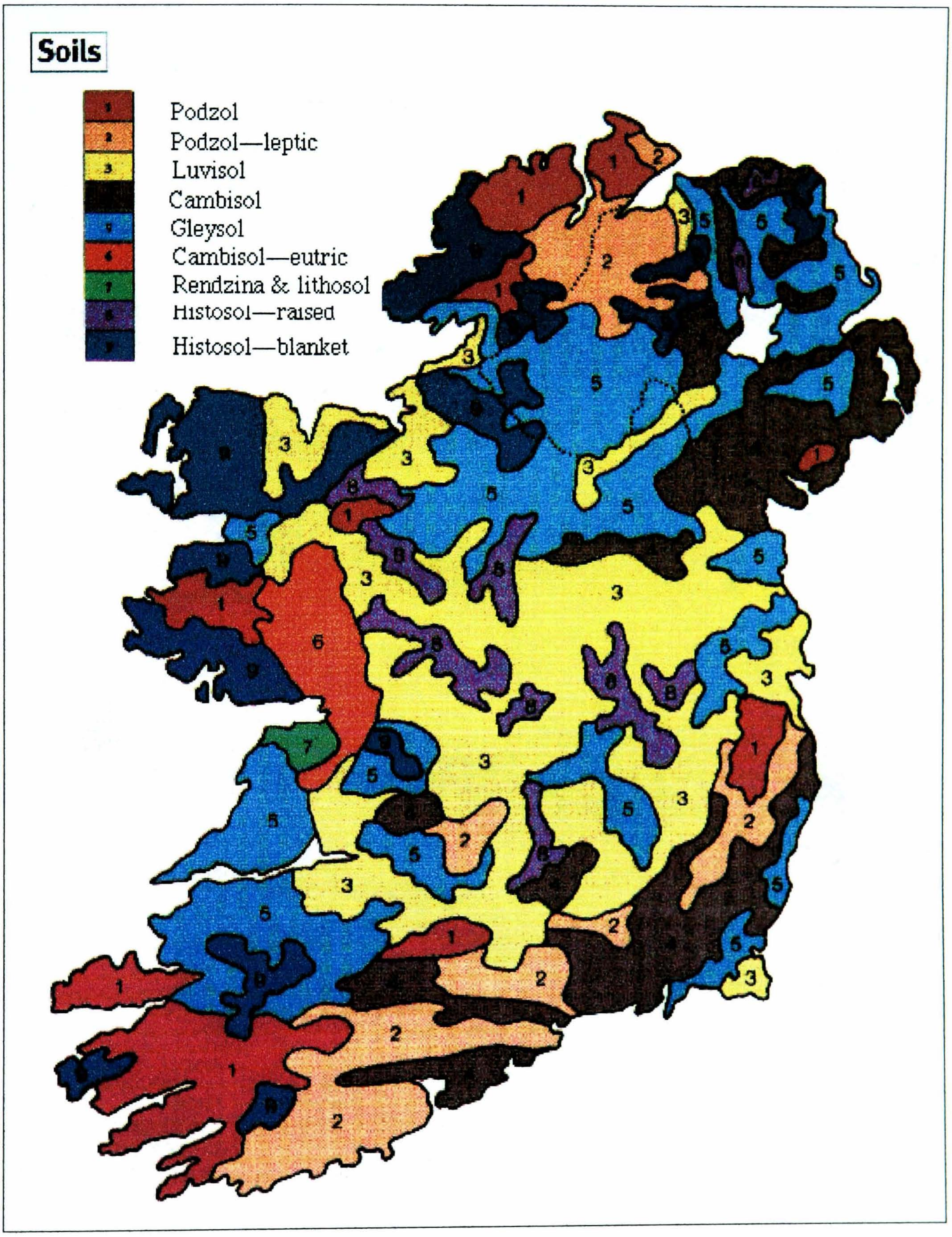


Figure 2.25: Map of North Mayo showing sites discussed in Chapter Two.

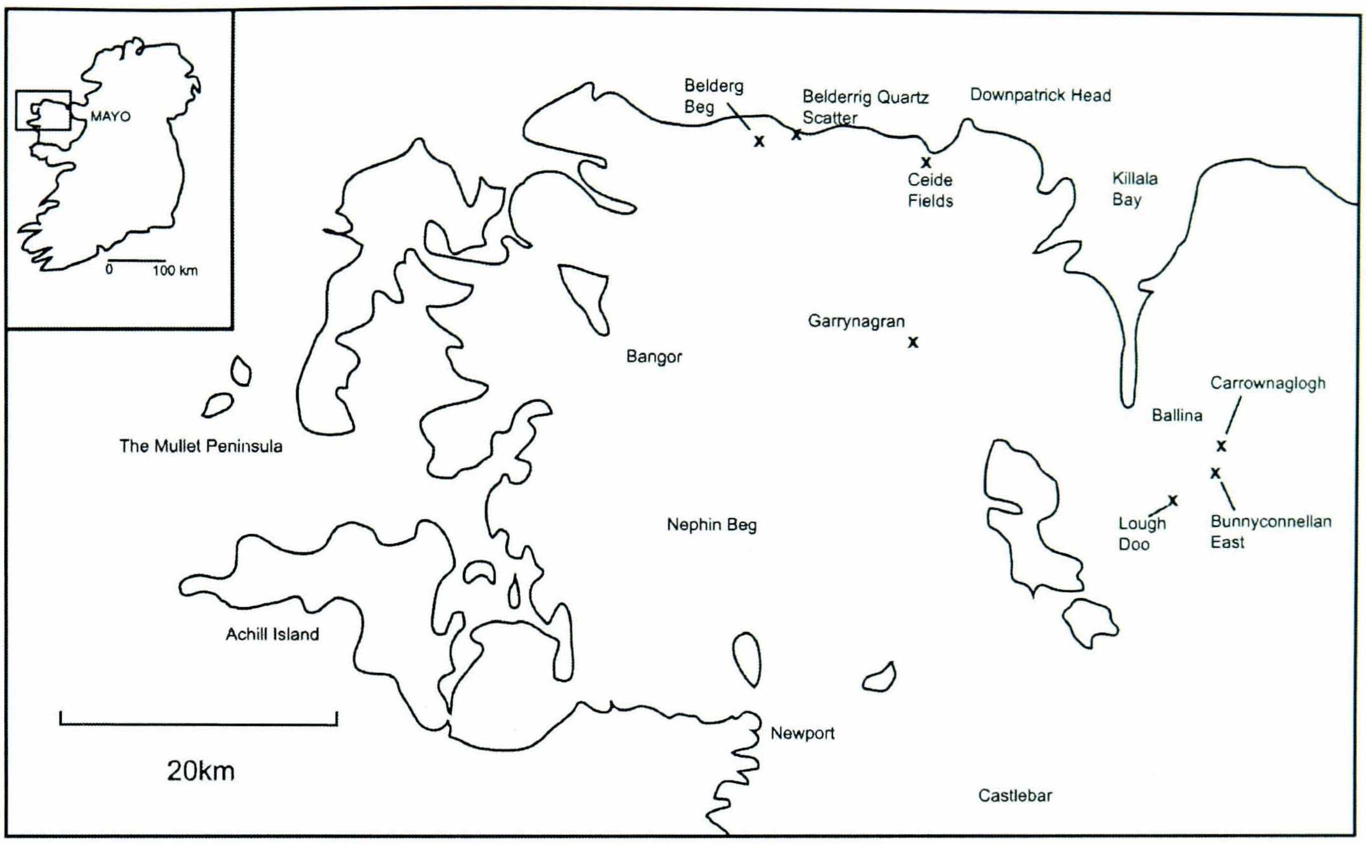


Figure 2.26: Garrynagran pollen percentage diagram. From O'Connell & Molloy 2001, 109, after Jennings 1997.

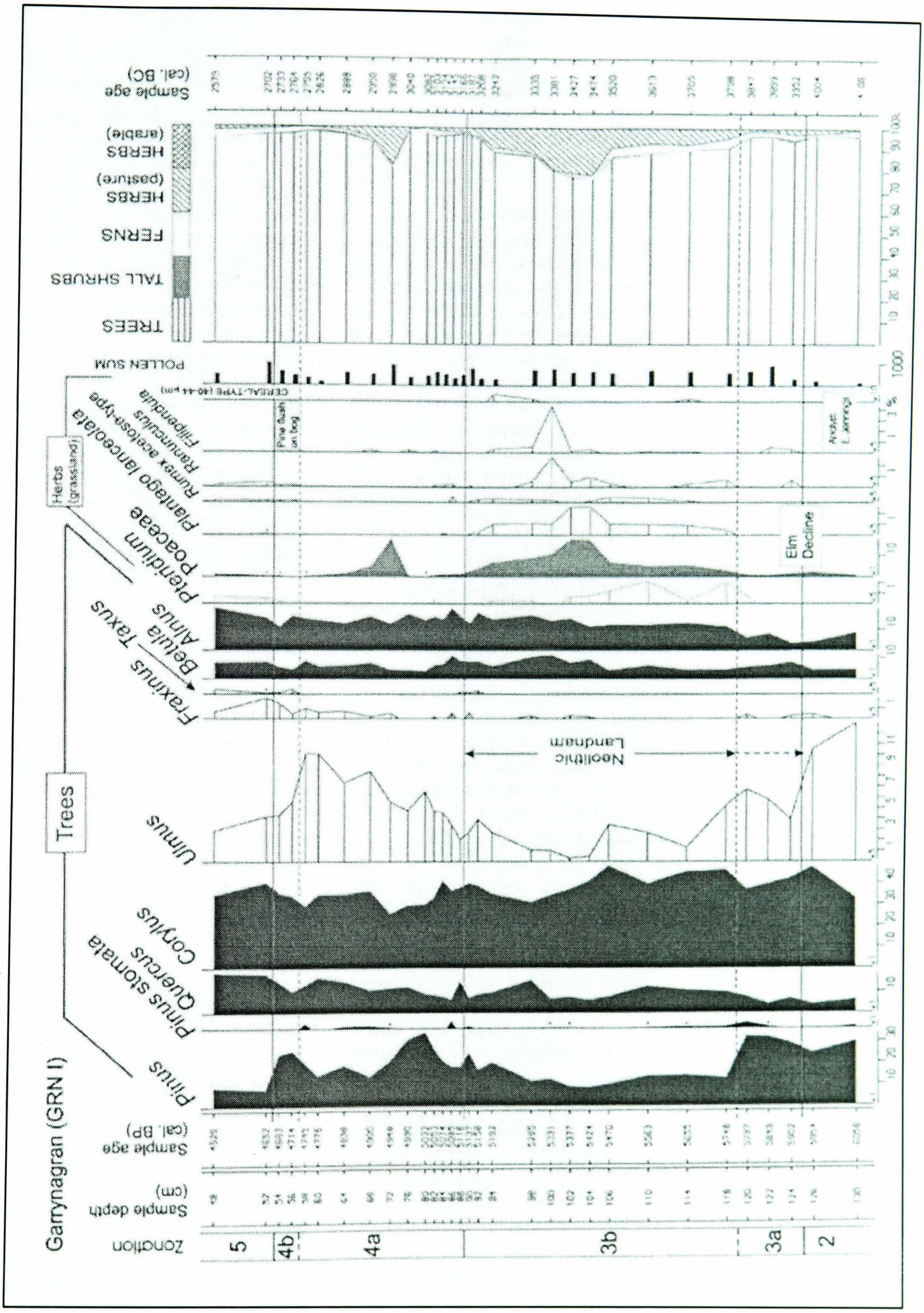


Figure 2.27: Lough Doo pollen percentage diagram. From O'Connell et al 1987, 152.

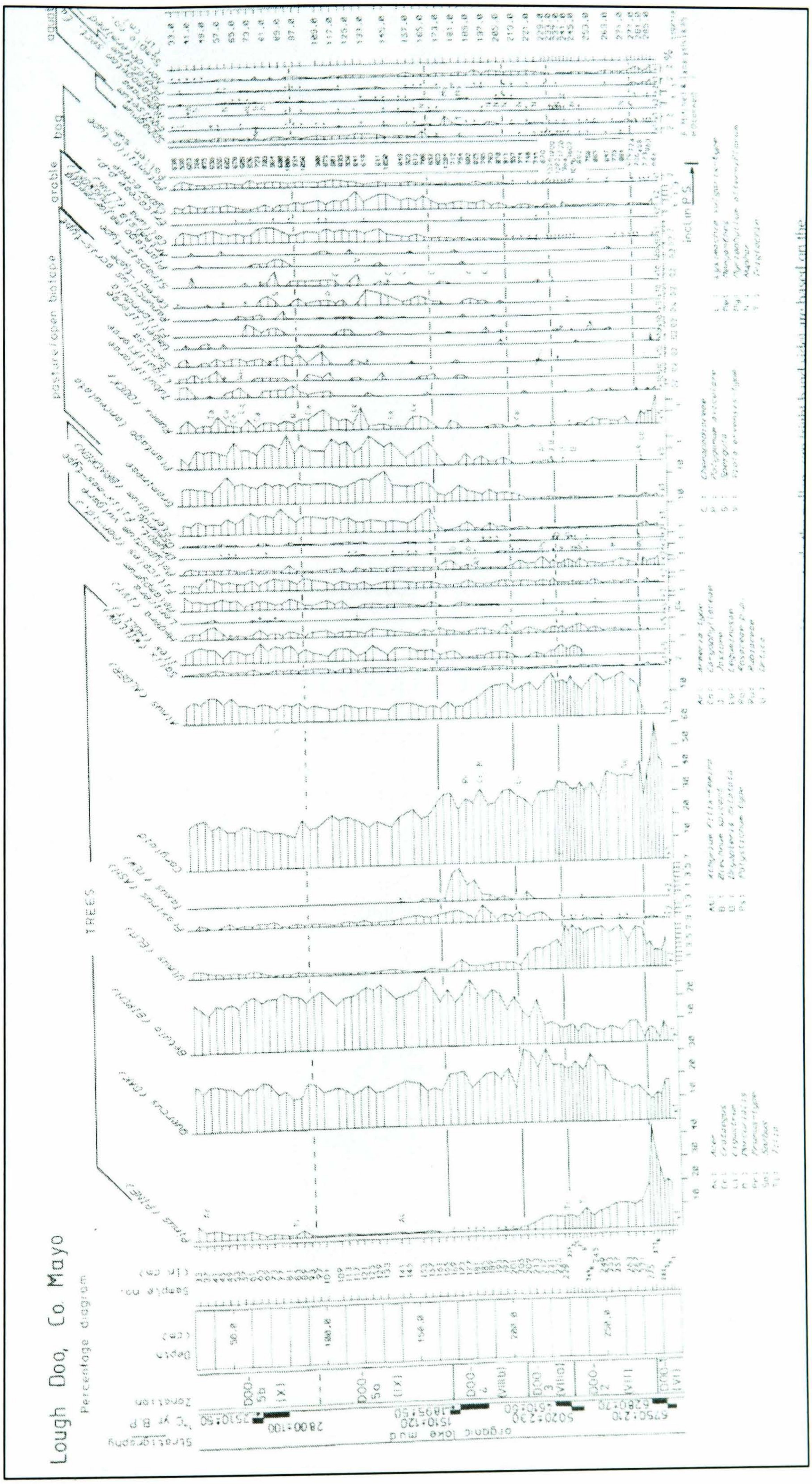


Figure 2.28: Lough Doo geochemical profile. From O'Connell et al 1987, 157.

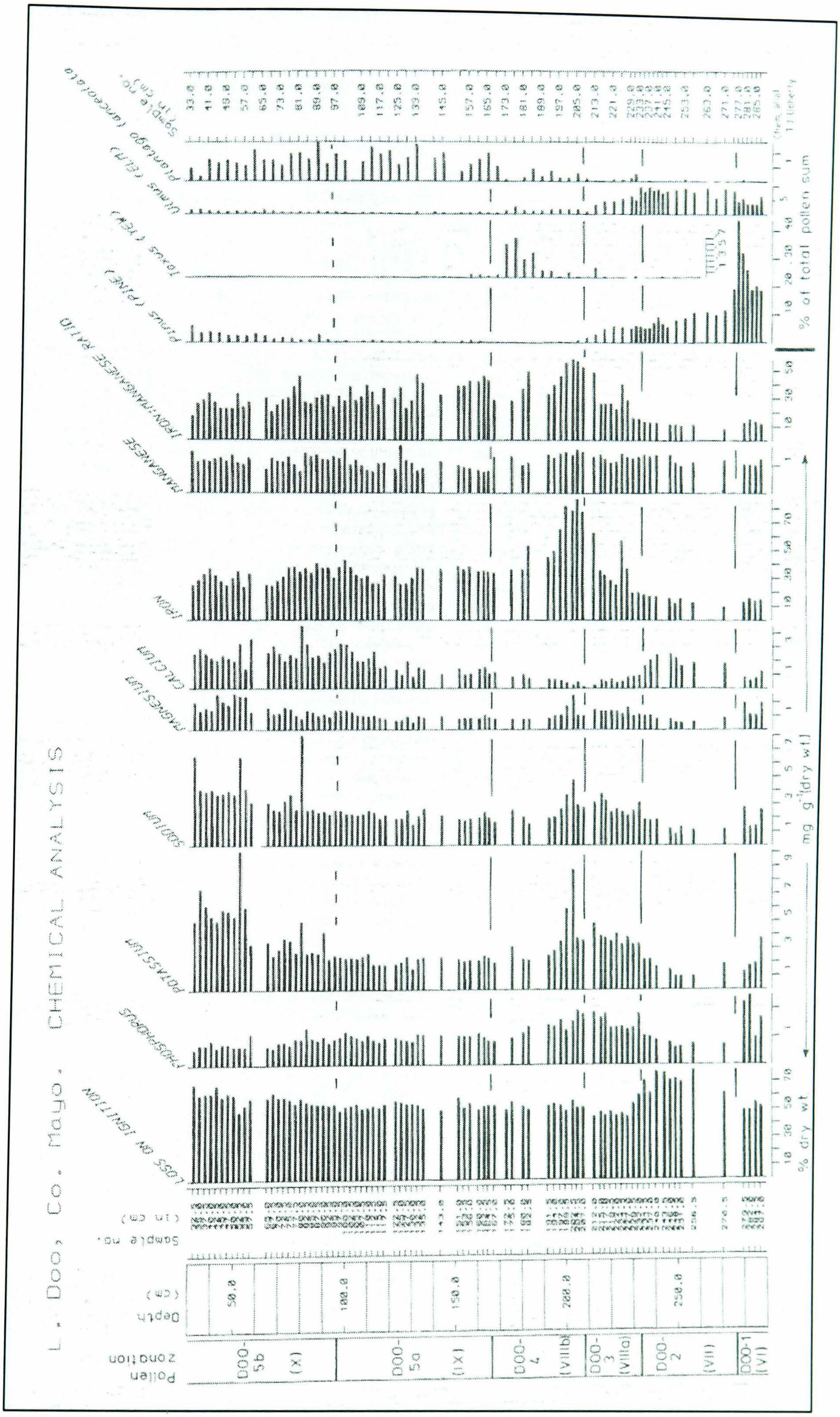


Figure 2.29: Bunnyconnellan East pollen percentage diagram. From O'Connell 1990b, 271.

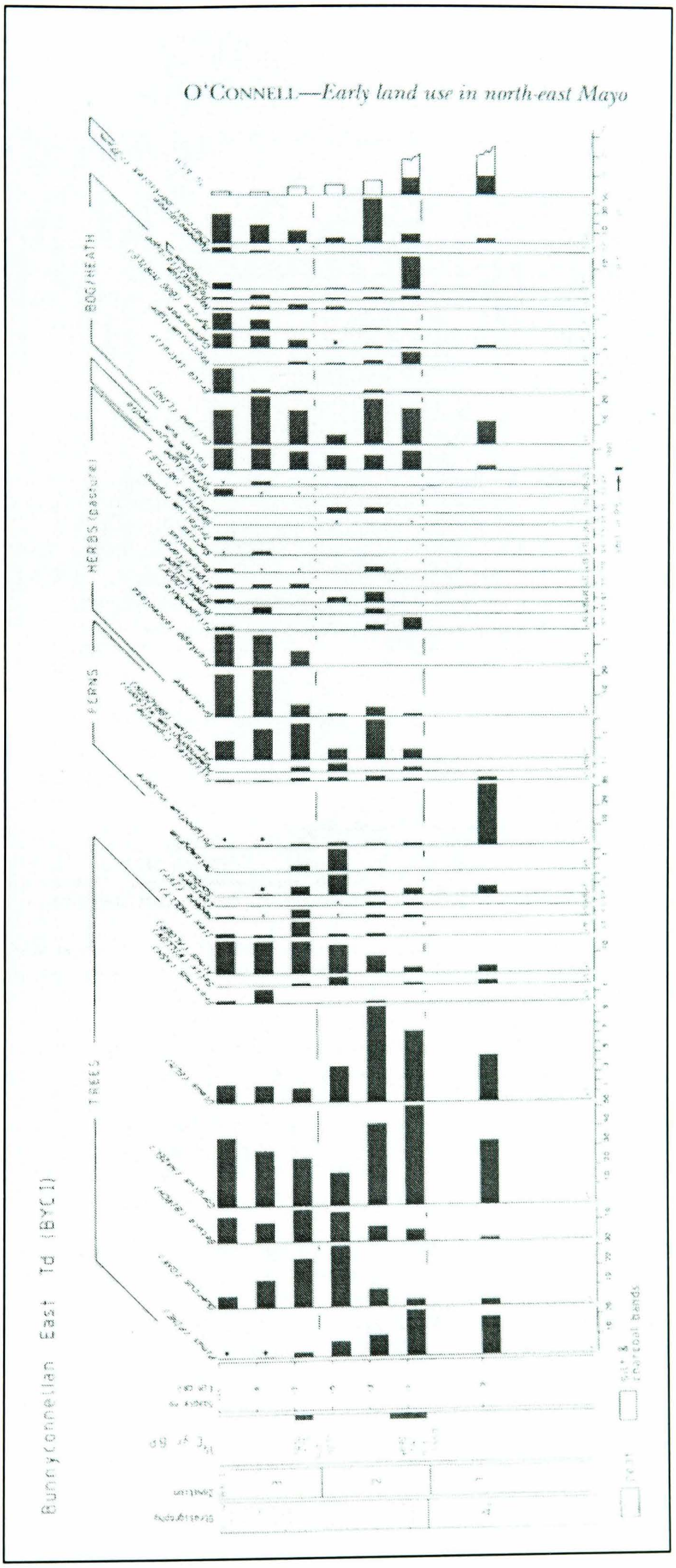
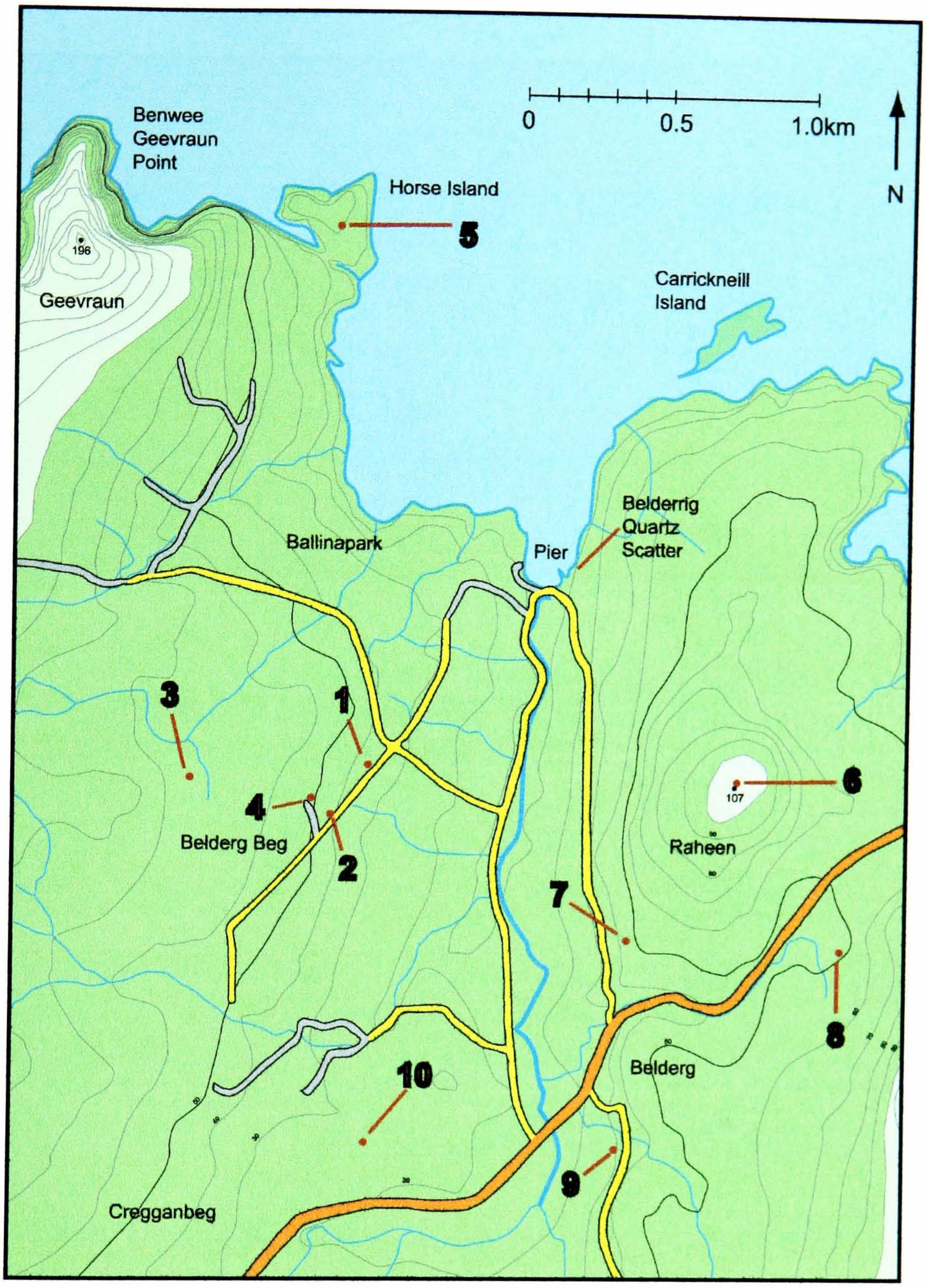


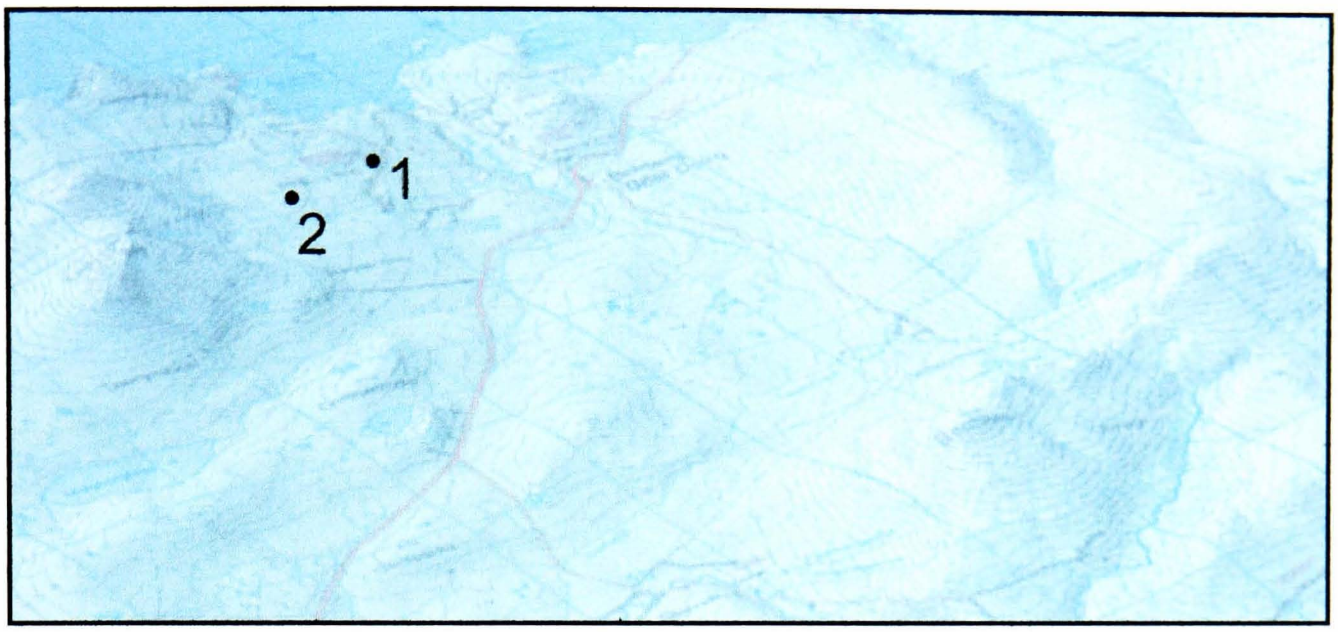
Figure 3.1: Detail of the Belderrig area with list of relevant Recorded Monuments.



Key to Figure 3.1

Number	SMR Entity Number	Classification	Townland
1	MA00076	House	Belderg Beg
2	MA00077	Enclosure	Belderg Beg
3	MA00078	Enclosure	Belderg Beg
4	MA00075	Field system	Belderg Beg
5	MA00068	Promontory fort	Horse Island
6	MA00087	Wedge tomb	Belderg Mór
7	MA00103	Megalithic tomb	Belderg Mór
8	MA00104	Court tomb	Belderg Mór
9	MA00105	Megalithic tomb	Belderg Mór
10	MA00070	Crannog	Belderg Mór

Figure 3.2: Location of Belderg Beg in its landscape context. From Warren 2004, 1.



Key

1: Roundhouse (see 1 in Figure 3.1above)

2. Sub-peat *Pinus* stump concentration

Figure 3.3a: Mean annual rainfall, island of Ireland 30 year average. From Met Éirann, http://www.met.ie/climate/rainfall.asp, accessed 09/01/06

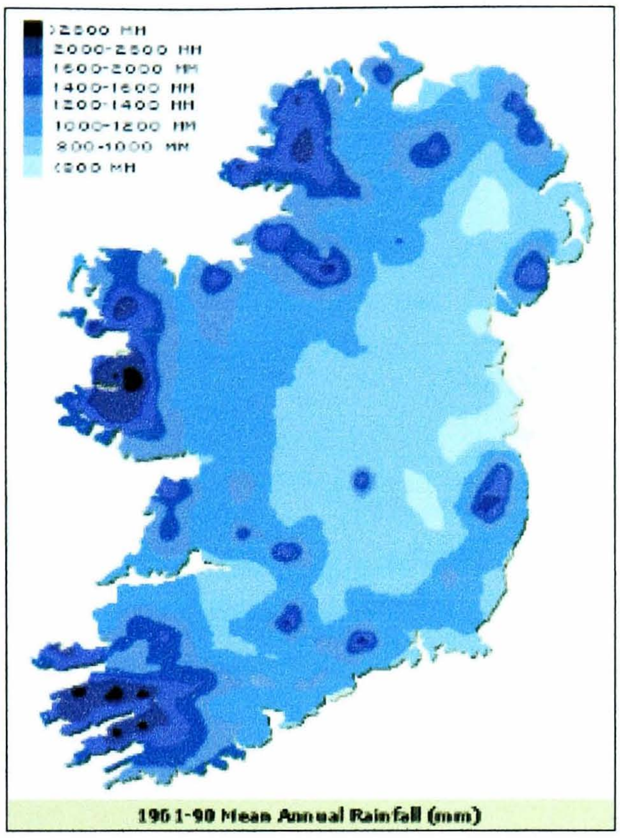


Figure 3.3b: Mean annual wind speed, island of Ireland 30 year average. From Met Éirann, http://www.met.ie/climate/wind.asp, accessed 09/01/06

Figure 3.3c: Percentage frequency of wind direction, island of Ireland 30 year average. From Met Éirann, http://www.met.ie/climate/wind.asp, accessed 09/01/06. Circled number = percentage of 'calm' on Beaufort scale.

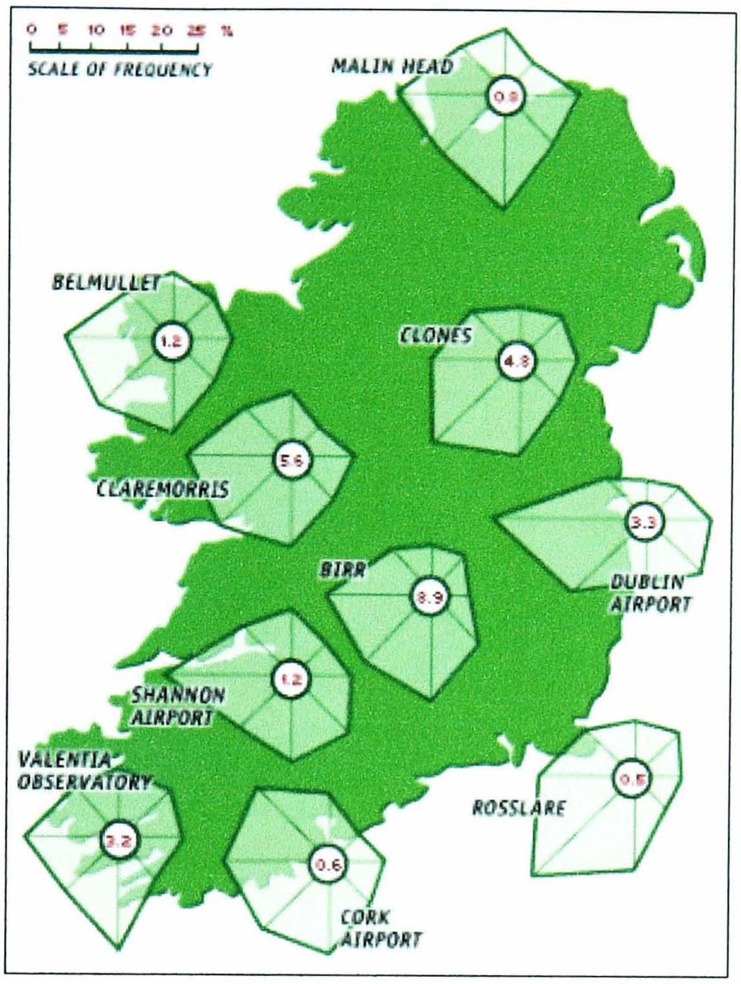


Figure 3.3d: Annual temperature range at Valentia Island, 30 year average. From Met Éirann, http://www.met.ie/climate/temperature.asp, accessed 09/01/06.

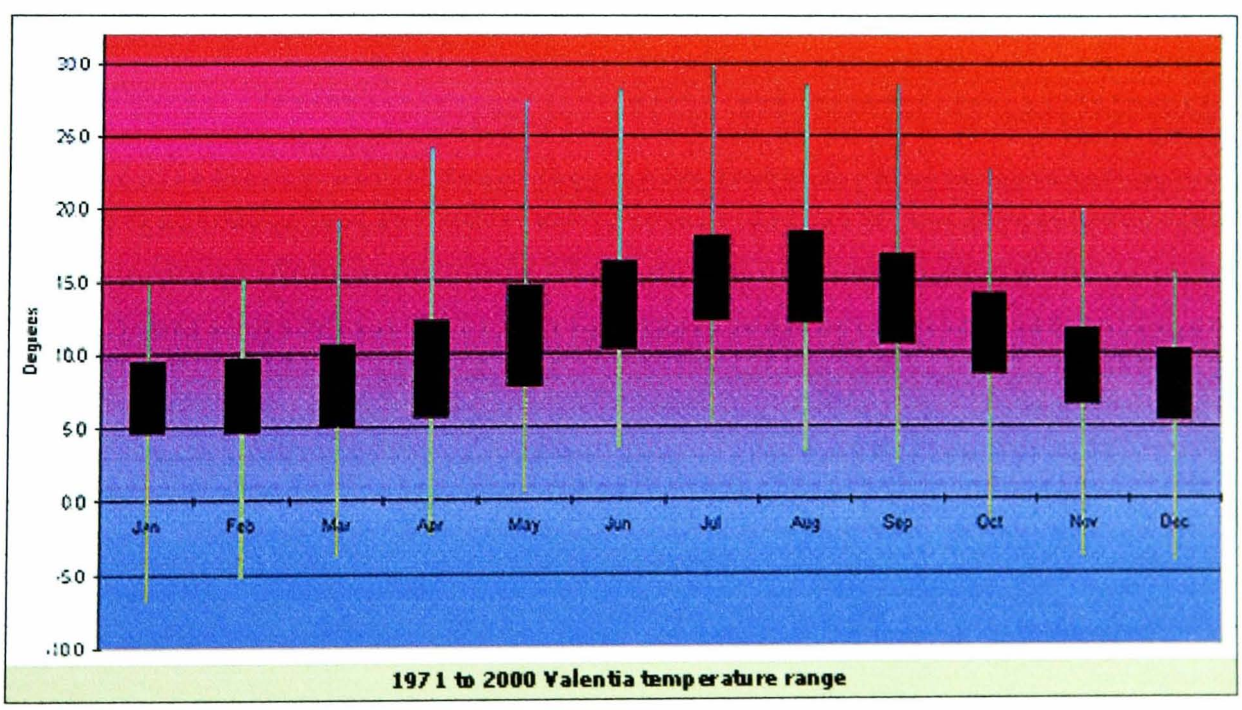
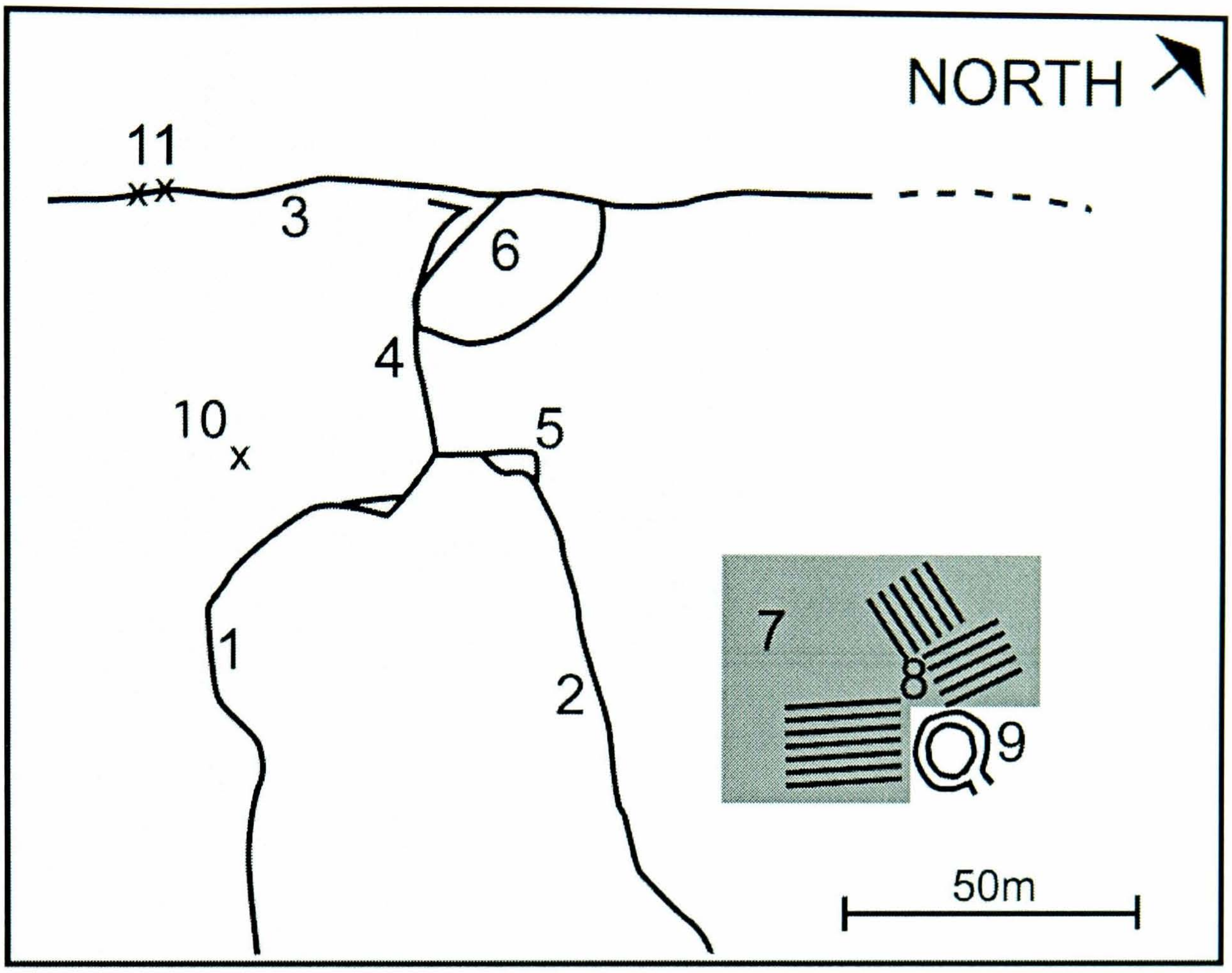


Figure 3.4: Plan of Belderg Beg archaeological site (adapted from Caulfield 1988)



1. Wall 1 (Neolithic)
2. Wall 2 (Neolithic)
3. Wall 3 (Bronze Age)
4. Wall 4 (Neolithic)
5. Neolithic pottery enclosure
6. Neolithic enclosure – robbed in Bronze Age
7. Ard-marked area (approximate)
8. Ridge & furrow plots
9. Bronze Age roundhouse
10. Pine stumps (UCD-C31 and UCD-C60 in Caulfield *et al* 1998, 633; see Appendix A)
11. Oak stakes (SI-1471 and SI-1472 in Caulfield 1978; see Appendix A)

Figure 3.5a: Inferred Neolithic features at Belderg Beg (after Caulfield 1988)

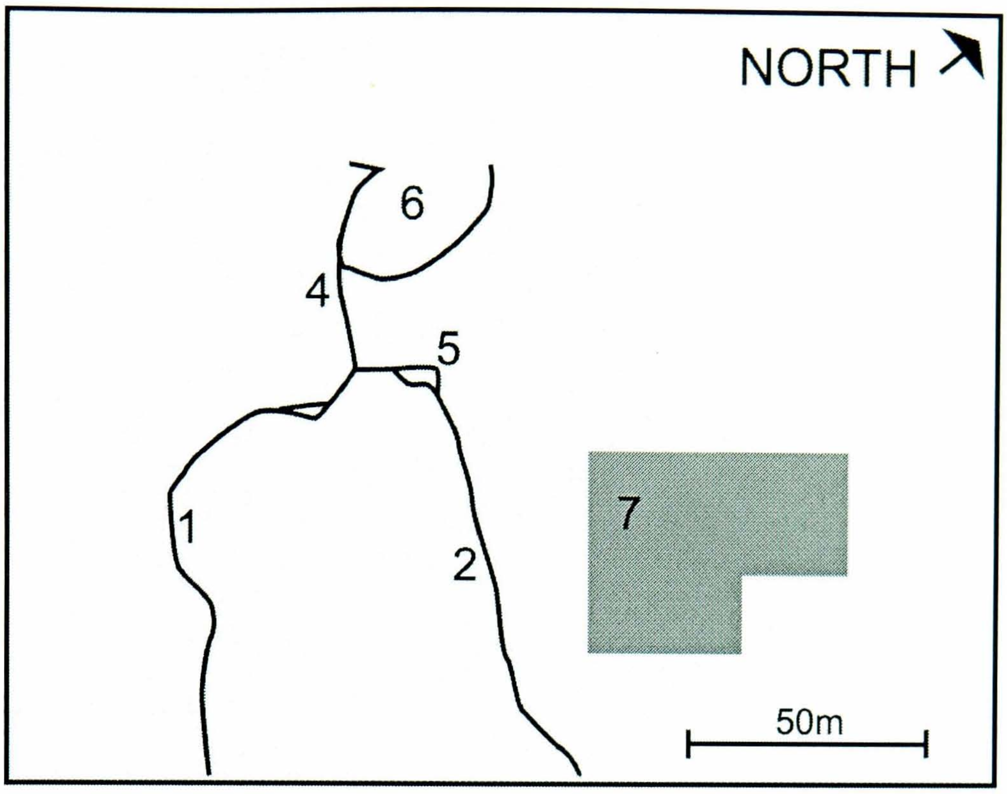


Figure 3.5b: Inferred Bronze Age features at Belderg Beg (after Caulfield 1988)

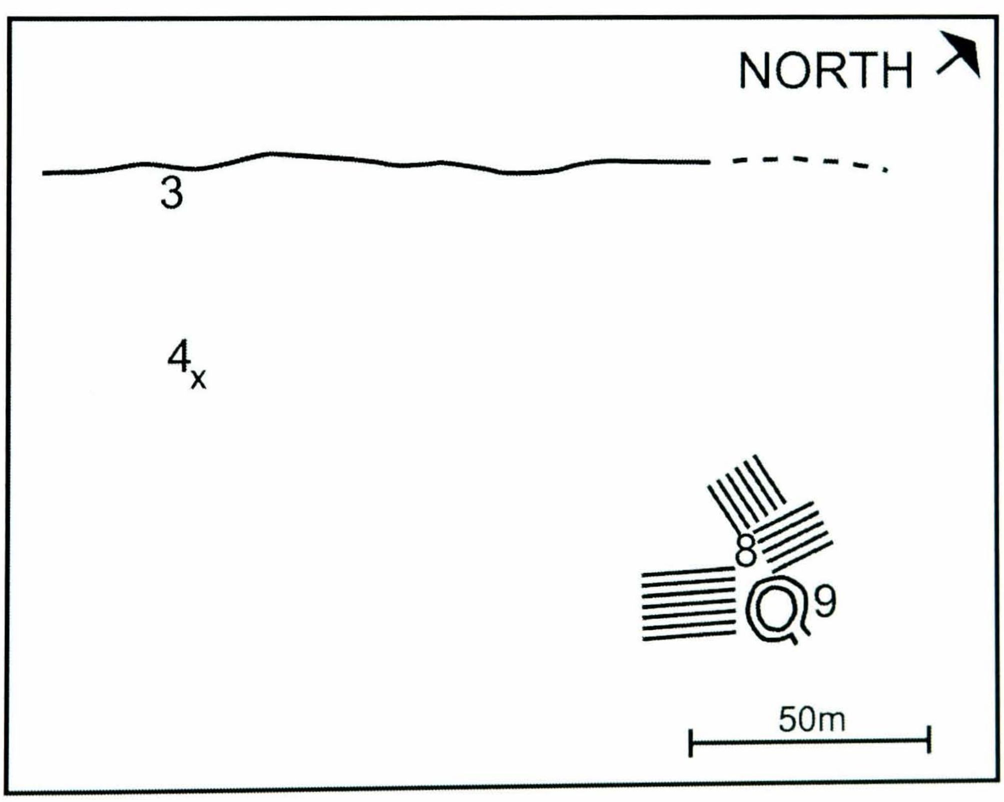


Figure 4.1: Sampling locations plotted on a detailed map of the Belderg Beg area

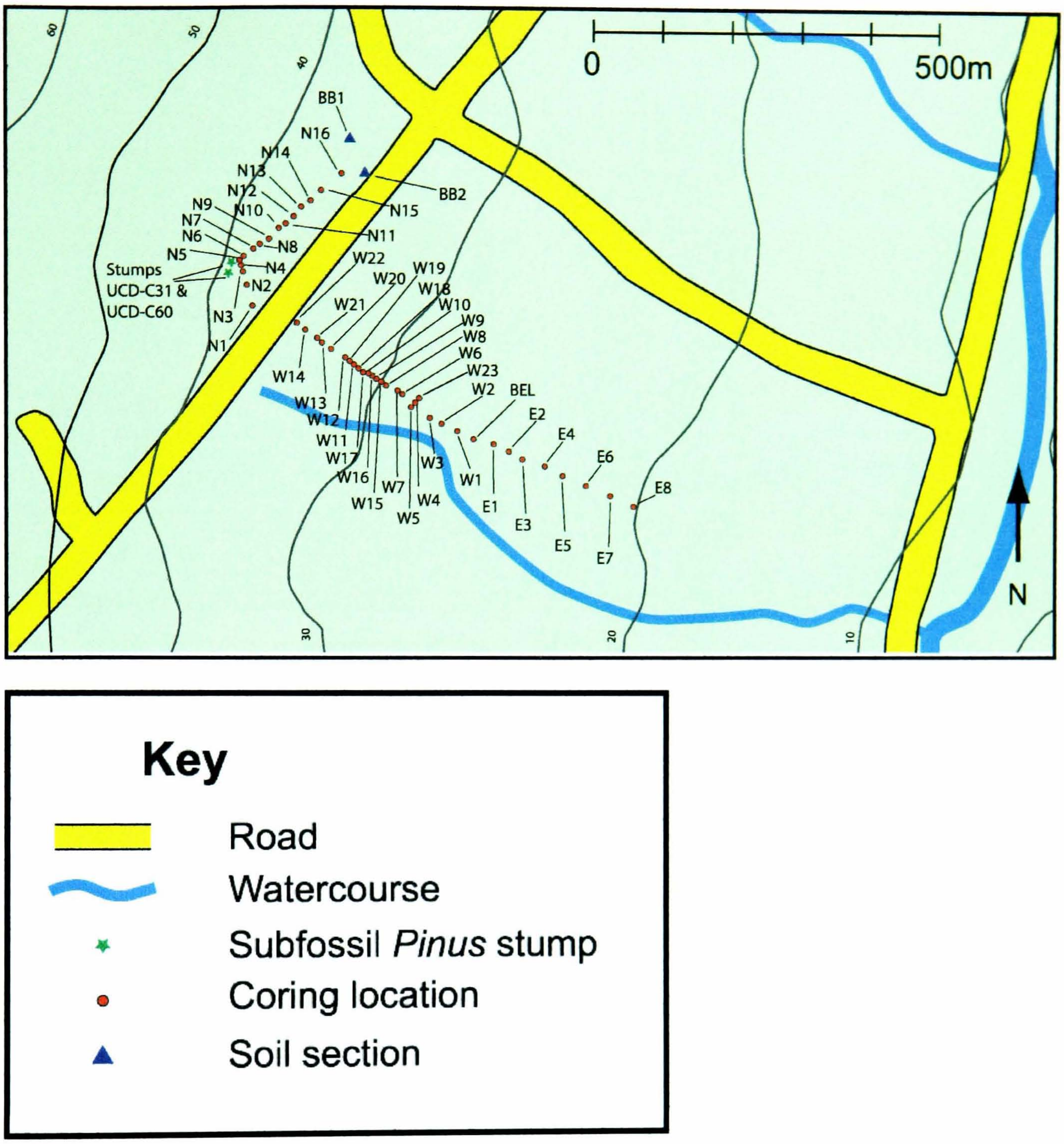
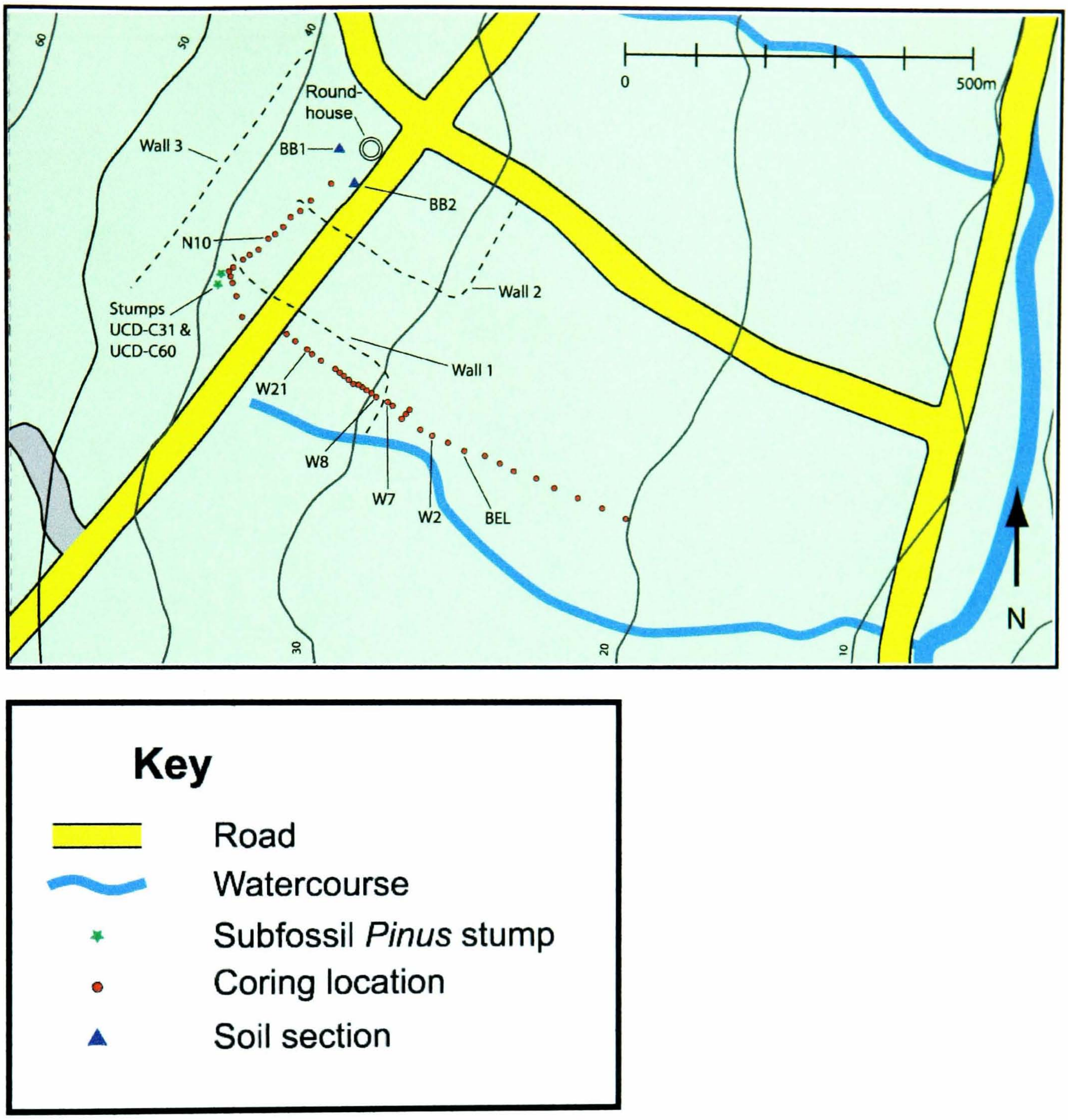


Figure 5.1: Sampling locations and main archaeological features



For identification of every coring location cross-refer to Figure 4.1

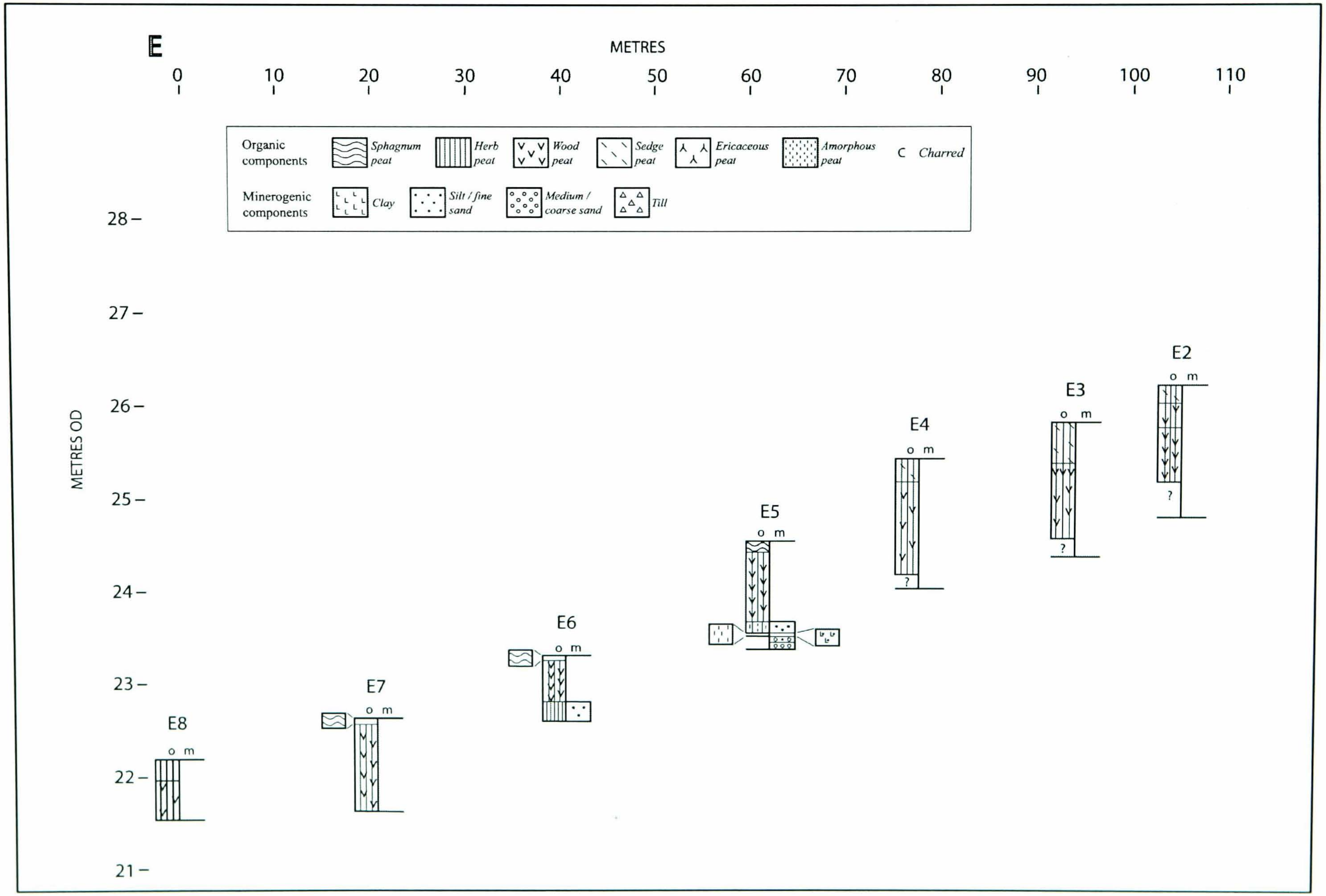


Figure 5.2a: Transect 1 in section. Note vertical exaggeration.

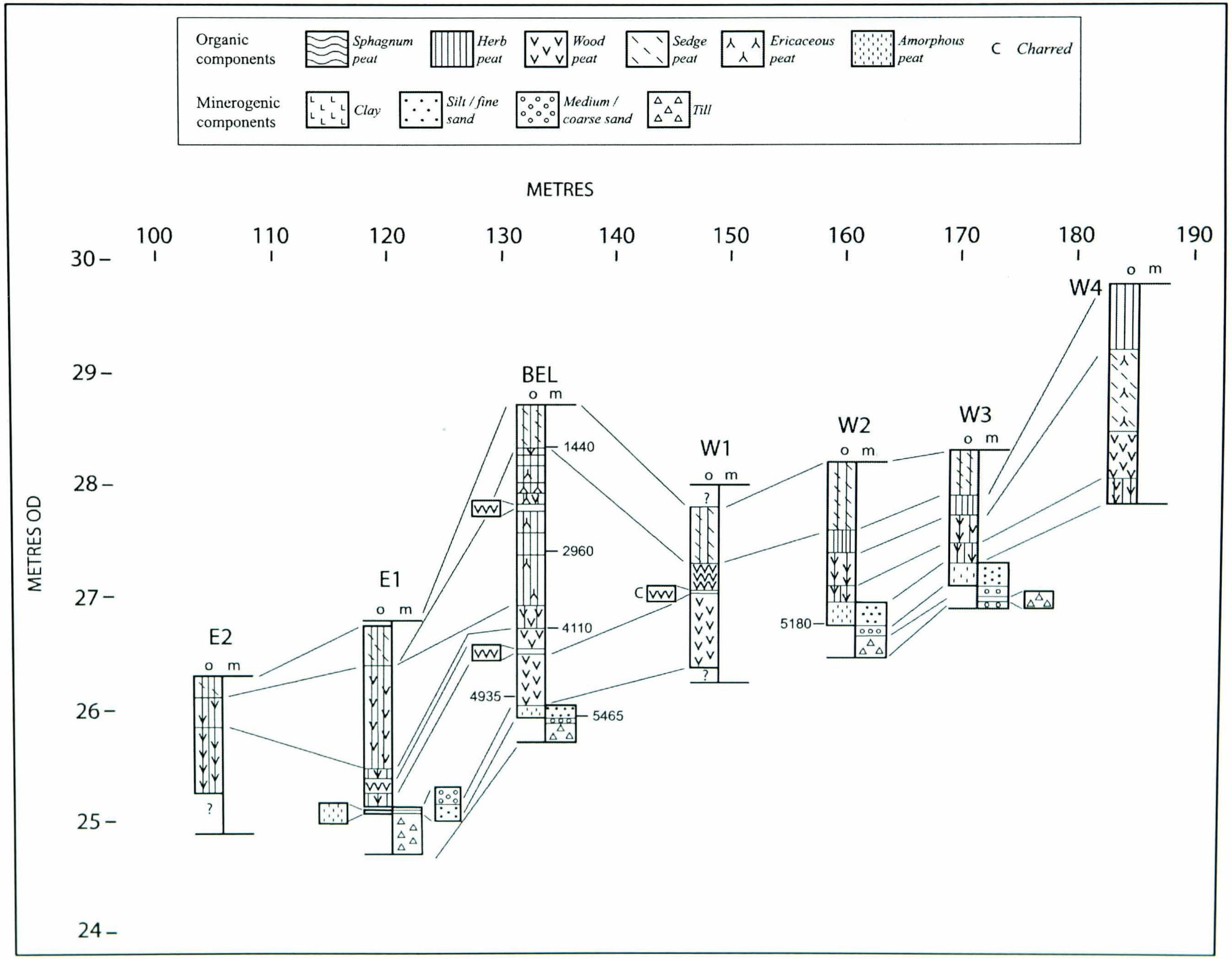


Figure 5.2b: Transect 1 in section (continued).

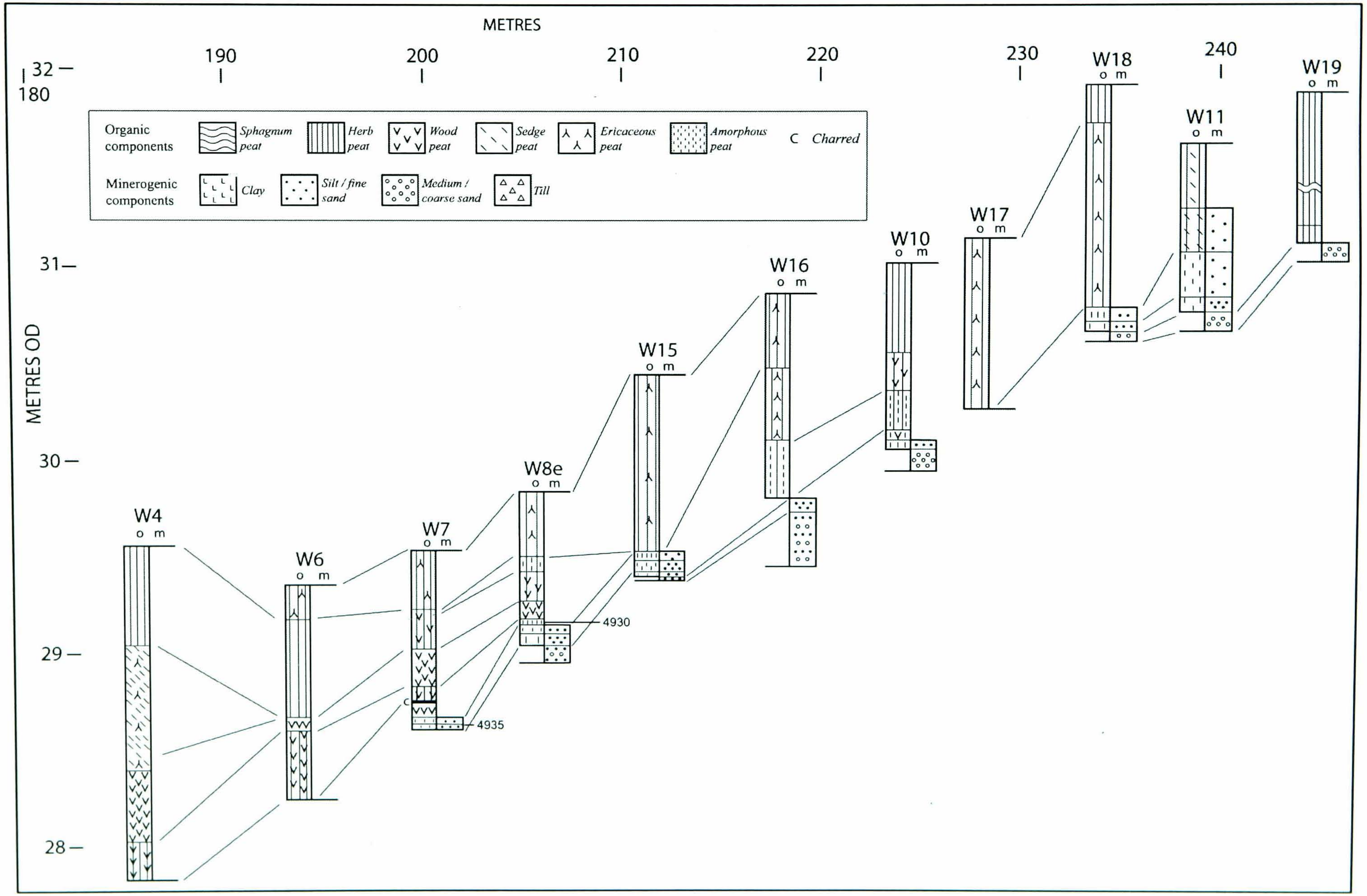
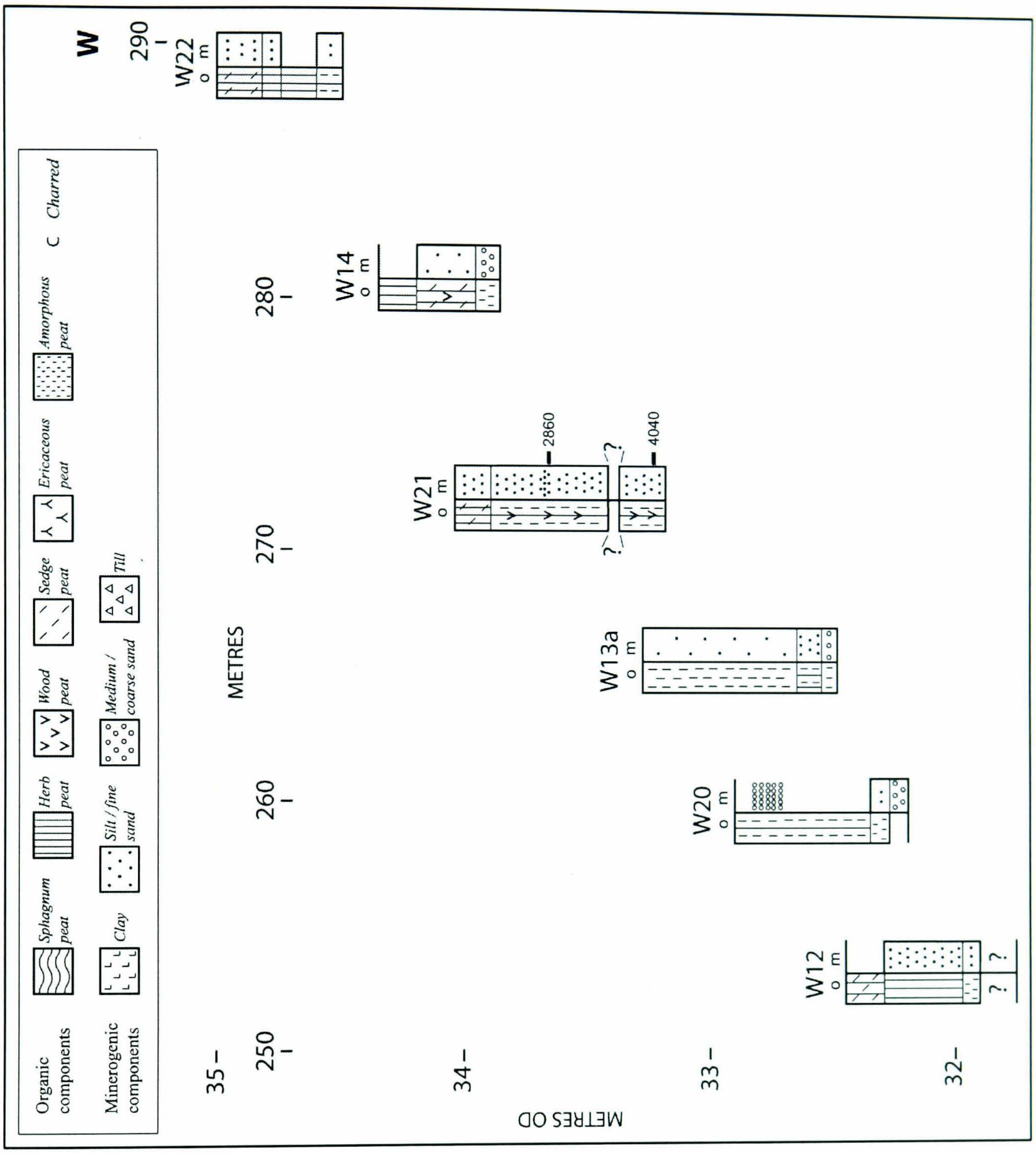


Figure 5.2c: Transect 1 in section (continued).

Figure 5.2d: Transect 1 in section (continued).



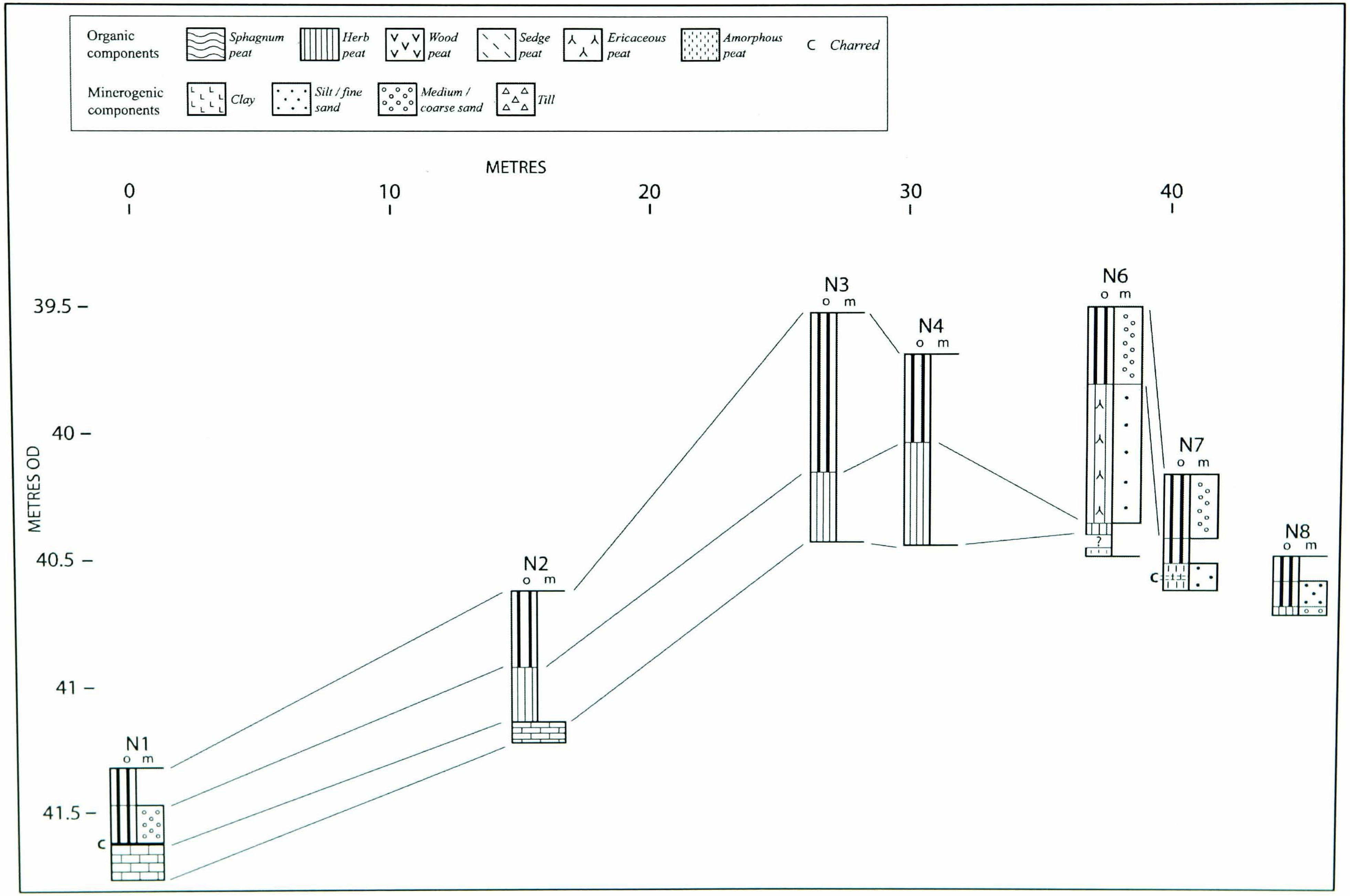


Figure 5.3a: Transect 2 in section. Note vertical exaggeration.

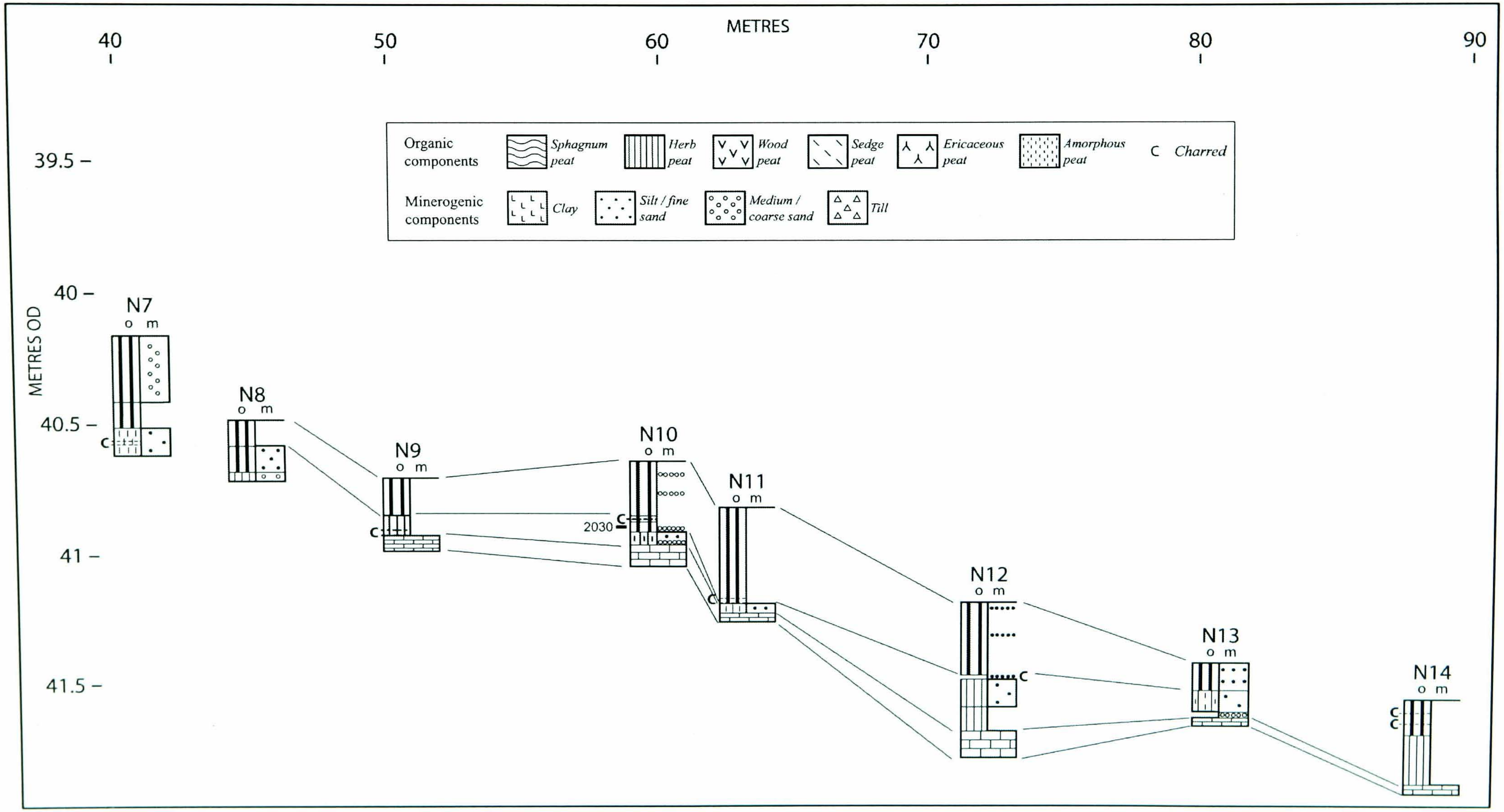


Figure 5.3b: Transect 2 in section (continued).

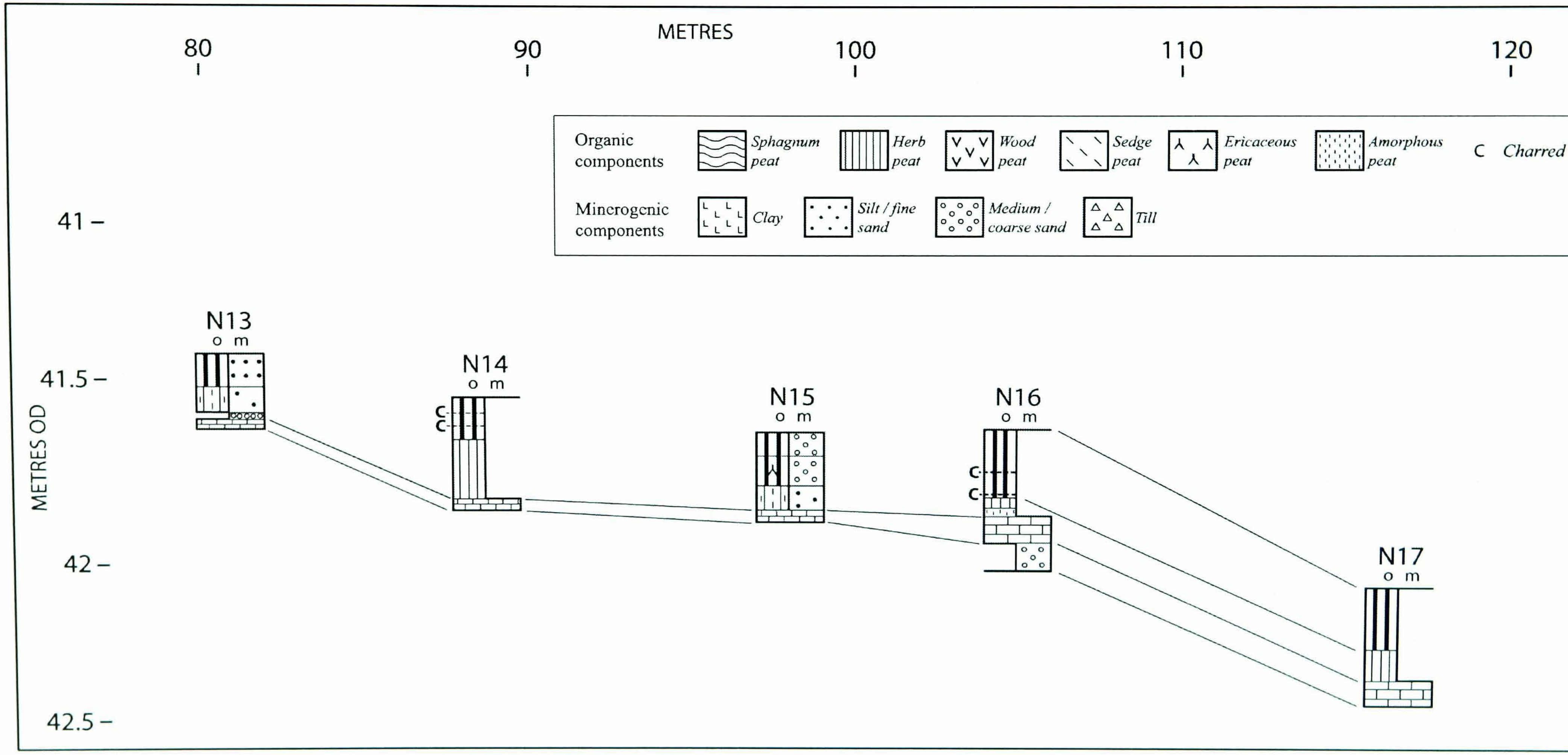


Figure 5.3c: Transect 2 in section (continued).

Figure 5.4a: Calibration details of GU-11634

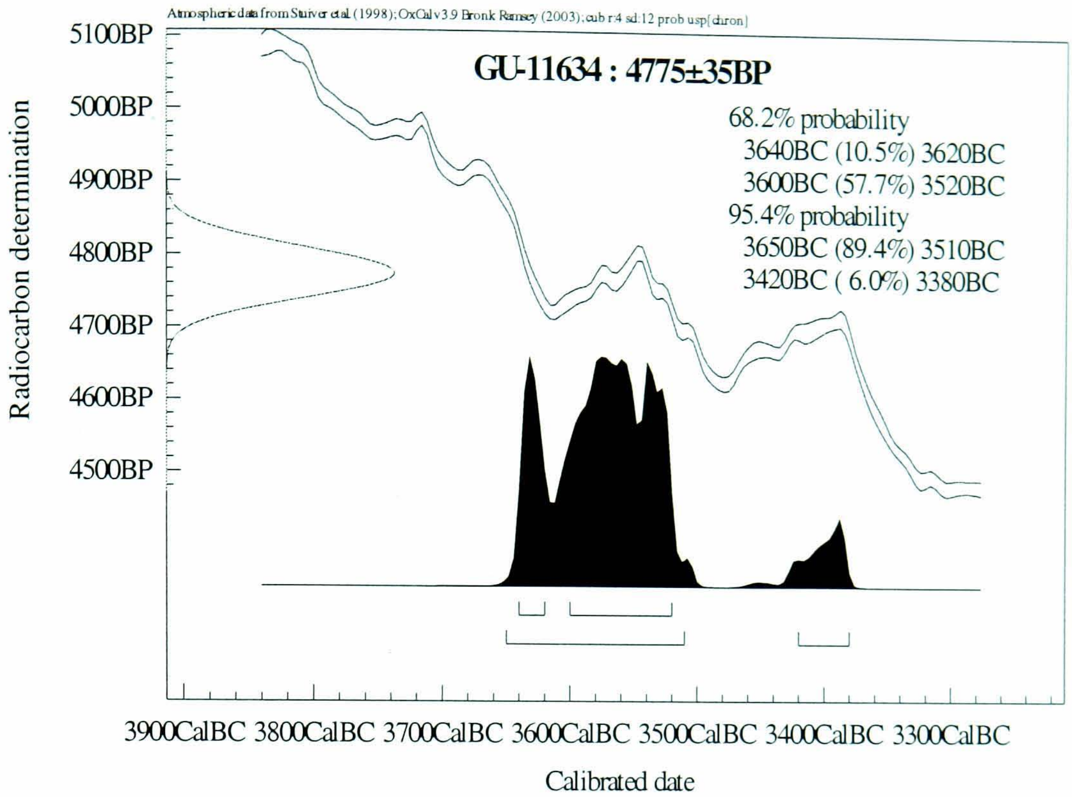


Figure 5.4b: Calibration details of GU-12211

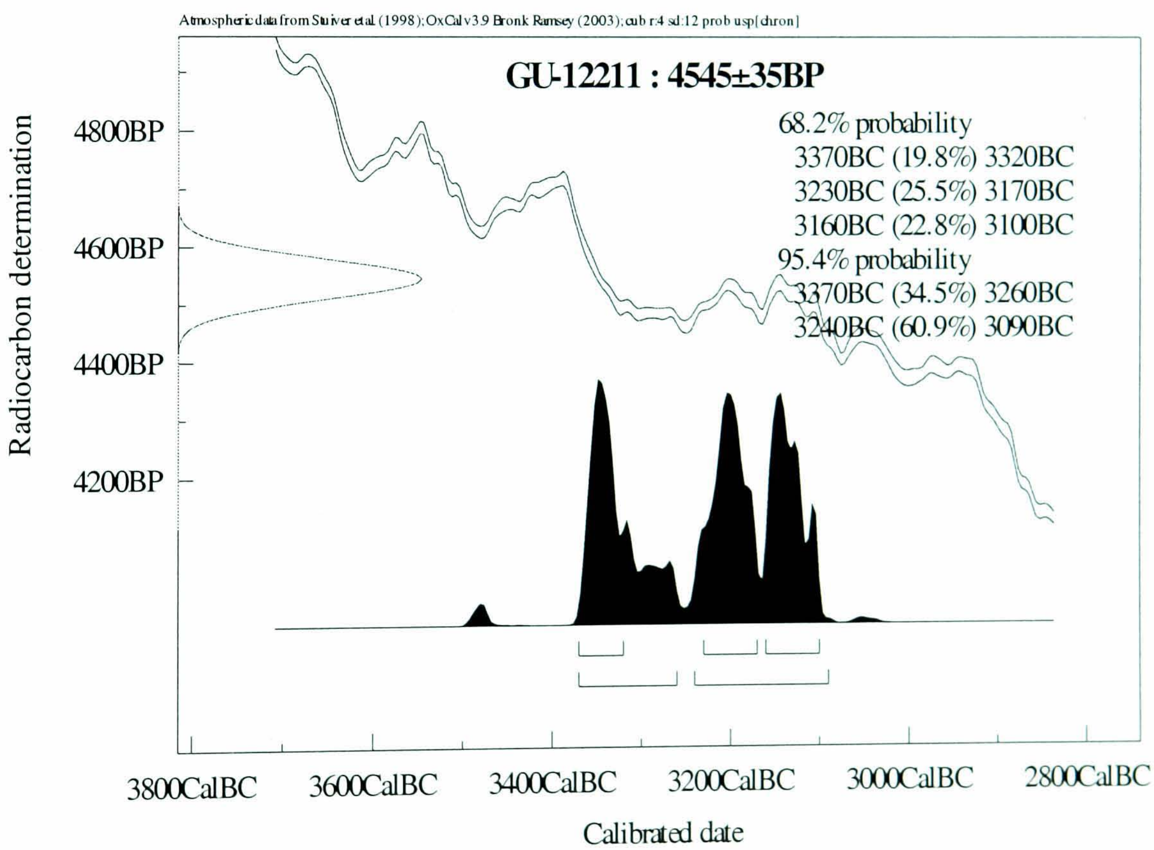


Figure 5.4c: Calibration details of GU-12725

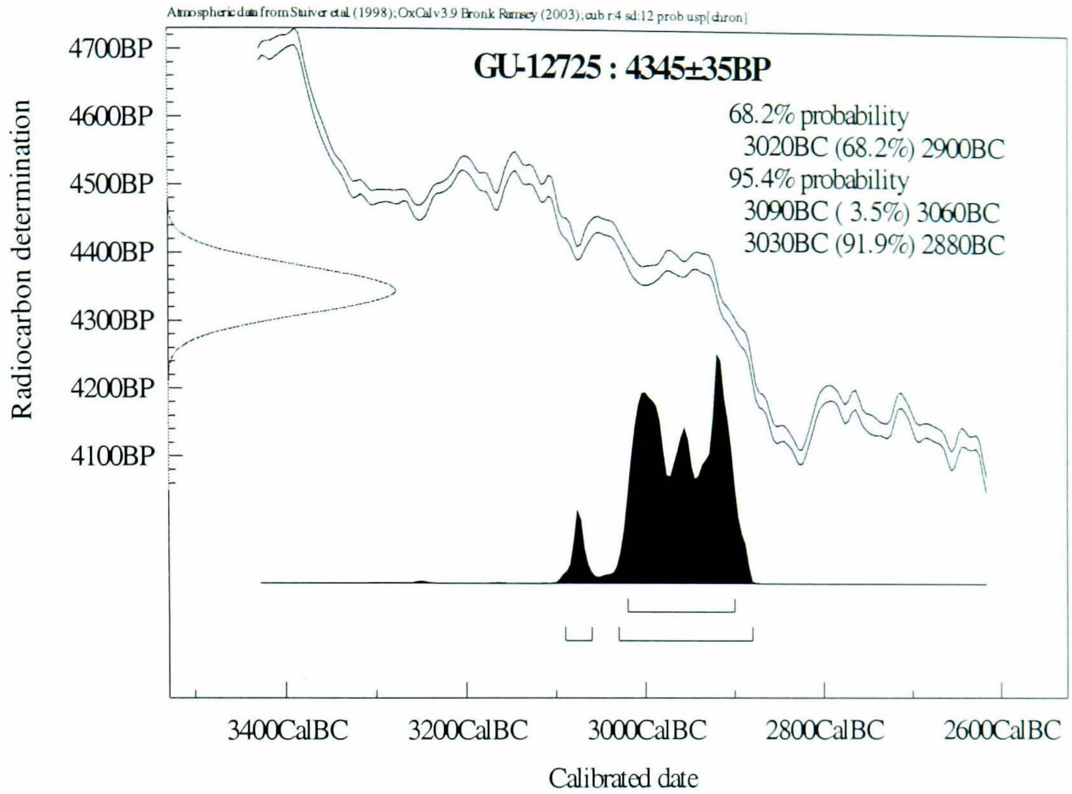


Figure 5.4d: Calibration details of GU-12726

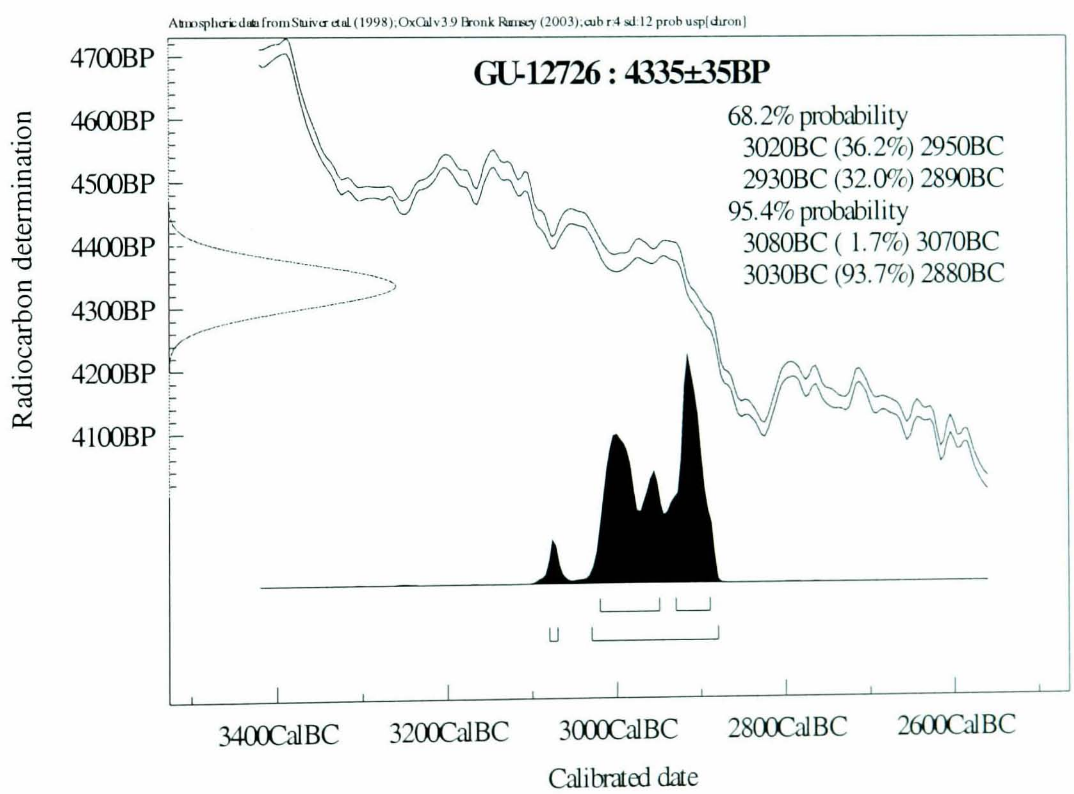


Figure 5.4e: Calibration details of GU-12616

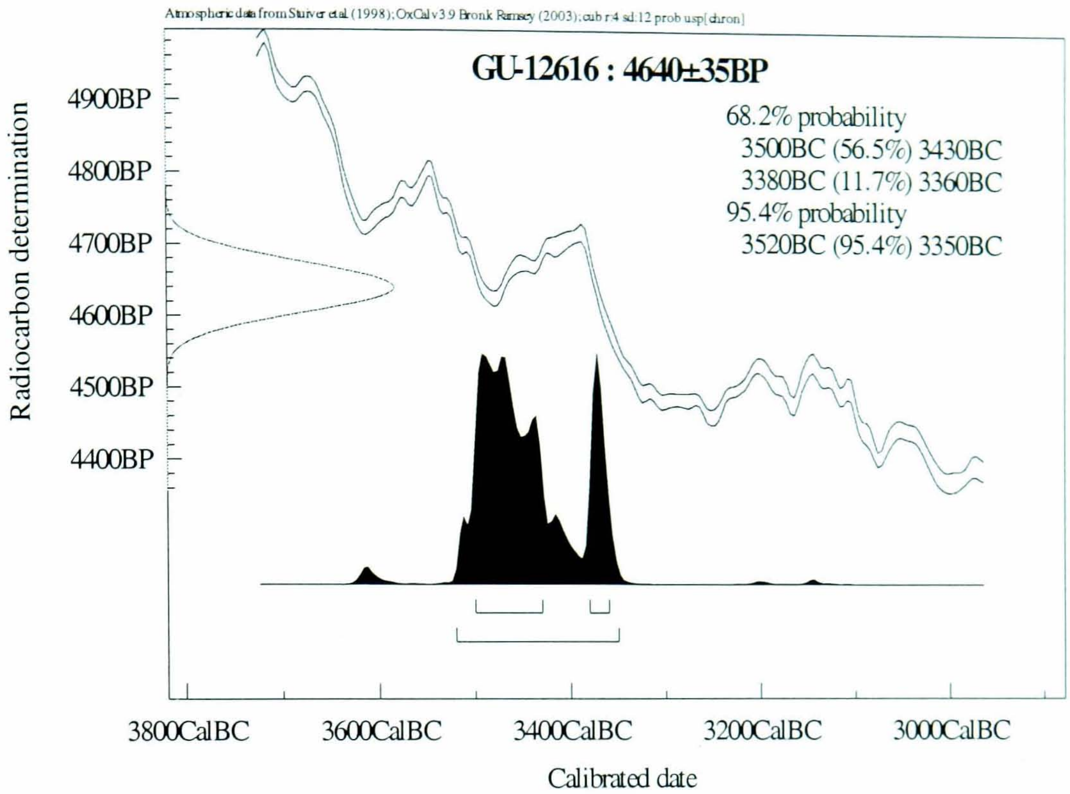


Figure 5.4f: Calibration details of GU-12212

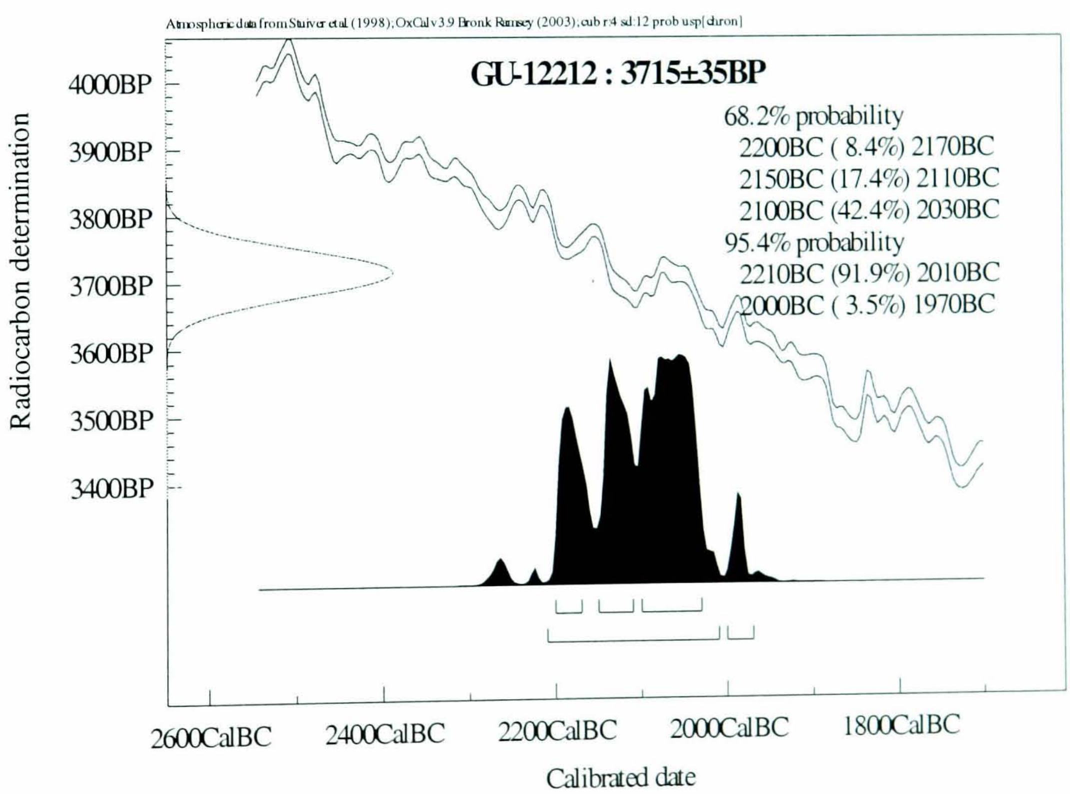


Figure 5.4g: Calibration details of GU-12728

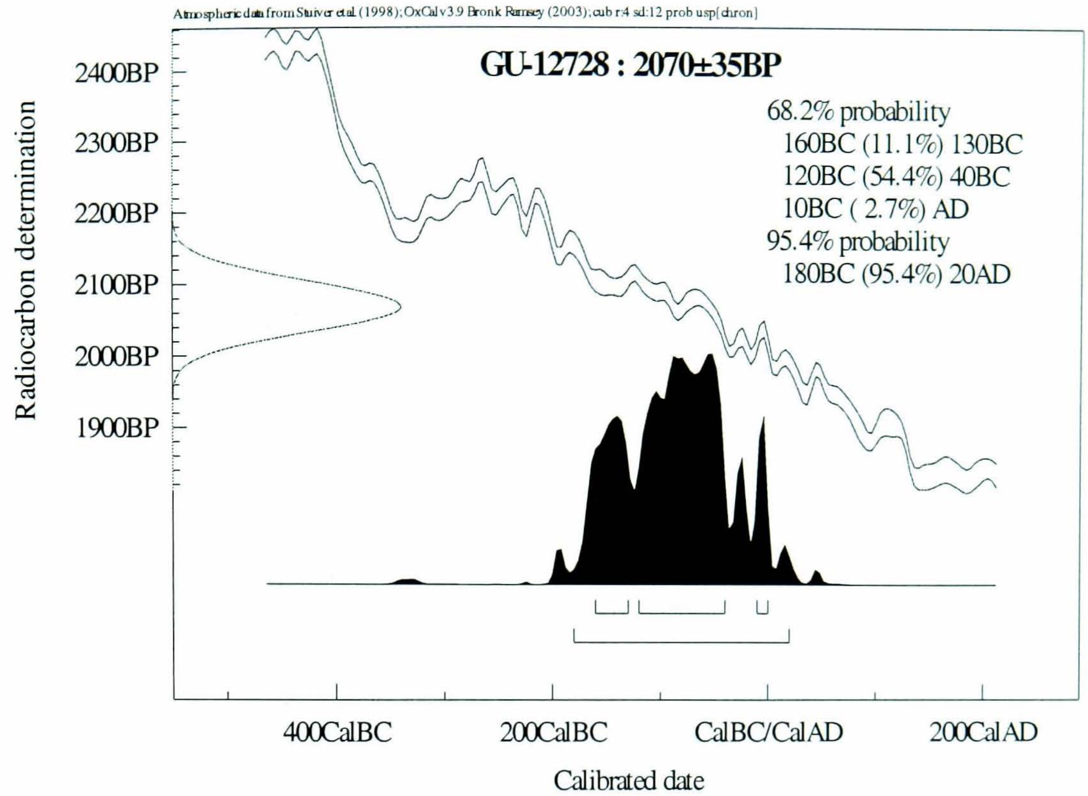


Figure 5.4h: Calibration details of GU-12727

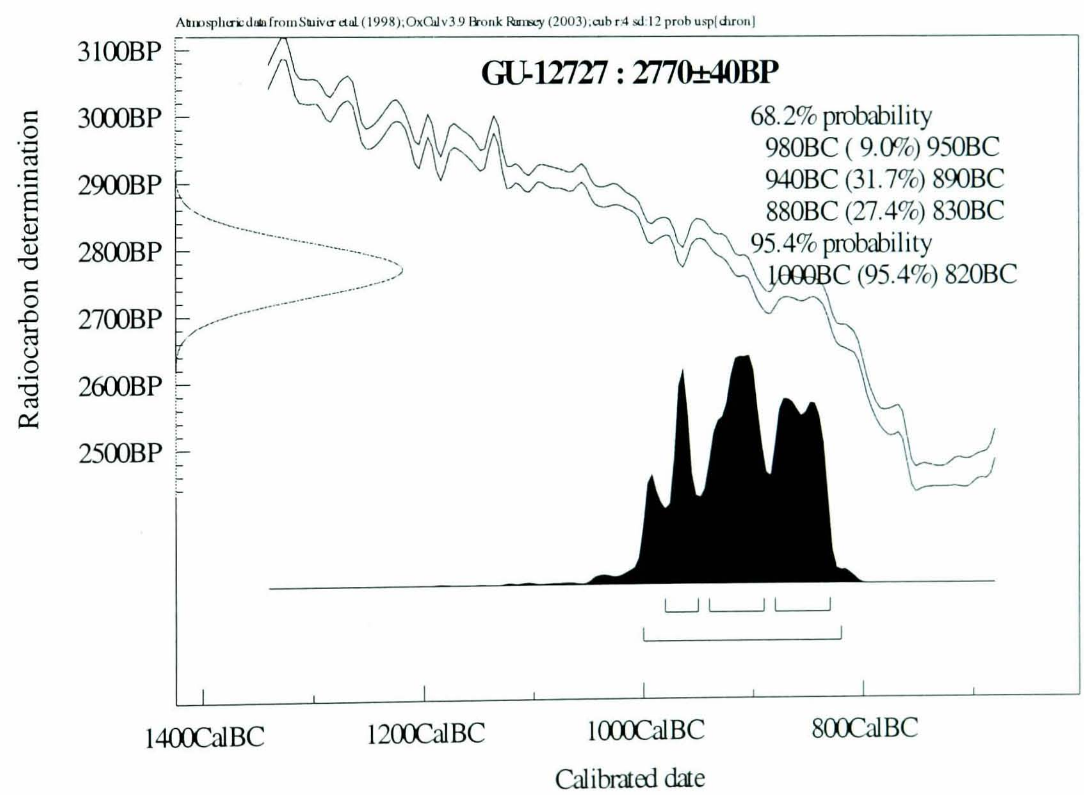


Figure 5.4i: Comparative plot showing calibration details of all transect cores

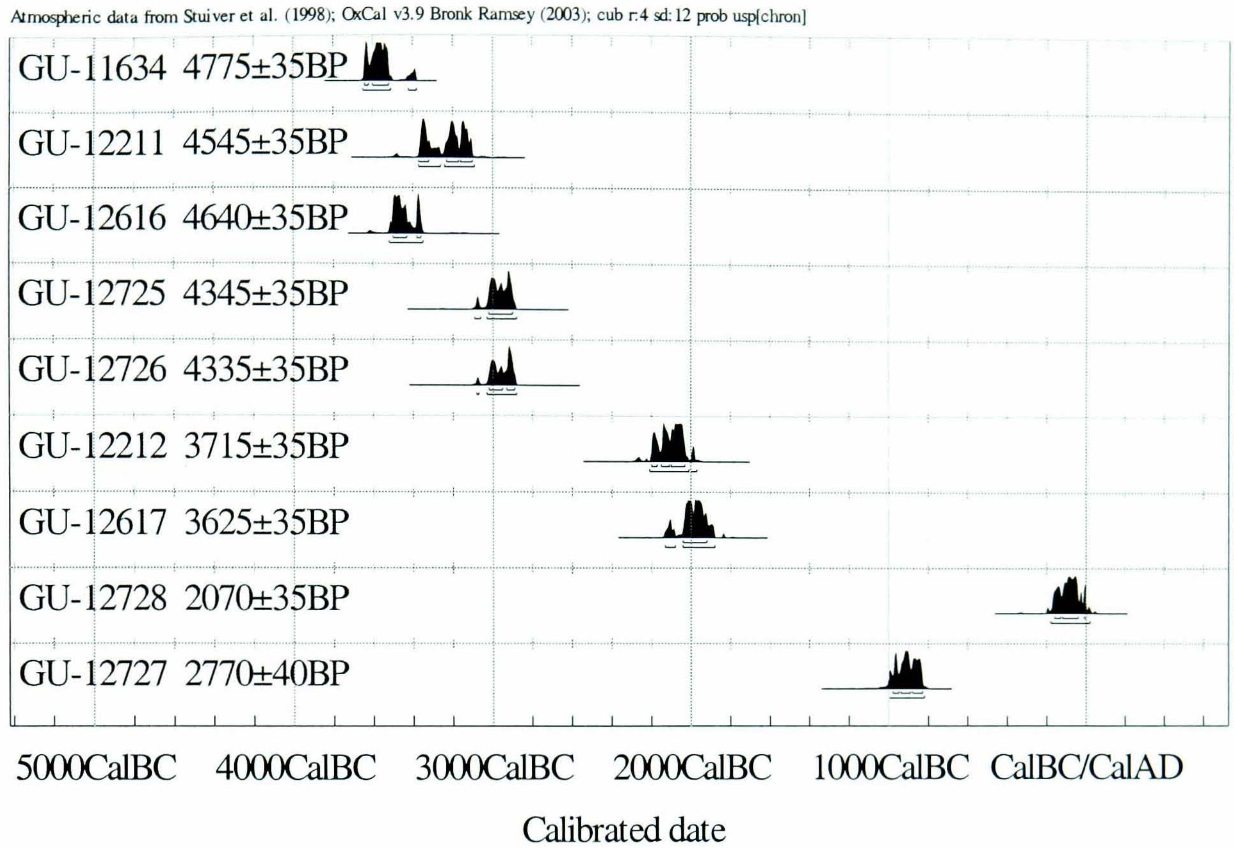


Figure 5.5: Influence of microtopography on peat initiation on a hillslope (after Edwards & Hirons 1982, 34· Figure 2 in original).

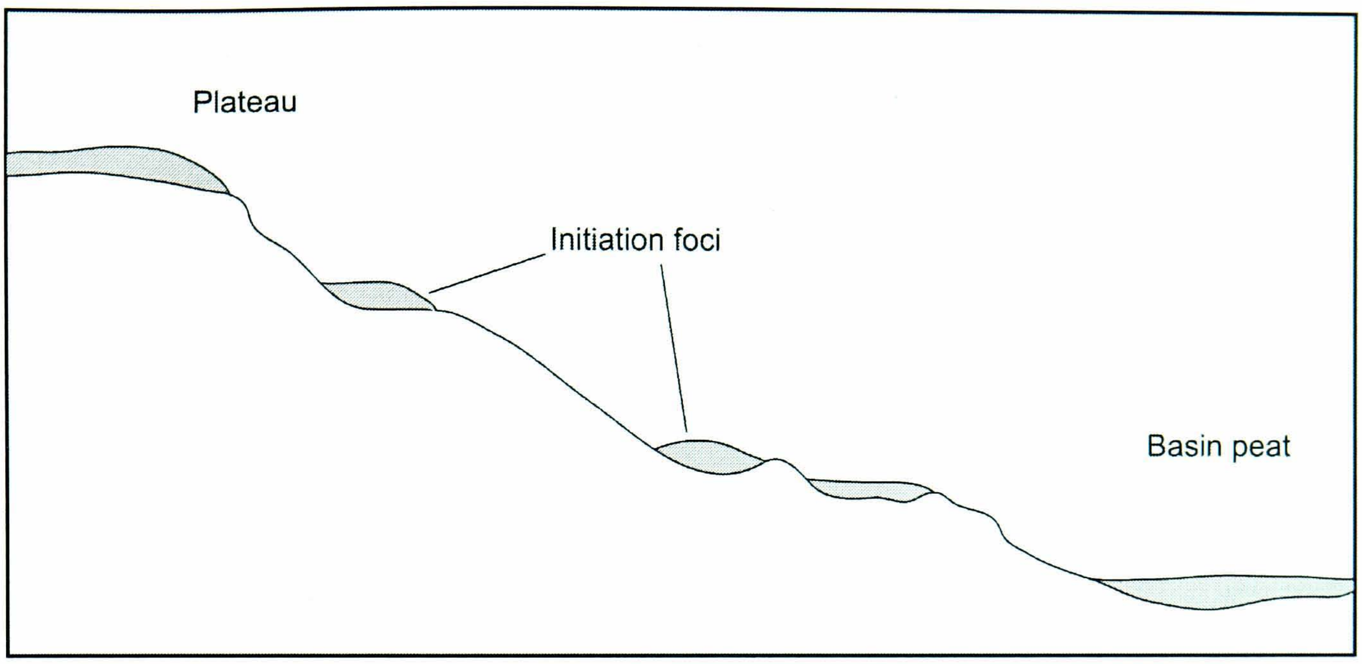
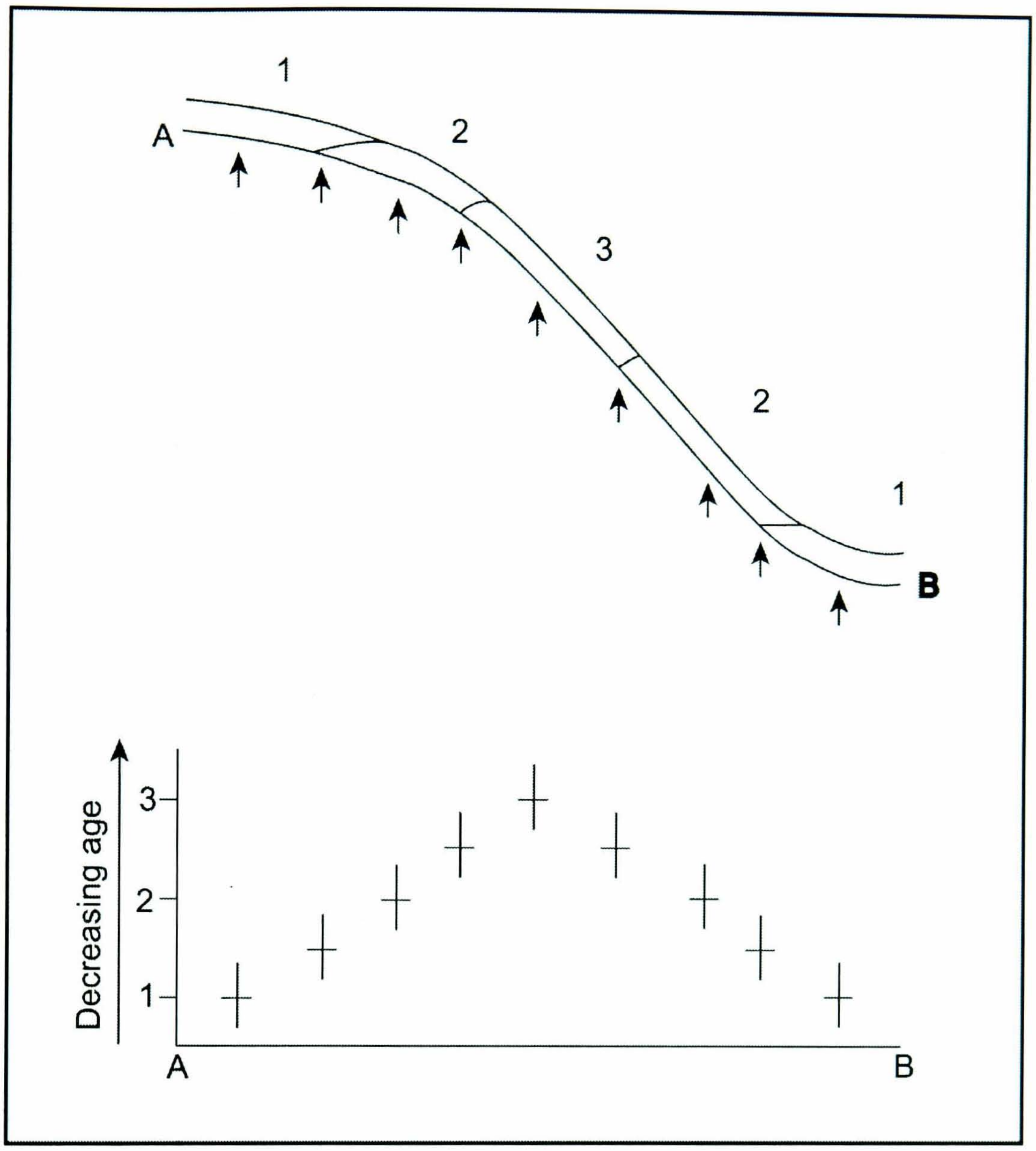


Figure 5.6: Model of primary-secondary-tertiary peat growth as applied to a theoretical smooth-sloped hillslope (from Edwards & Hirons 1982, 35; Figure 3 in original).



Idealised slope A-B (above) showing three ages of deposit as blanket peat merges from basin and plateau. 1=oldest phase; 3=youngest phase. Arrows show location of ^{14}C samples. ^{14}C determinations (below) for transect A-B.

Figure 5.7a: Calibration details of GU-11630

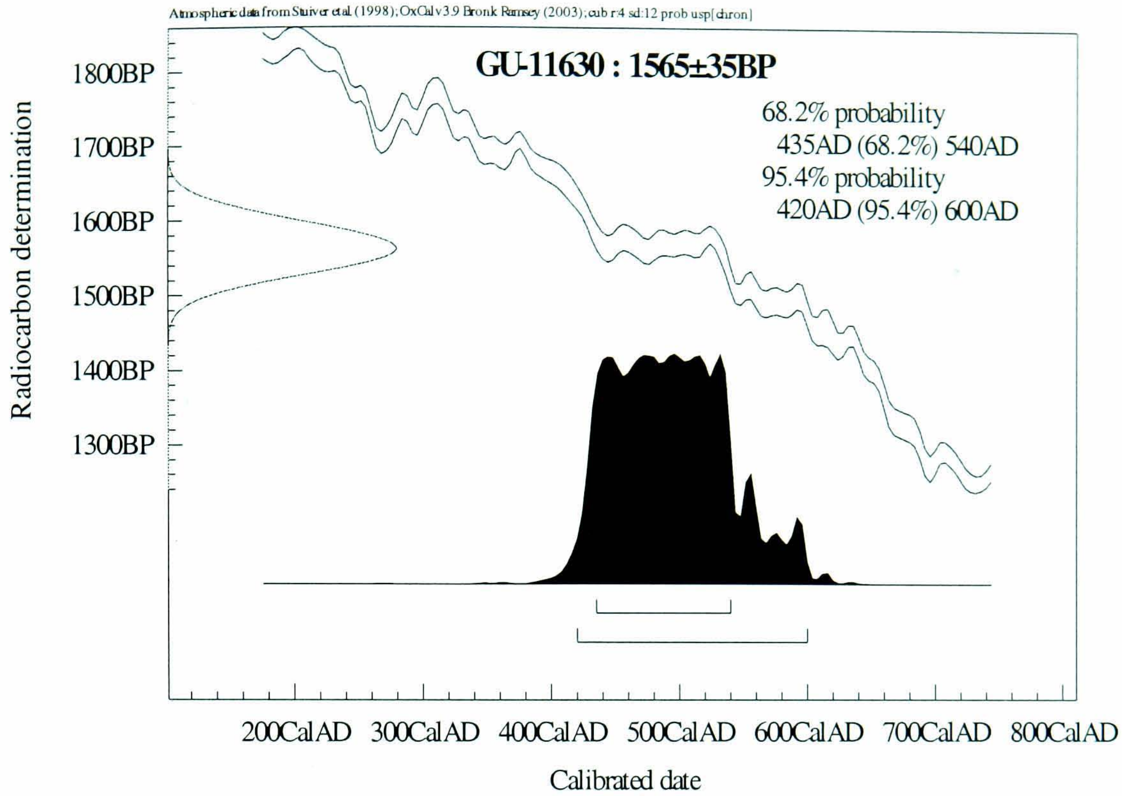


Figure 5.7b: Calibration details of GU-11631

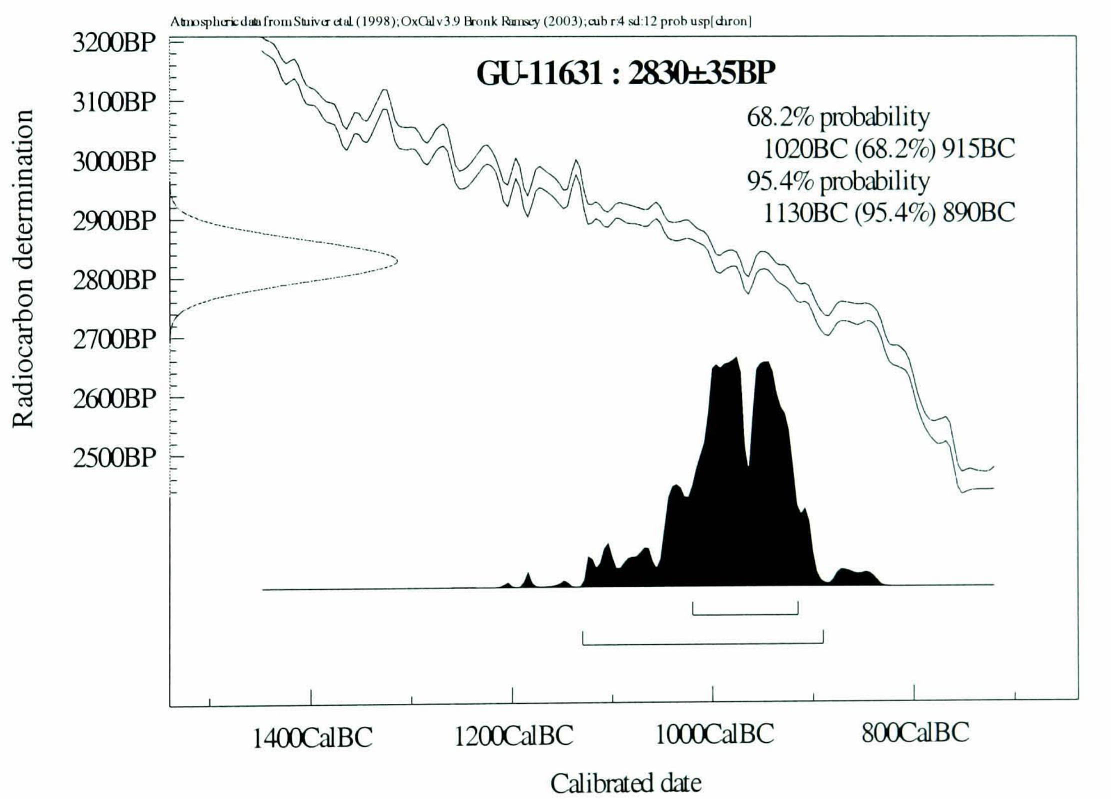


Figure 5.7c: Calibration details of GU-11632

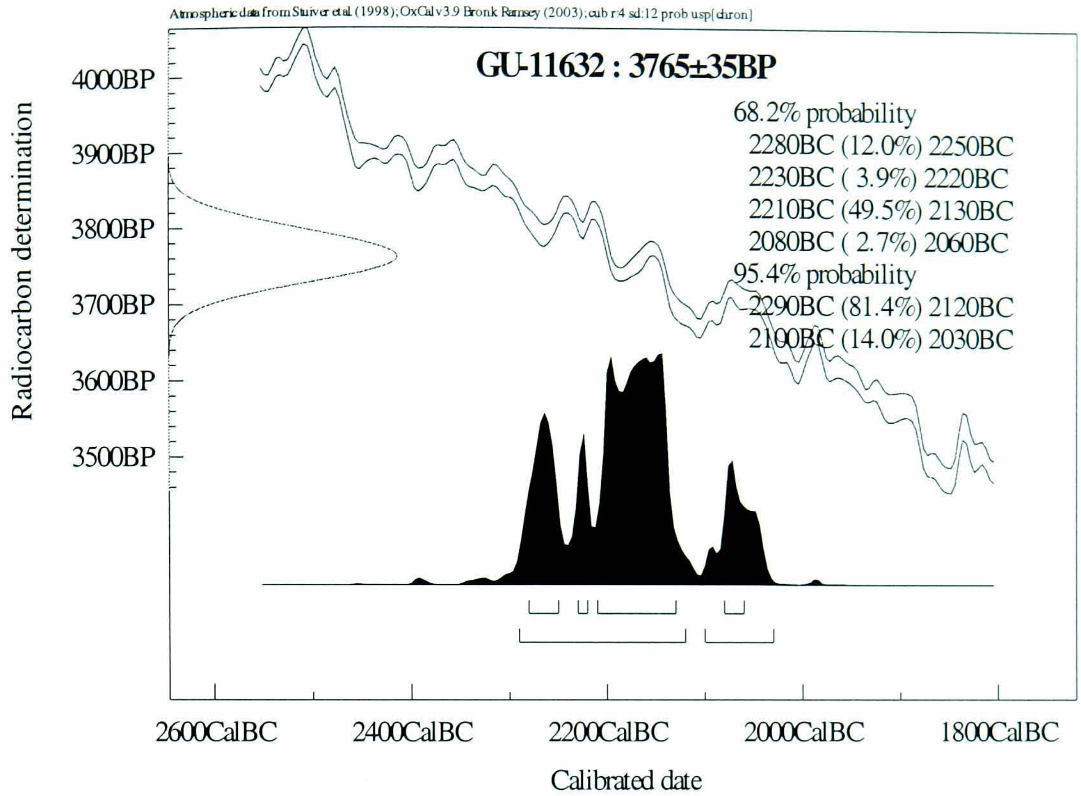


Figure 5.7d: Calibration details of GU-11633

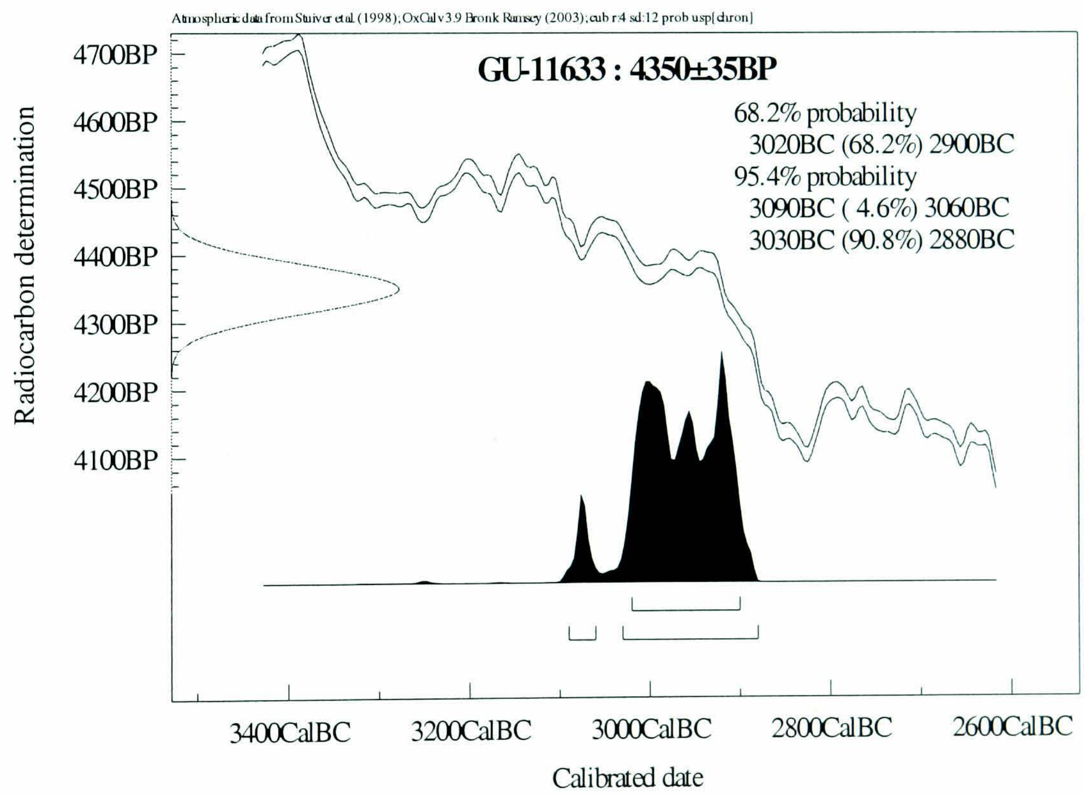


Figure 5.7e: Calibration details of GU-11634

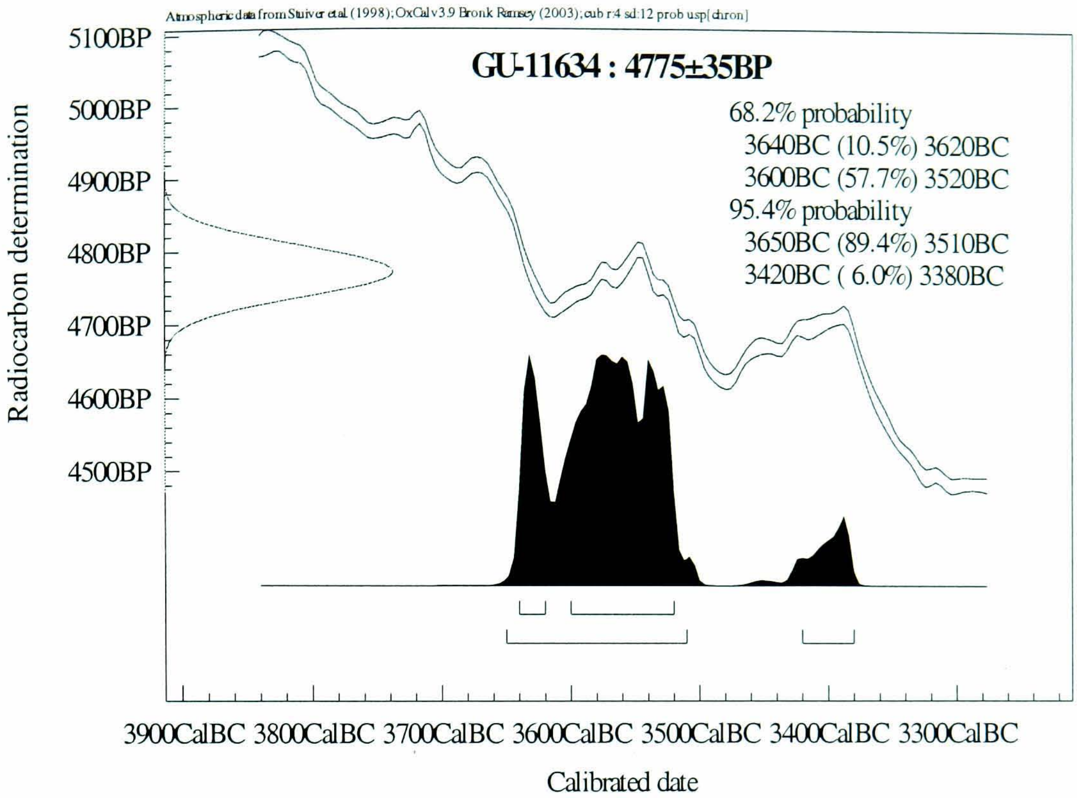


Figure 5.7f: Comparative plot showing calibration details of all radiocarbon assays from the BEL core

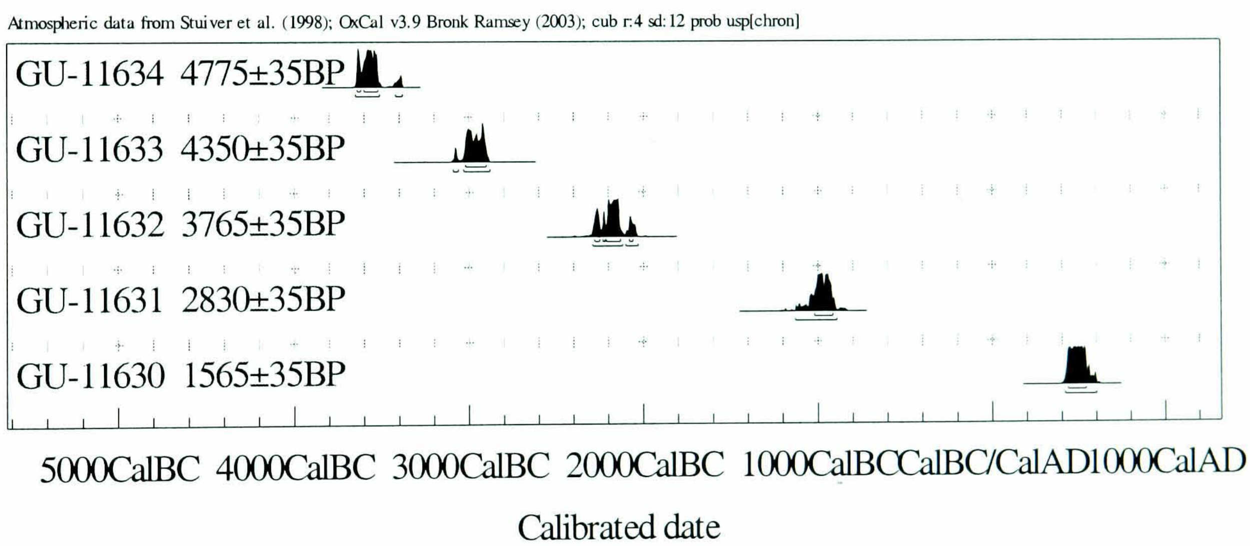
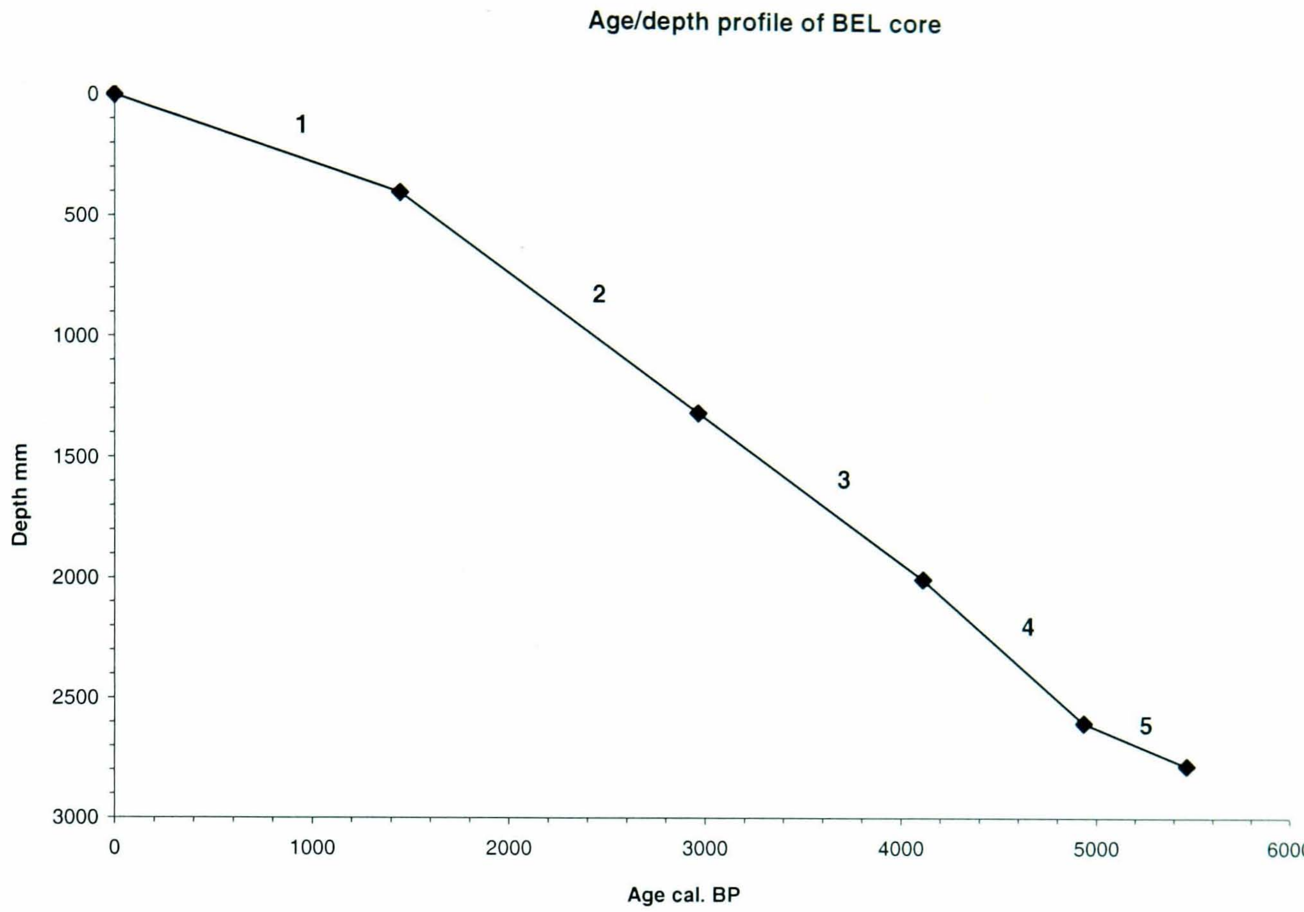


Figure 5.8: Age/depth relations for the BEL core



Trendline (see graph)	Depths (mm)	Ages cal. BP (midpoint)	Regression equation	Growth rate mm/cal. yr	Growth rate cal. yr/mm
1	0 – 400	0 – 1440	y = 0.2778x	0.28	3.6
2	400 – 1310	1440 – 2960	y = 0.5987x - 462.11	0.6	1.67
3	1310 – 2000	2960 – 4110	y = 0.6x - 466	0.6	1.67
4	2000 – 2600	4110 – 4935	y = 0.7273x - 989.09	0.73	1.38
5	2600 – 2780	4935 – 5465	y = 0.3396x + 923.96	0.34	2.94

Figure 5.9: Volume magnetic susceptibility (κ) of all BEL cores and monoliths

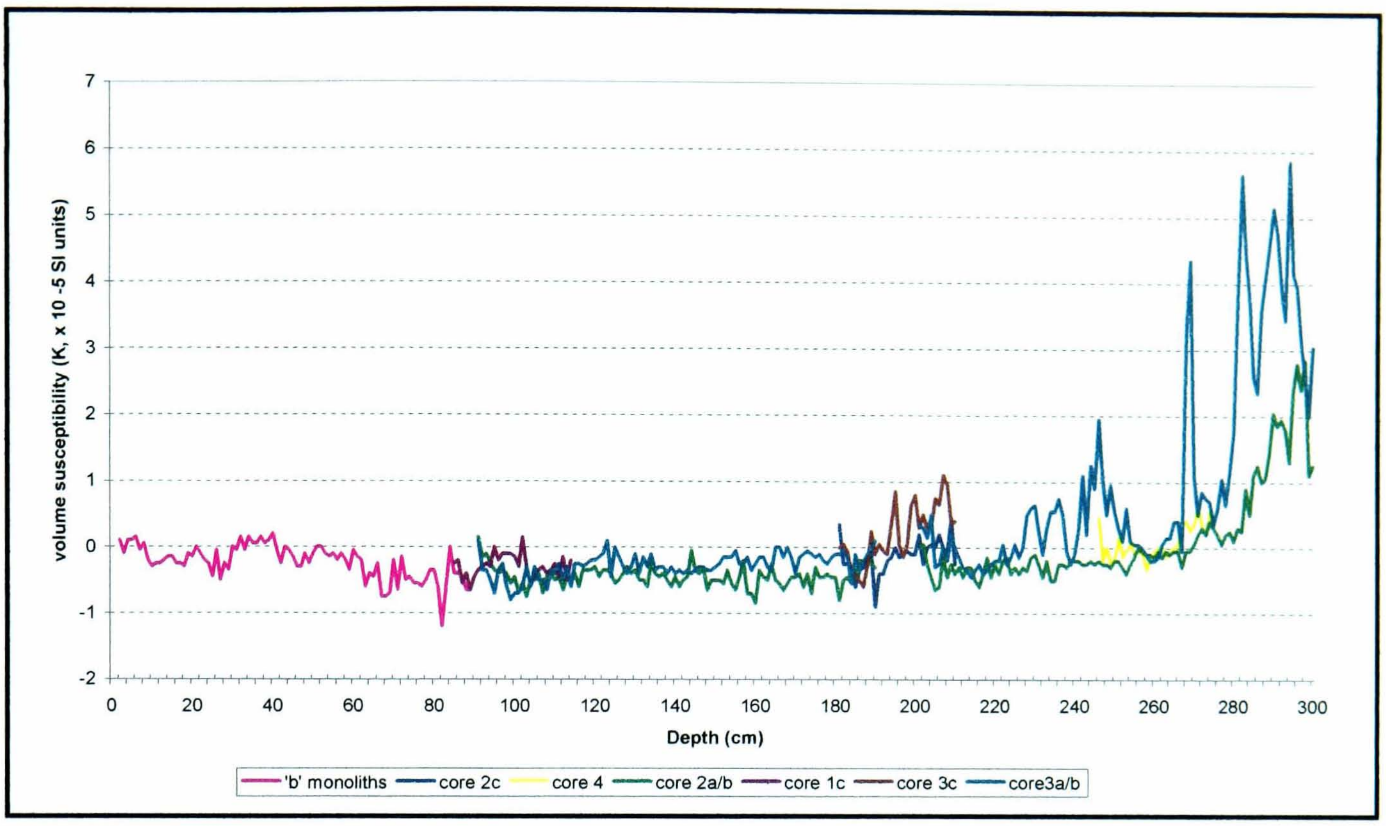


Figure 5.10: Mean volume magnetic susceptibility (κ) of all BEL cores and monoliths

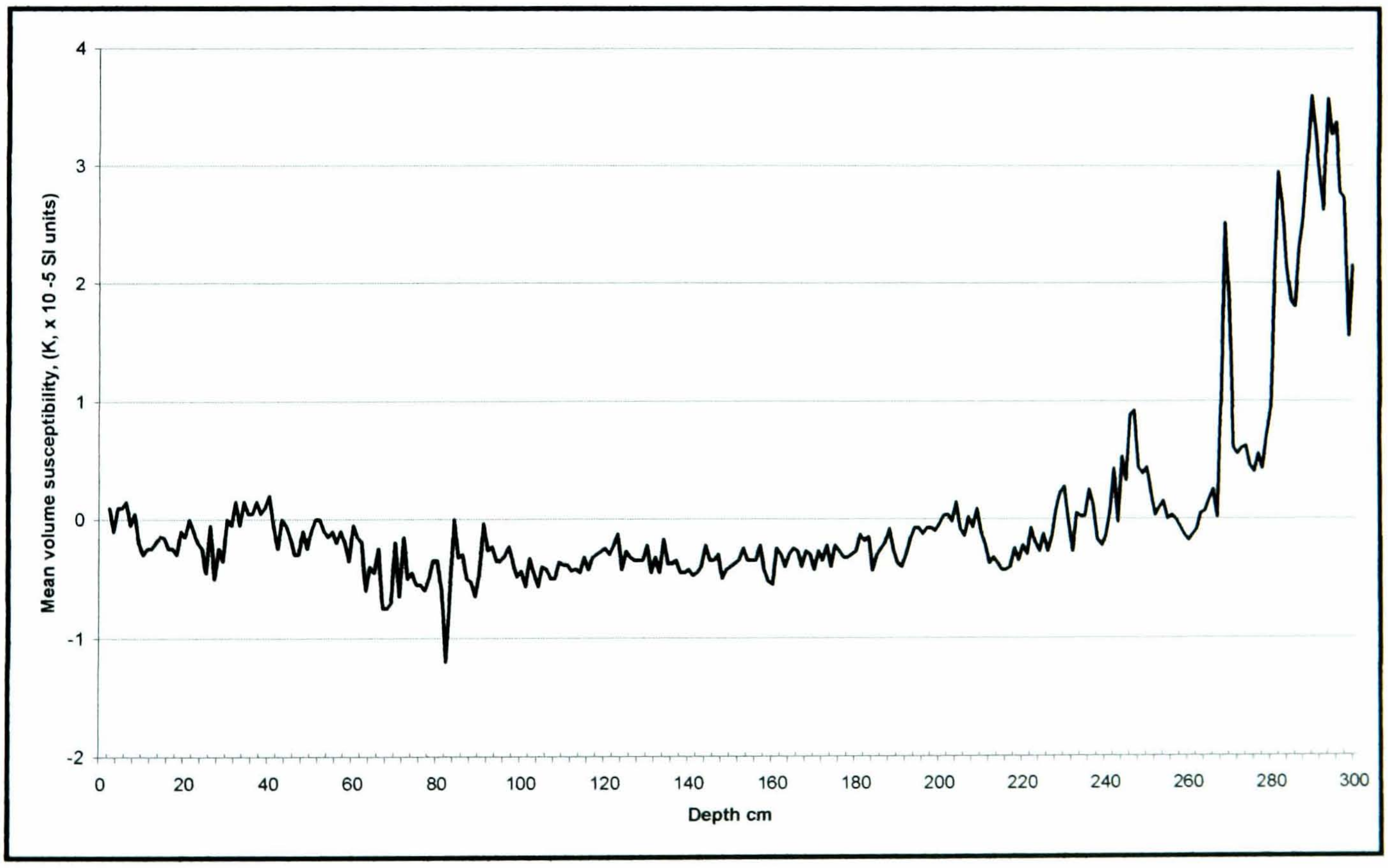


Figure 5.11: Percentage loss-on-ignition of BEL core

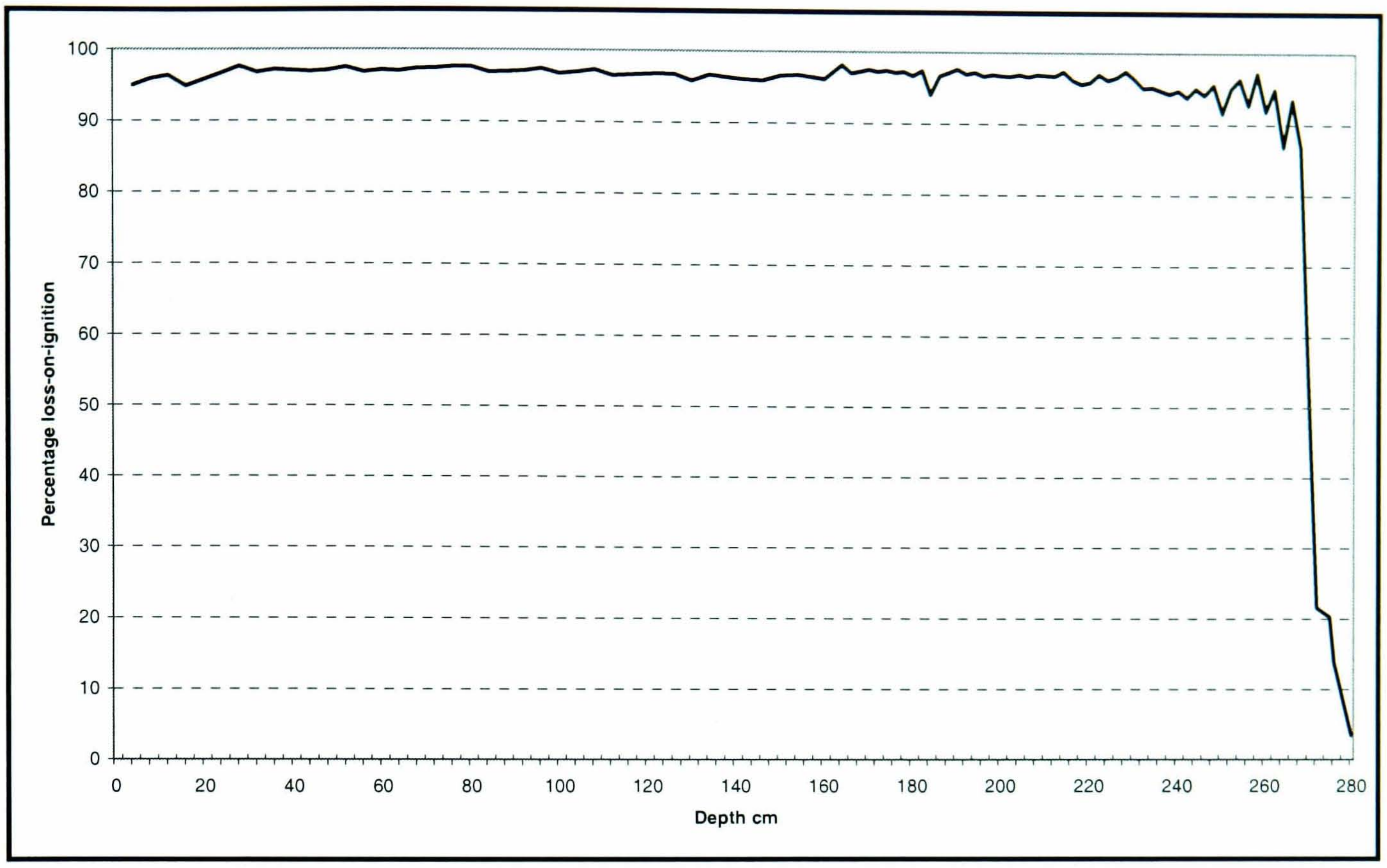


Figure 5.12: Percentage ash content of BEL core

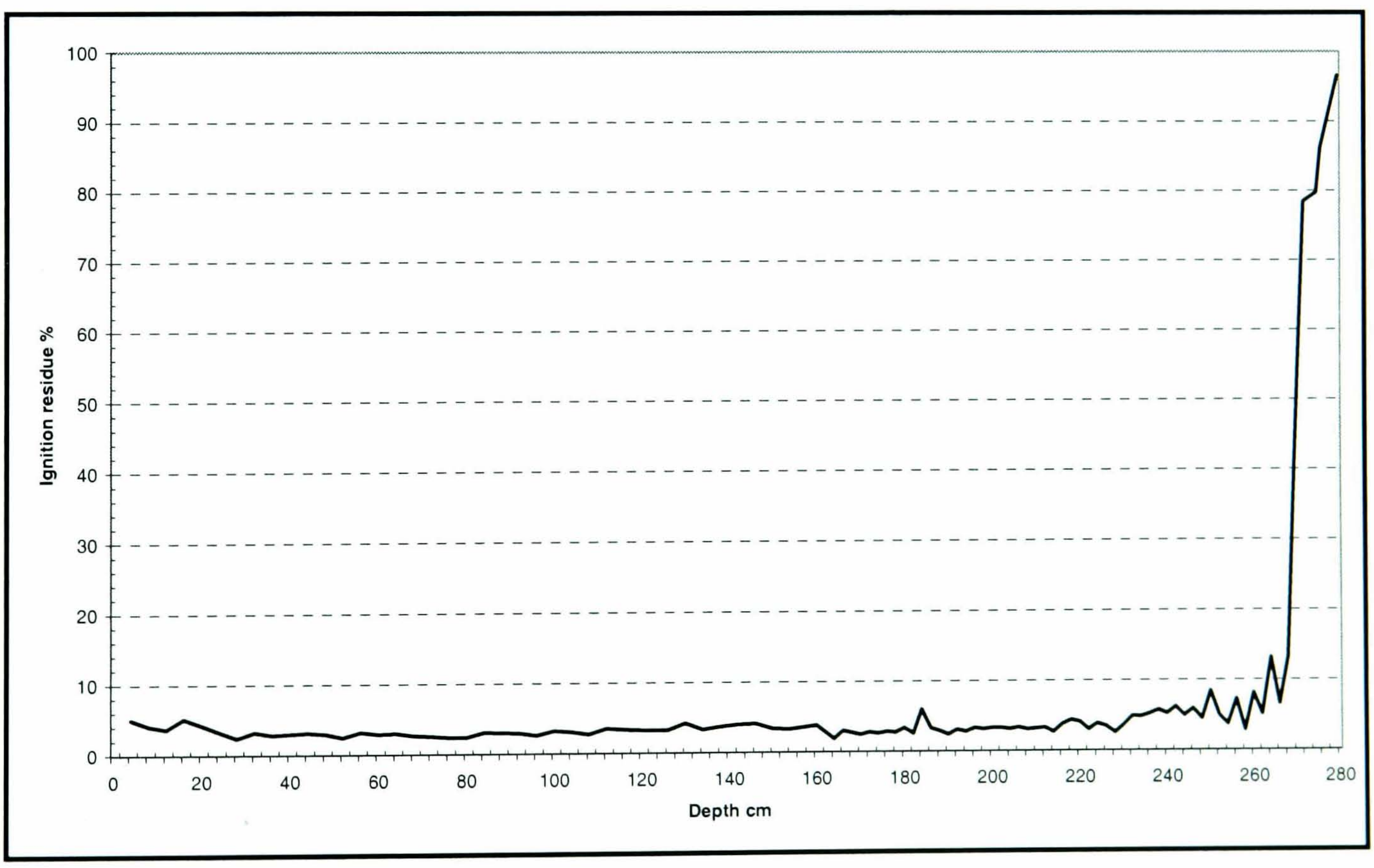


Figure 5.13: Percentage transmission values of BEL core showing 3-point running mean

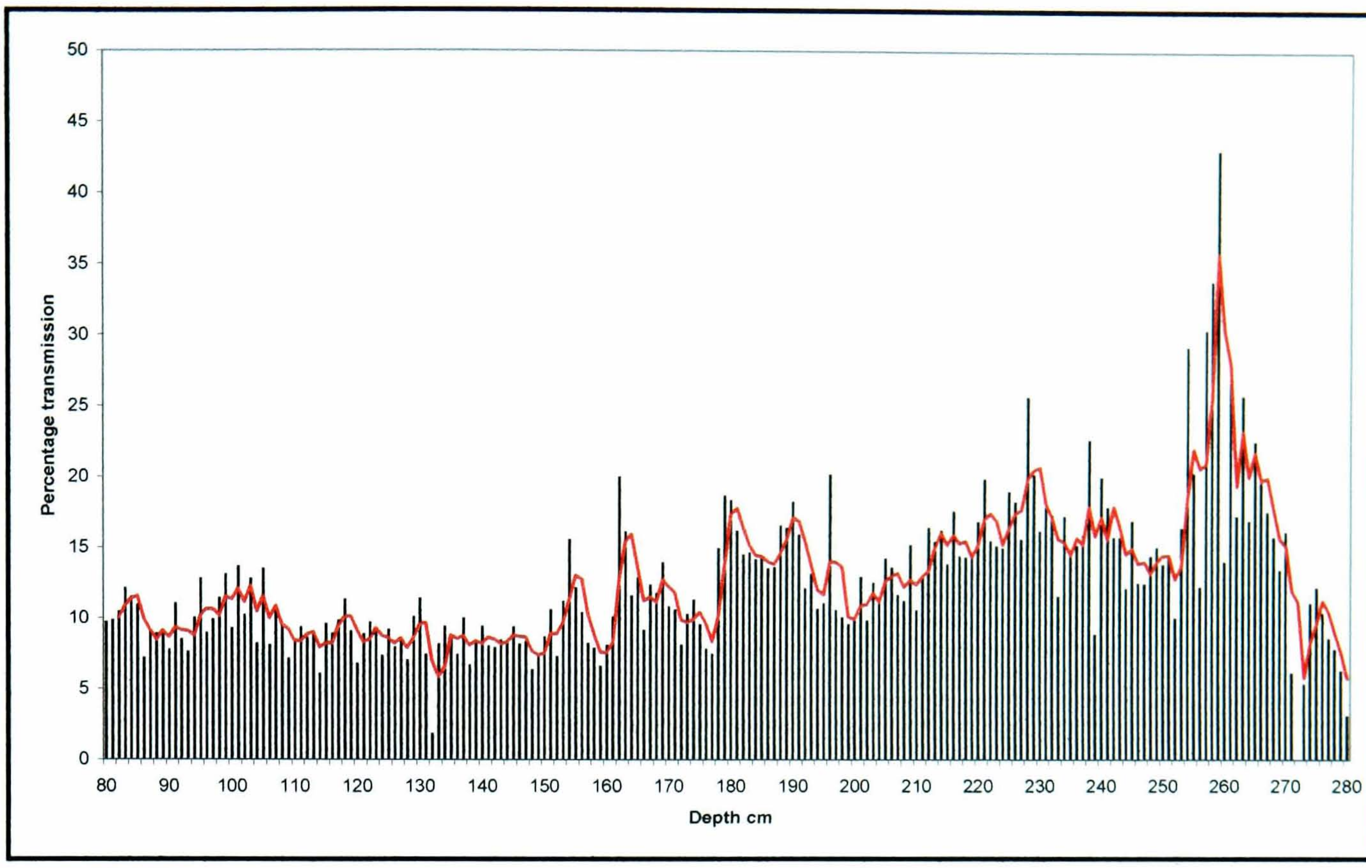
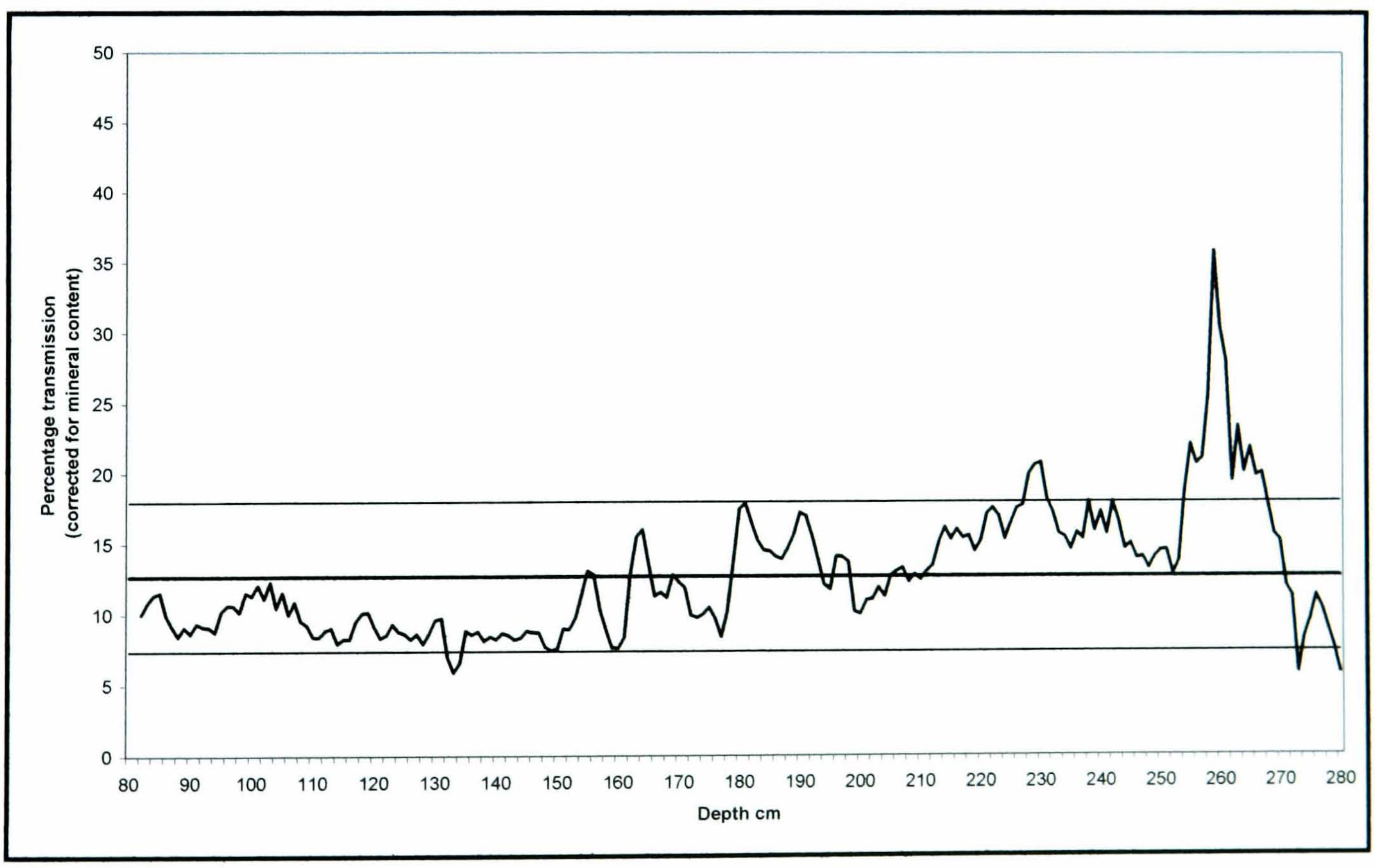


Figure 5.14: Percentage transmission curve of BEL core showing mean transmission values plus and minus one standard deviation



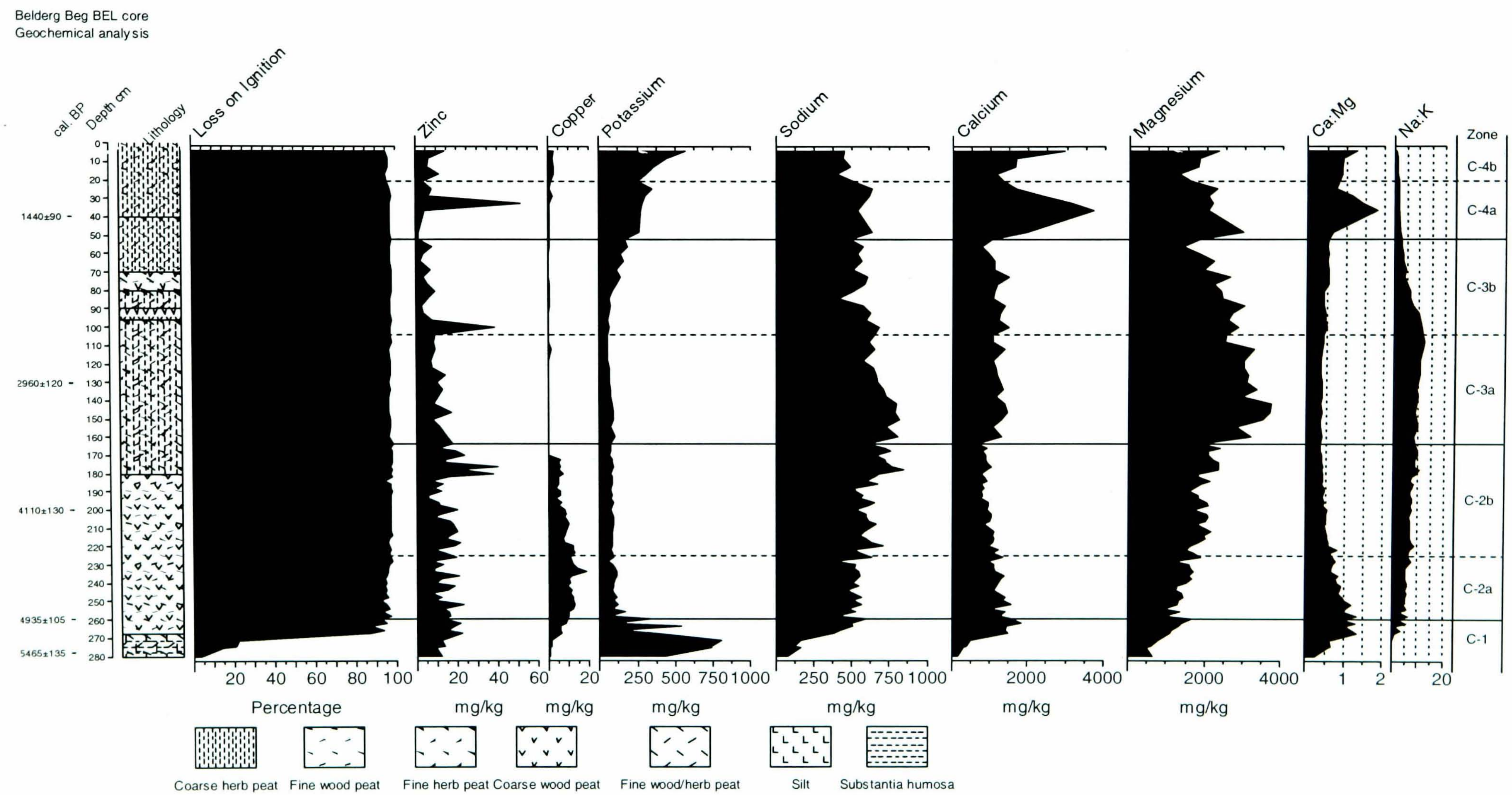


Figure 5.15: Geochemical profile of BEL core

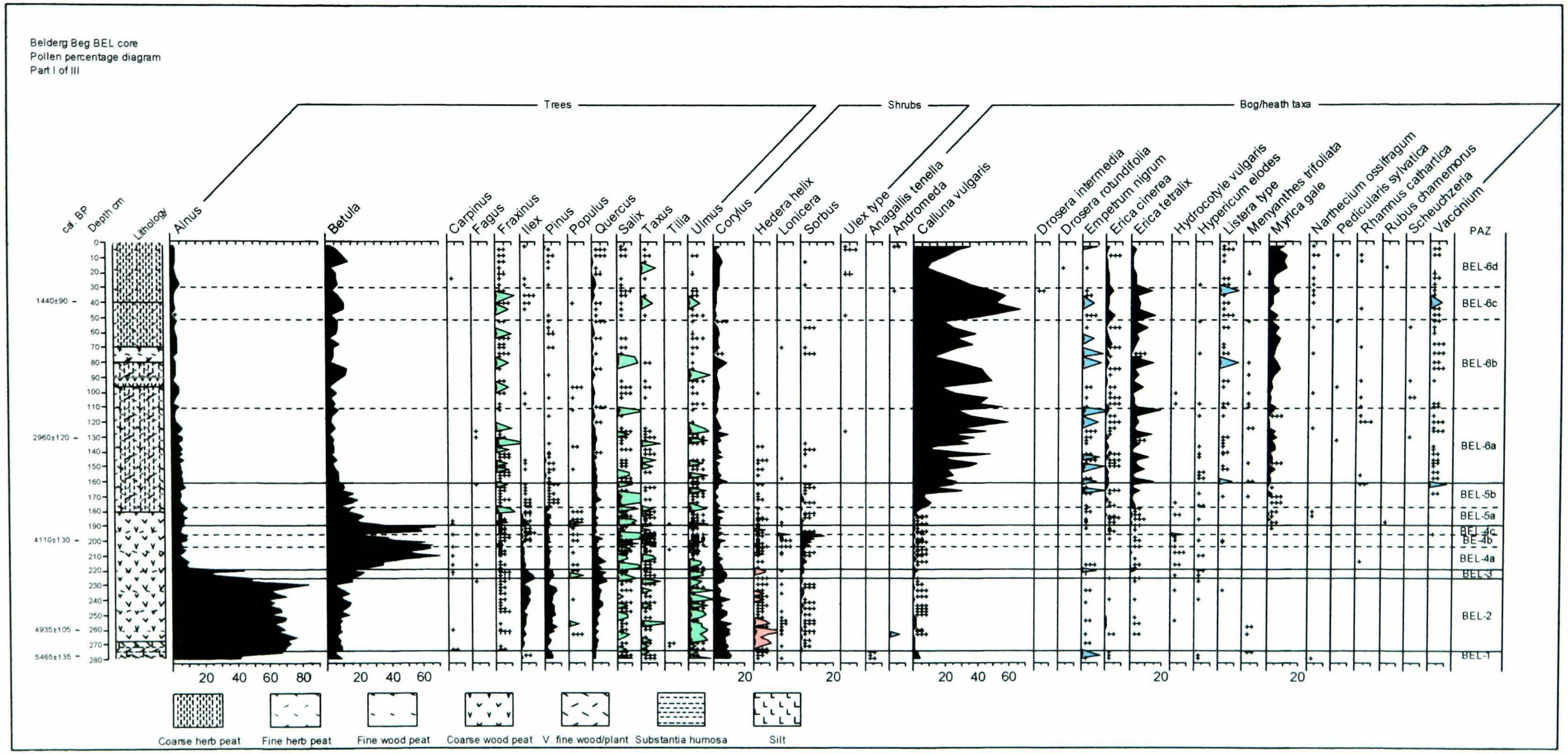


Figure 5.16a: Pollen percentage diagram, BEL core

Figure 5.16b: Pollen percentage diagram, BEL core (continued)

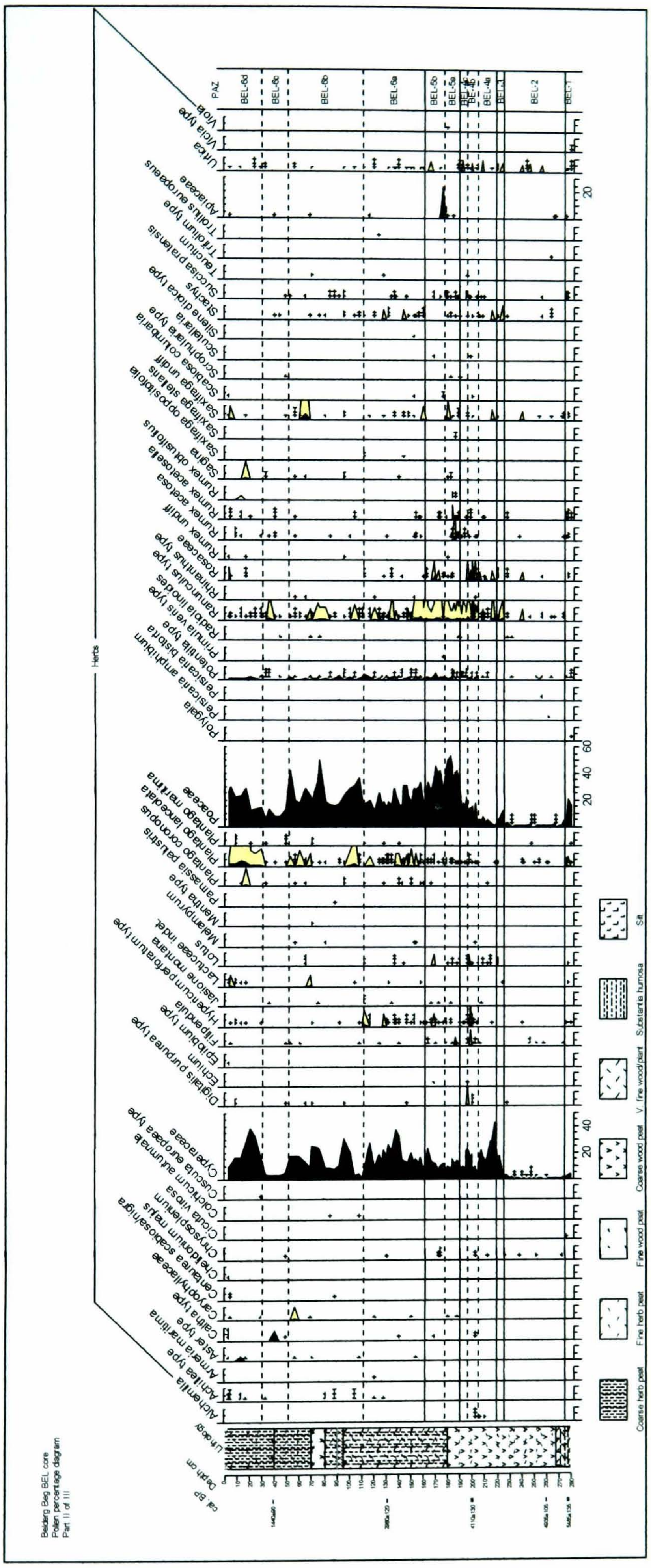


Figure 5.16c: Pollen percentage diagram, BEL core (continued)

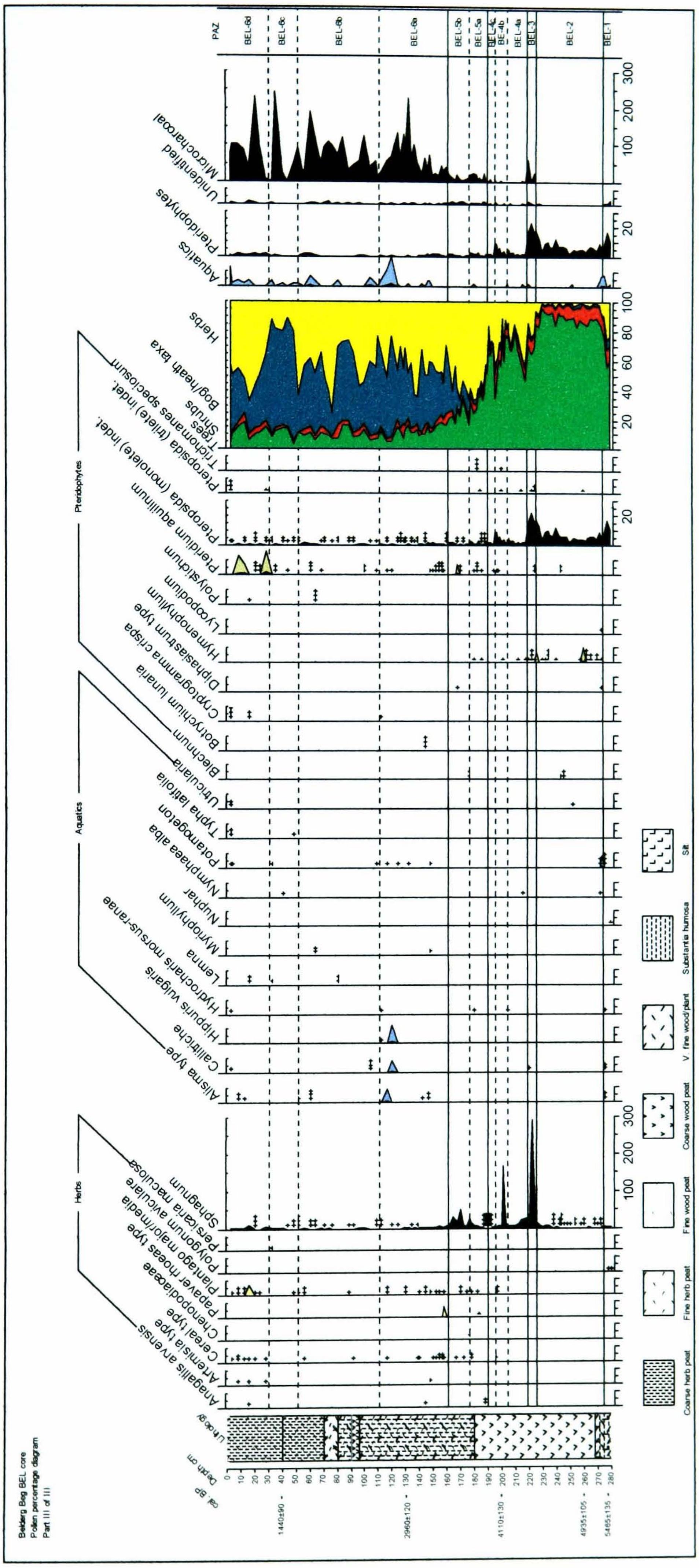


Figure 5.17a: Pollen percentage diagram, BEL core

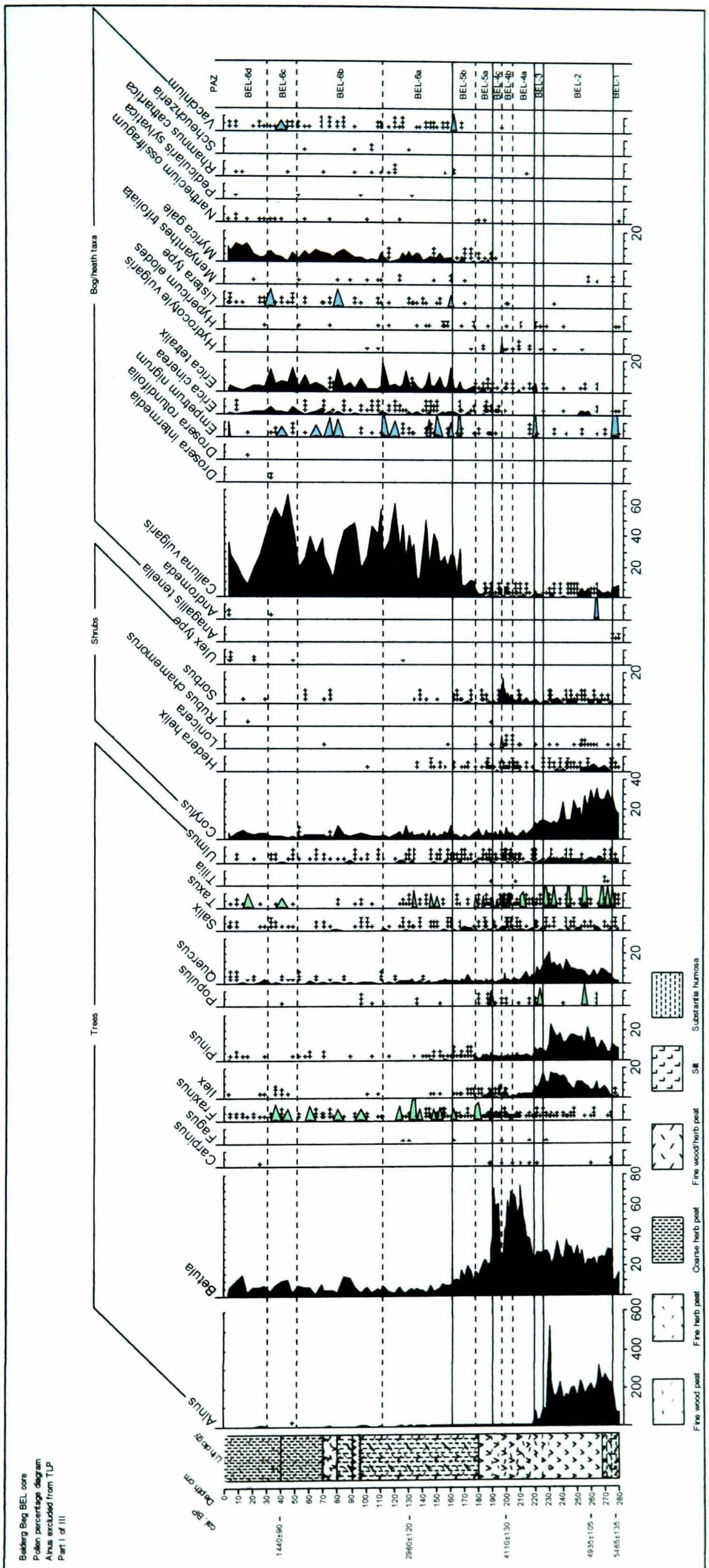
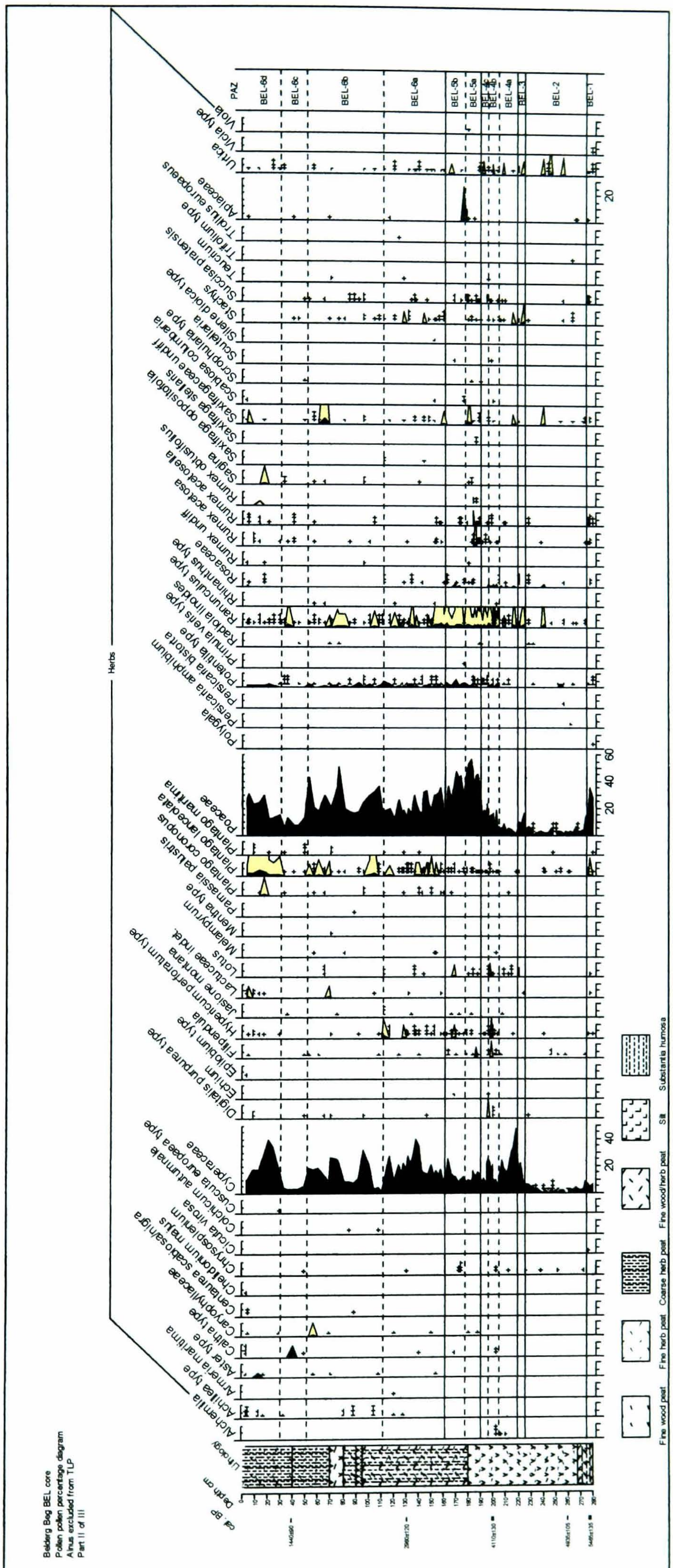


Figure 5.17b: Pollen percentage diagram, BEL core (continued)



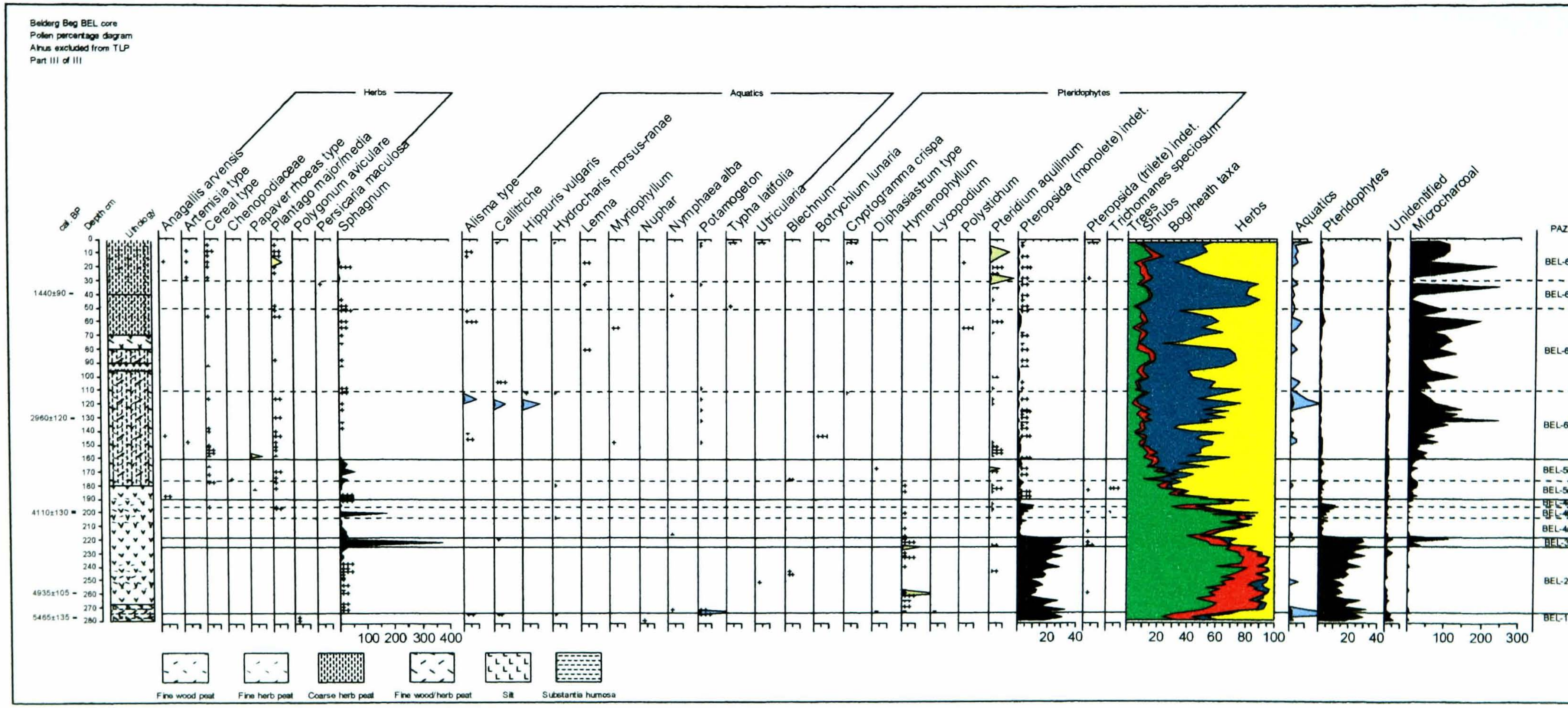


Figure 5.17c: Pollen percentage diagram, BEL core (continued)

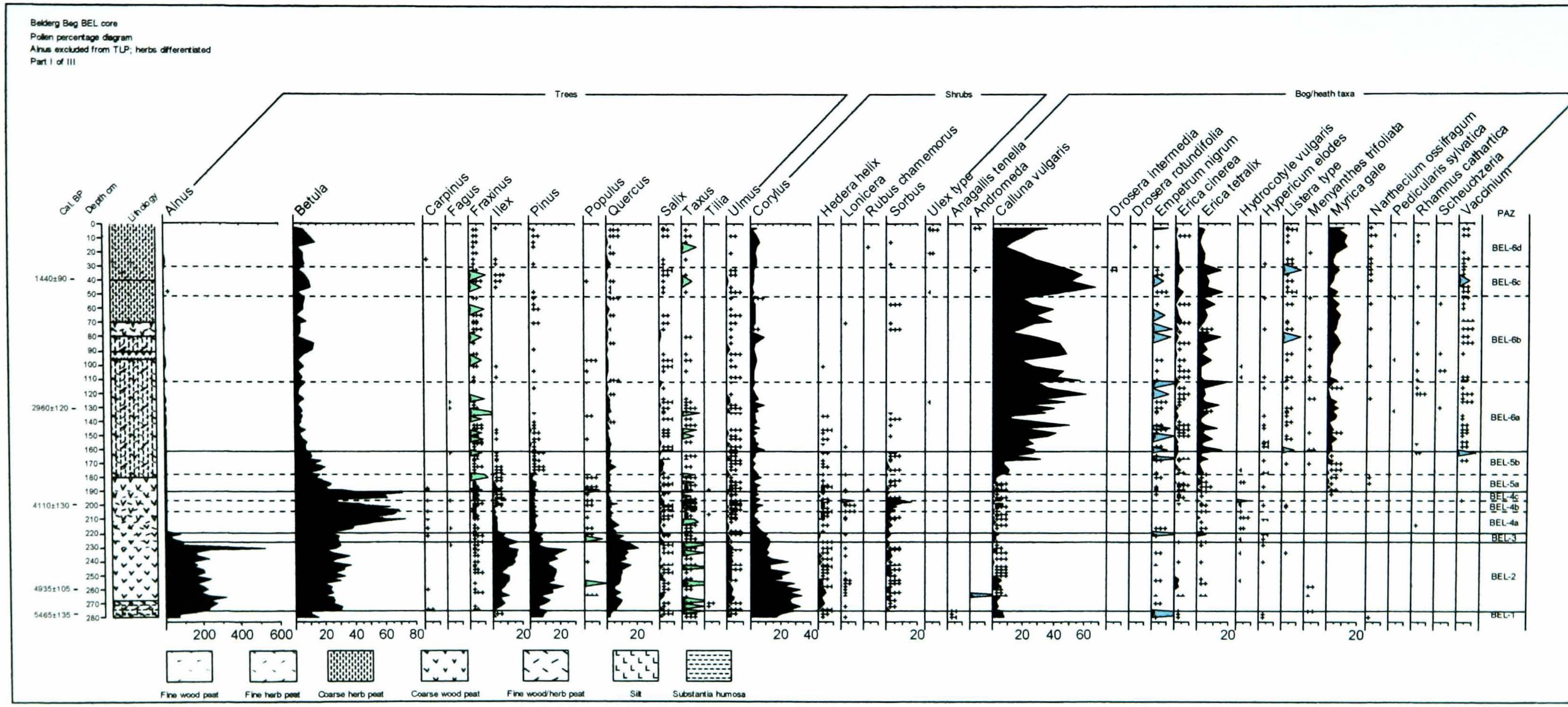


Figure 5.18a: Pollen percentage diagram, BEL core

Figure 5.18b: Pollen percentage diagram, BEL core (continued)

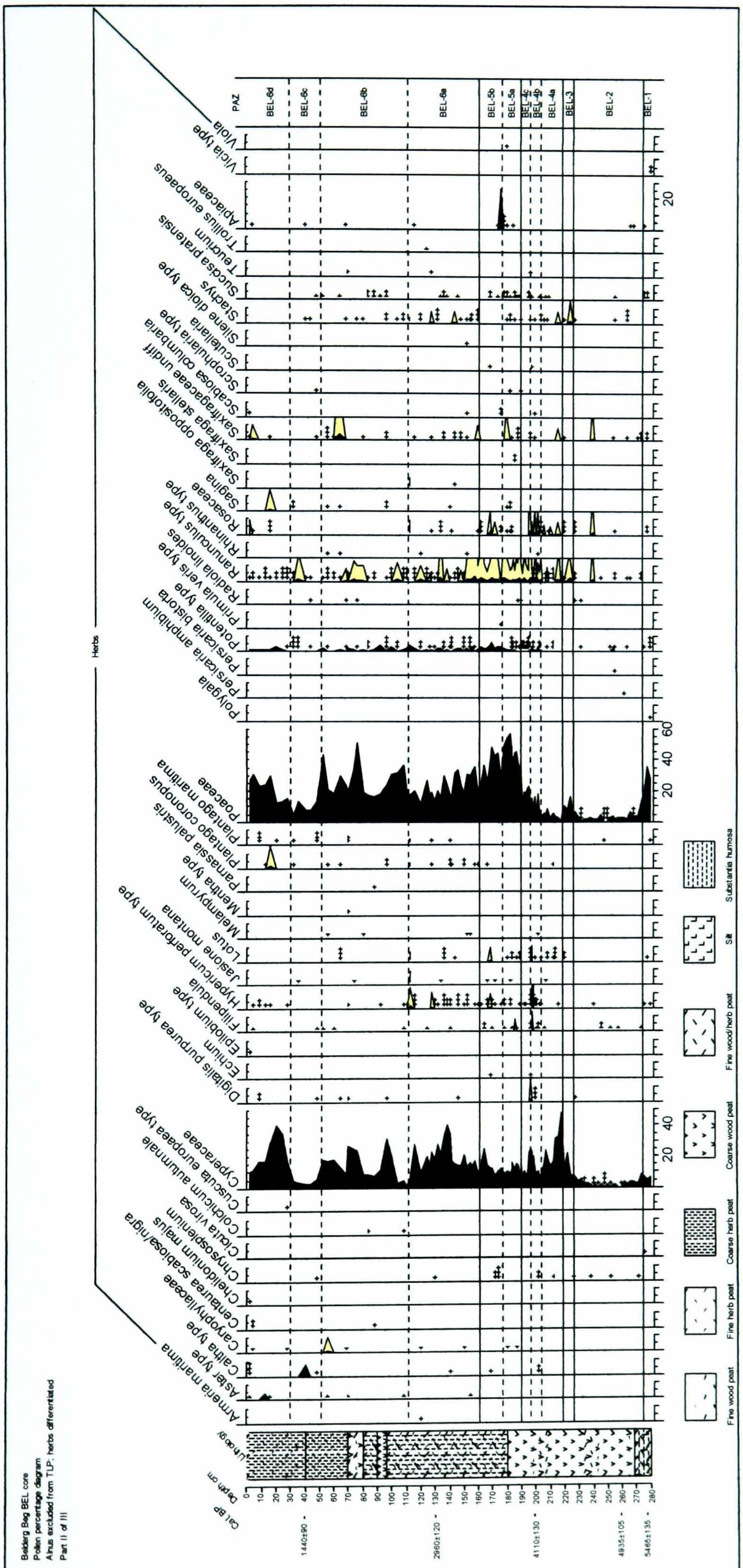


Figure 5.18c: Pollen percentage diagram, BEL core (continued)

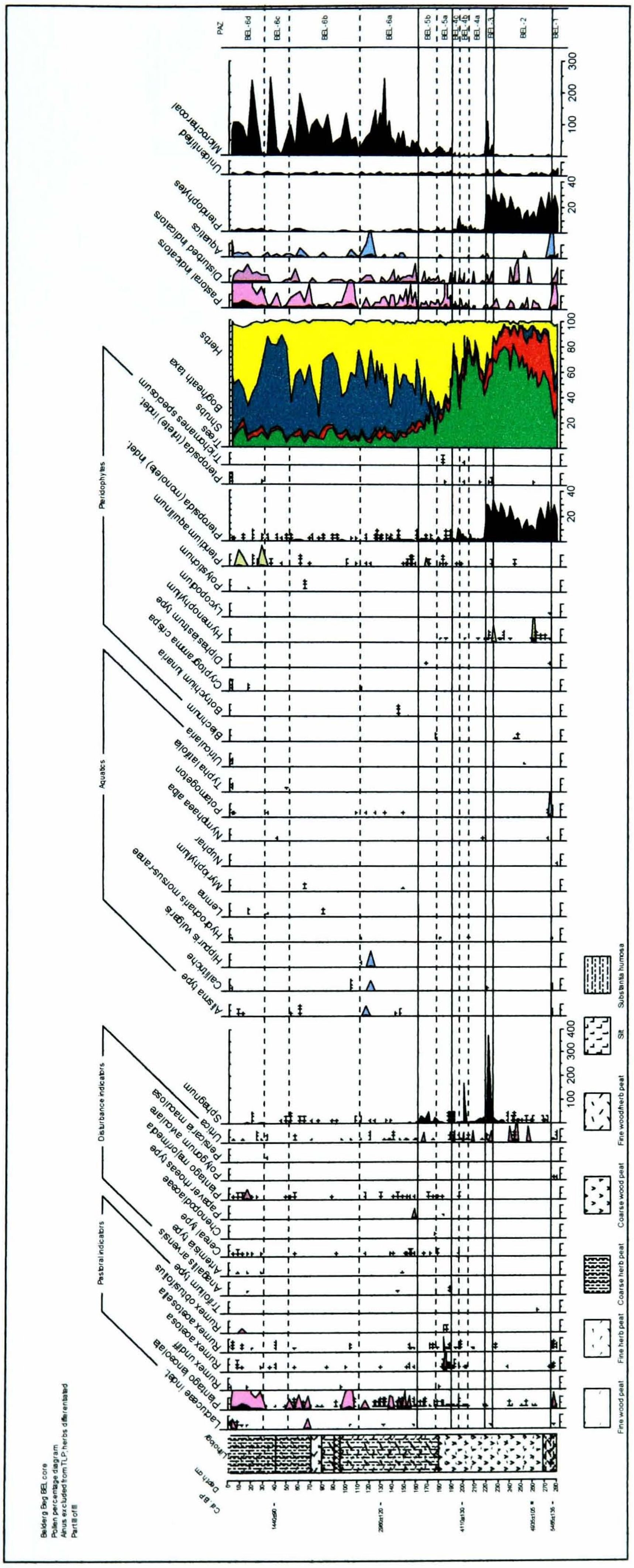


Figure 5.19: Pollen percentage diagram, BEL core (main taxa, CONISS plotted)

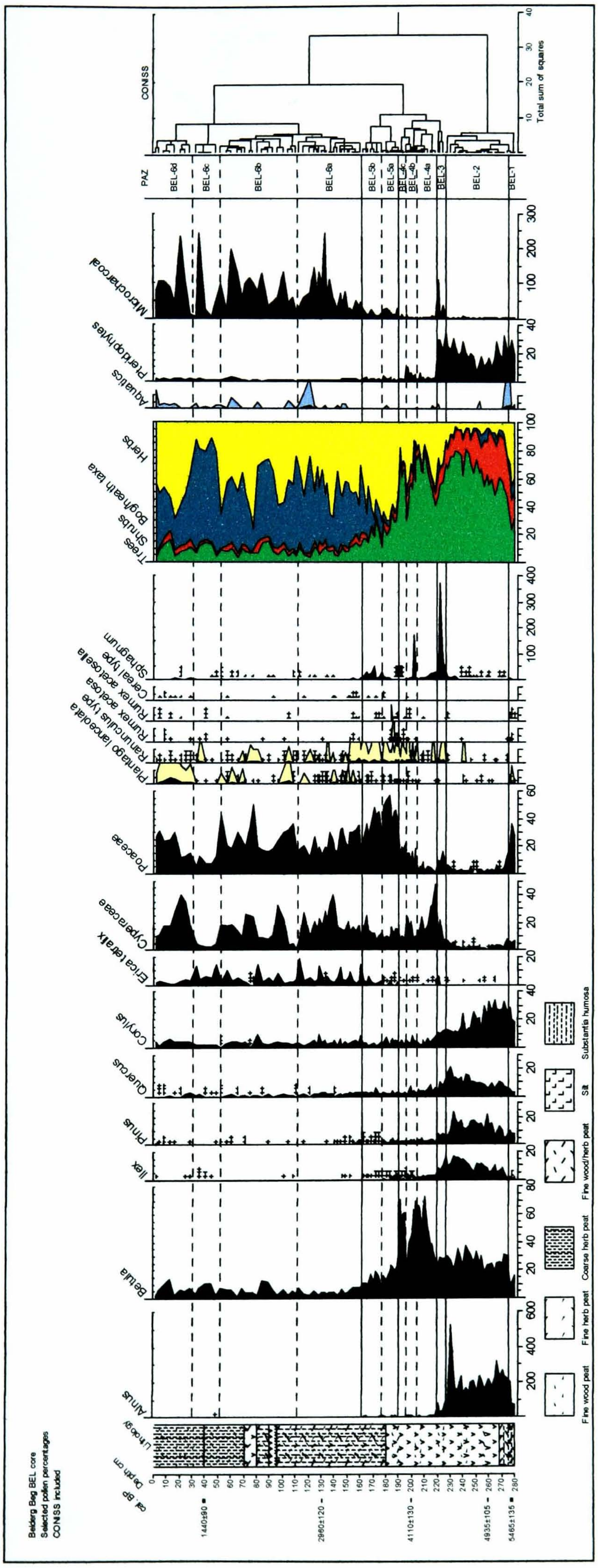


Figure 5.20: Pollen influx diagram, BEL core

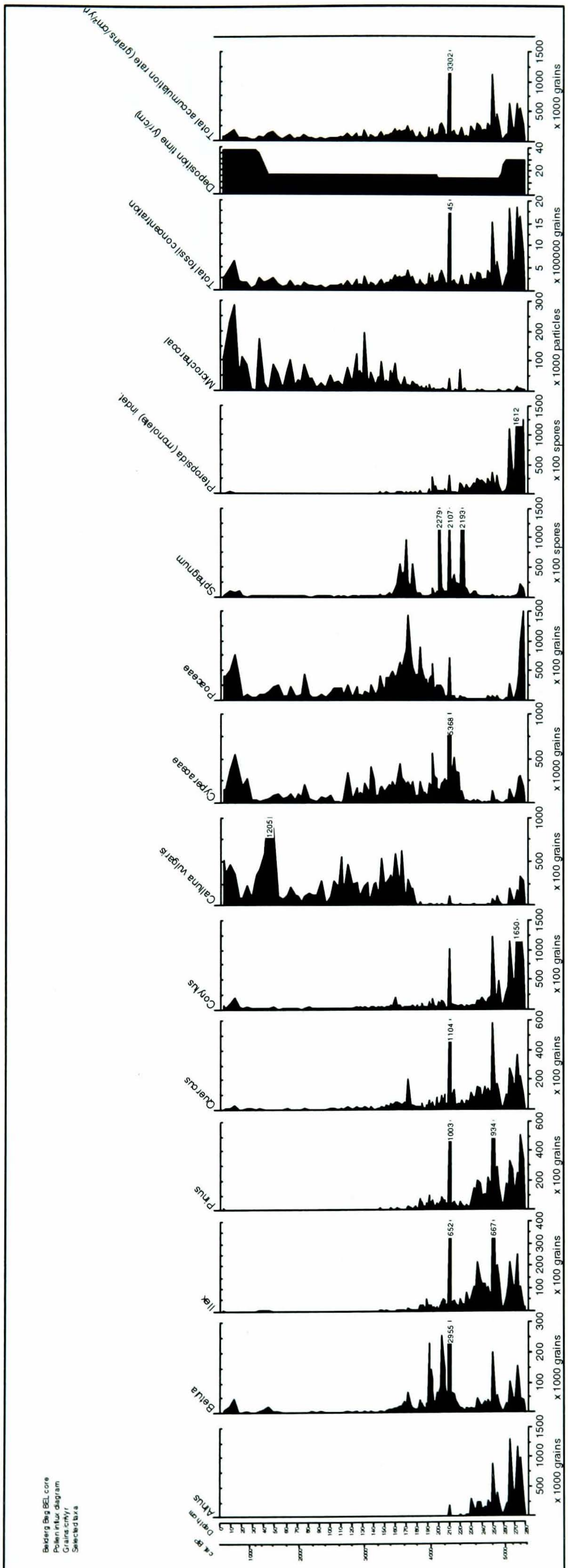


Figure 5.21: Pollen concentration diagram, BEL core

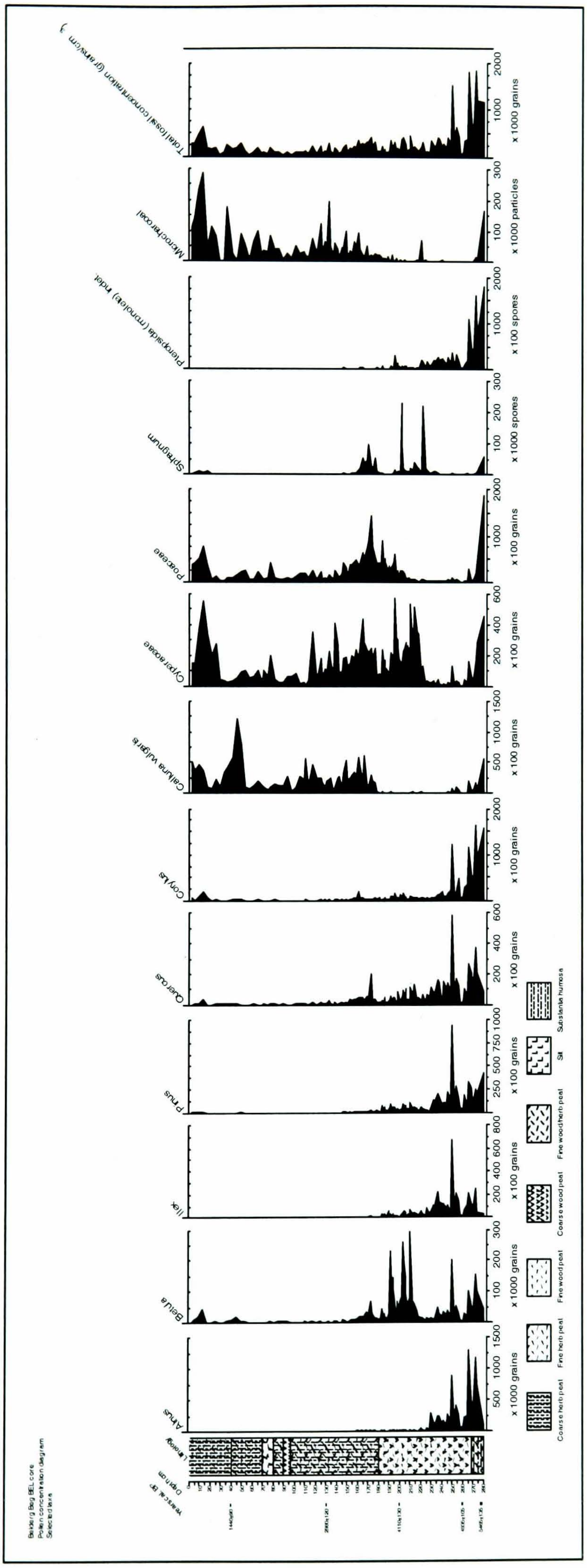


Figure 5.22: Interpreted sediment sequence of Belderg Beg valley side at c. 5500 cal. BP, following Figure 3.3 in Rapp & Hill (1998, 58)

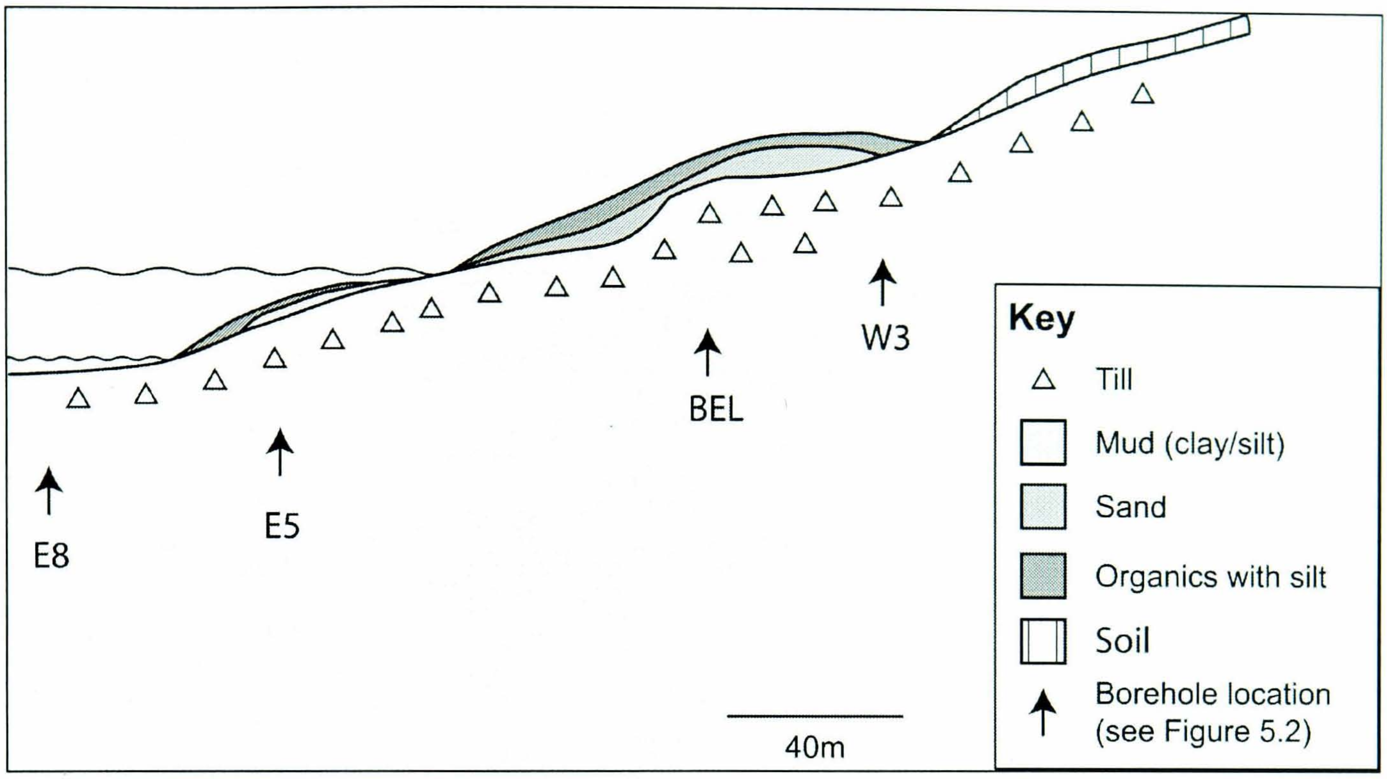


Figure 6.1: Location of BB1 and BB2 profiles (cross-reference to Figure 5.1 for landscape location)

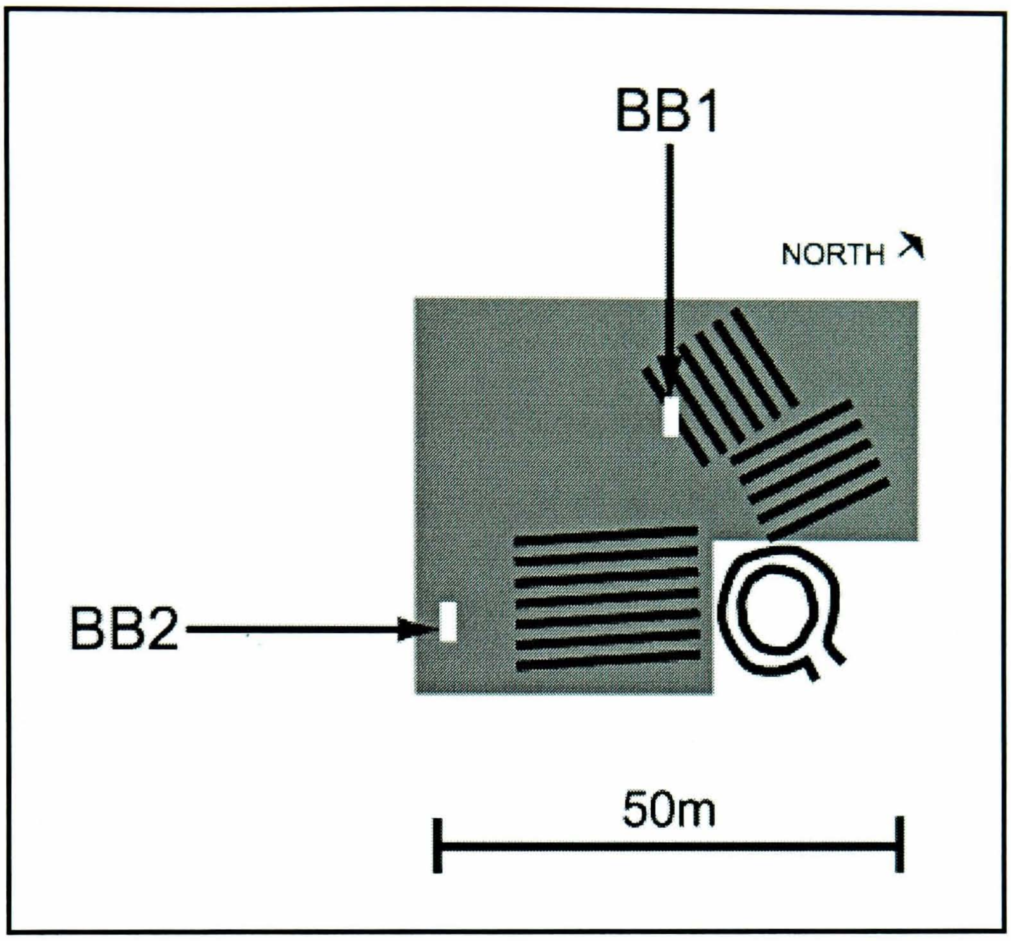
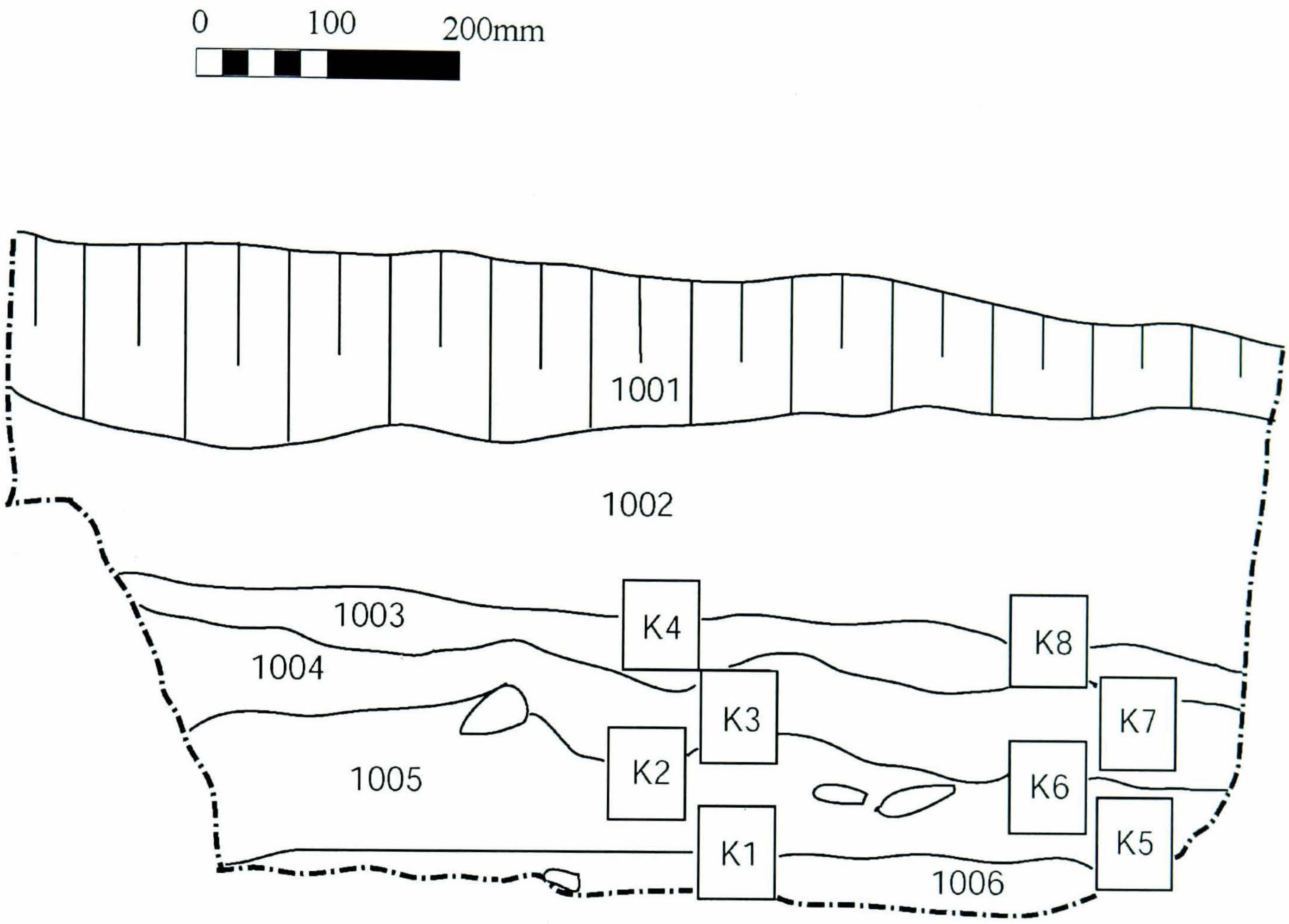
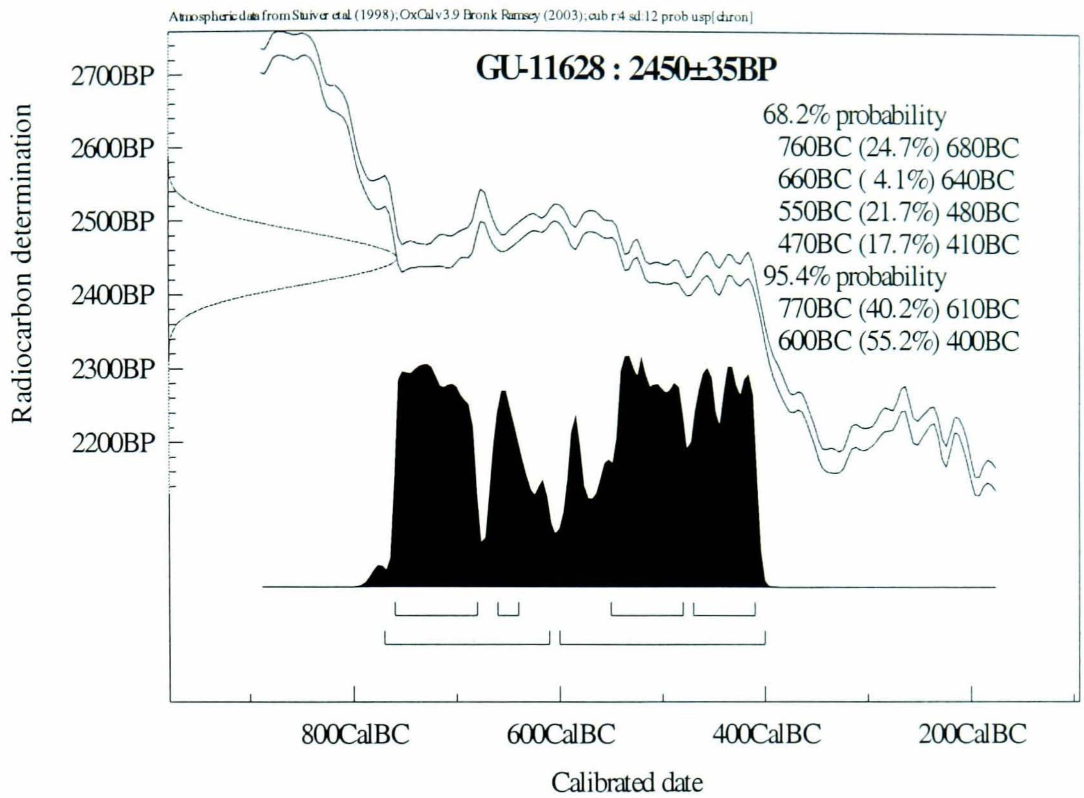


Figure 6.2: Section drawing of BB1 with locations of Kubiena sampling tins



Context	Description
1001	Acrotelm. N(f)4, N3, S0, E0, Si2 / H1/ Tl0.5, Th1, Dl0.5, Dh0.5, Ag0.5, Gmin1
1002	Poorly humified fibrous peat. N(f)3, N3, S0, E0, Si2 / H1 / Th1, Dh1, Ag1, Ga1
1003	Amorphous, very well humified peat. N(f)4, N4, S0, E2, Si2.5 / H3 / Dg1, Sh2, Ag1
1004	Compact highly organic peaty soil. N(f)2.5, N2, S0, E1, Si3 / H3 / Sh1, Ag2, Ga1
1005	Moderately organic medium sand. Weak consistence. Frequent charcoal and coarse pebble inclusions. Gs2, Ga1, Ag1
1006	Loose inorganic silty sand. Pebble inclusions. Vertical extent unknown.

Figure 6.3: Calibration details of GU-11628



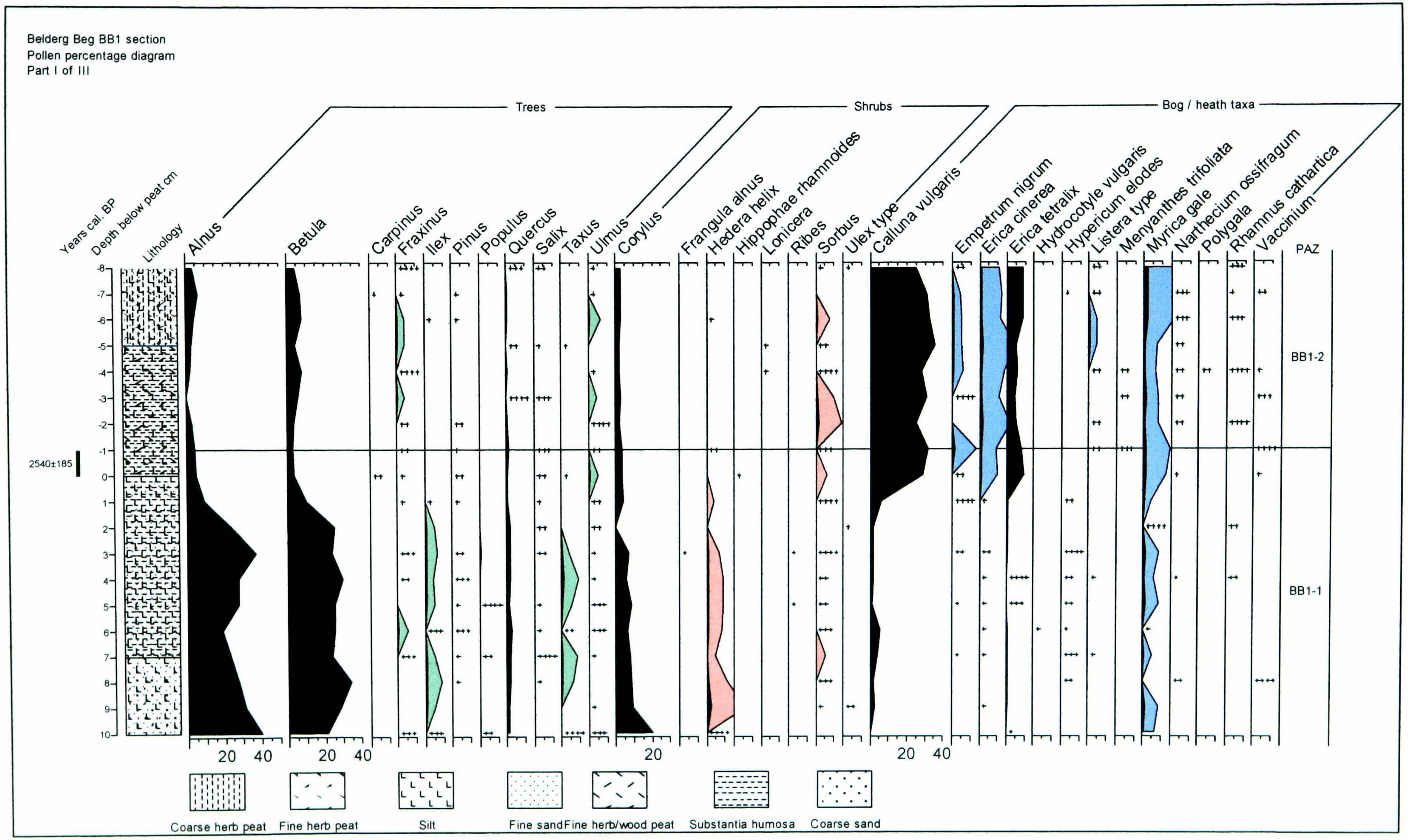
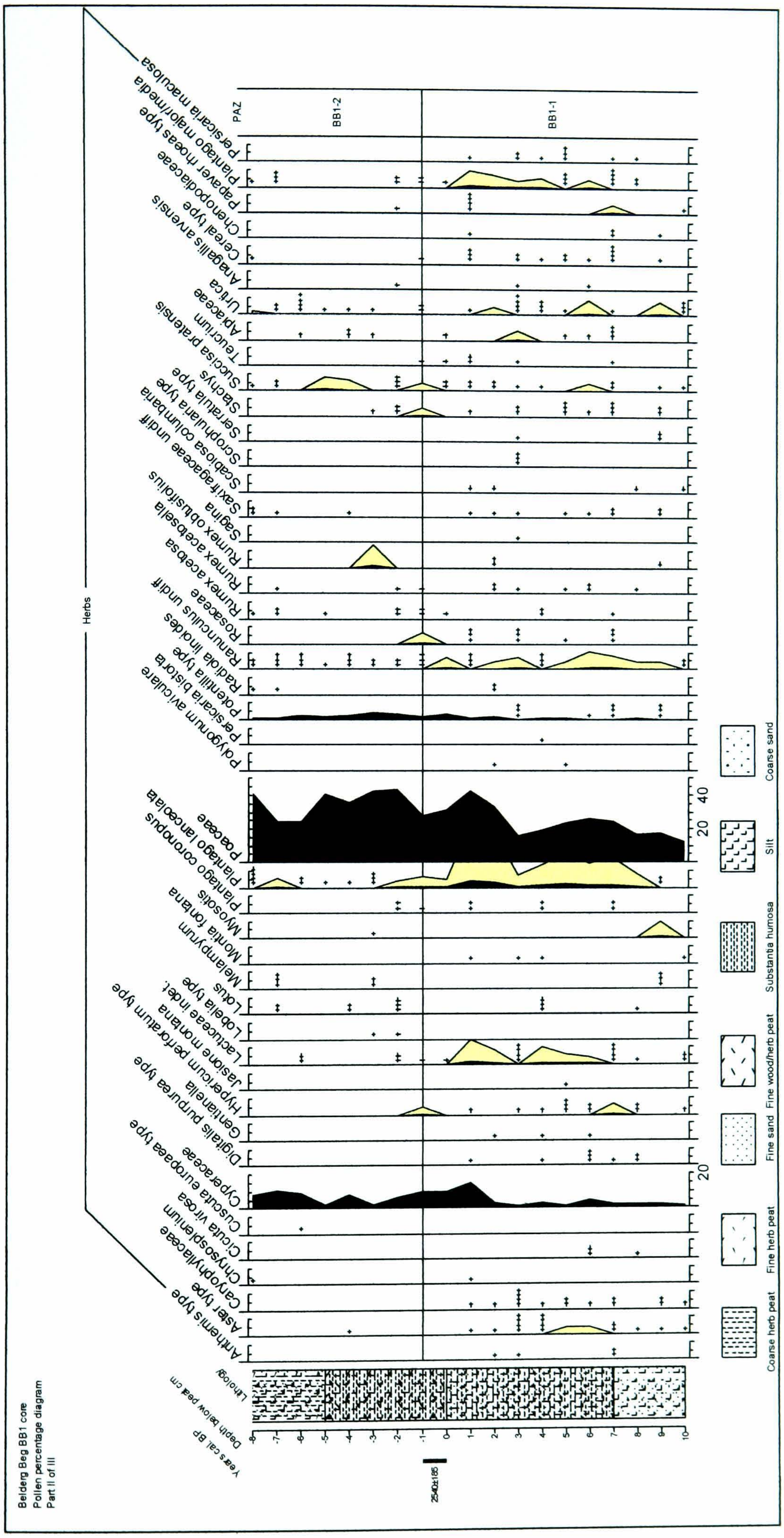


Figure 6.4a: Pollen percentage diagram, BB1 section

Figure 6.4b: Pollen percentage diagram, BB1 section (continued)



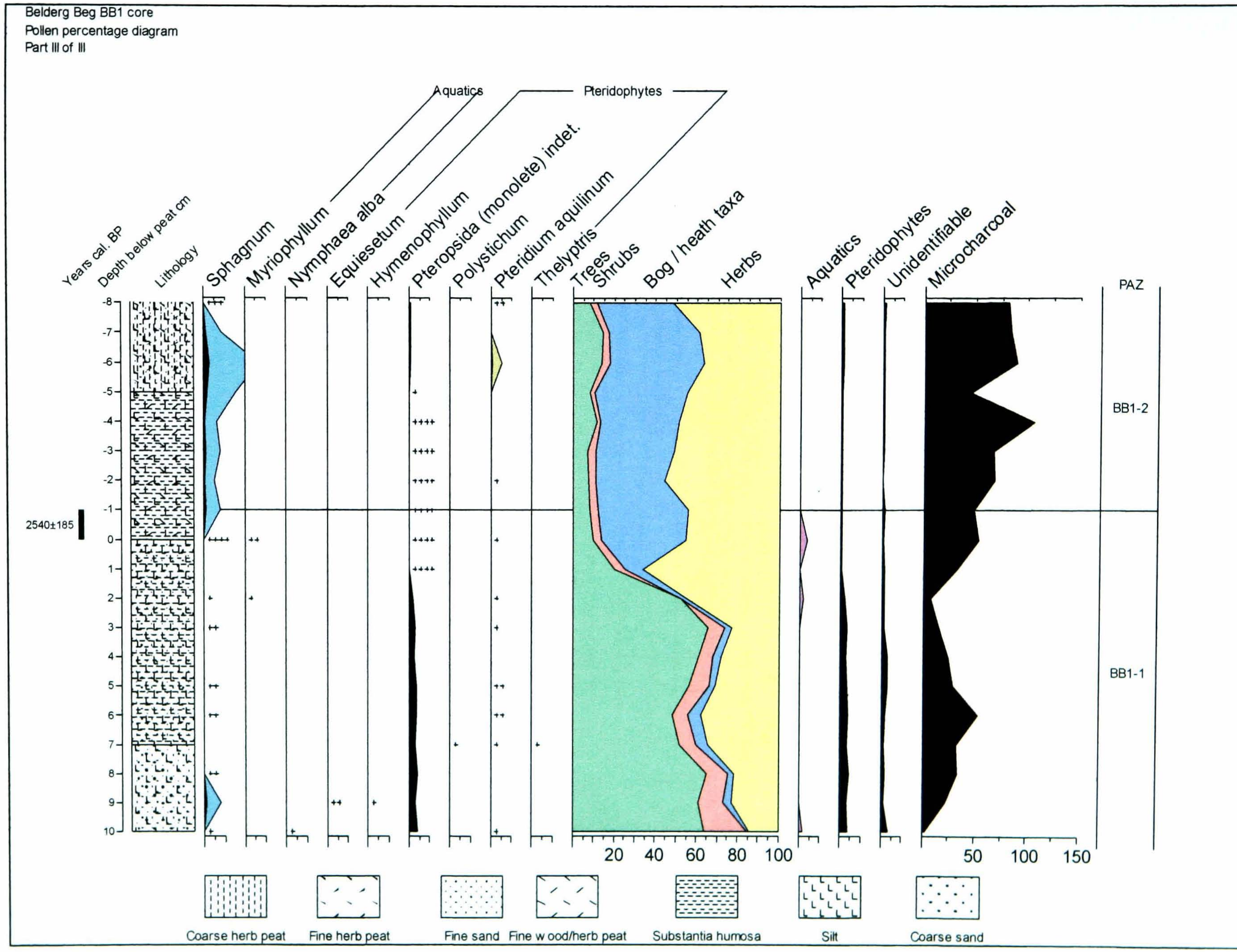


Figure 6.4c: Pollen percentage diagram, BB1 section (continued)

Figure 6.5a: Pollen percentage diagram, BB1 section

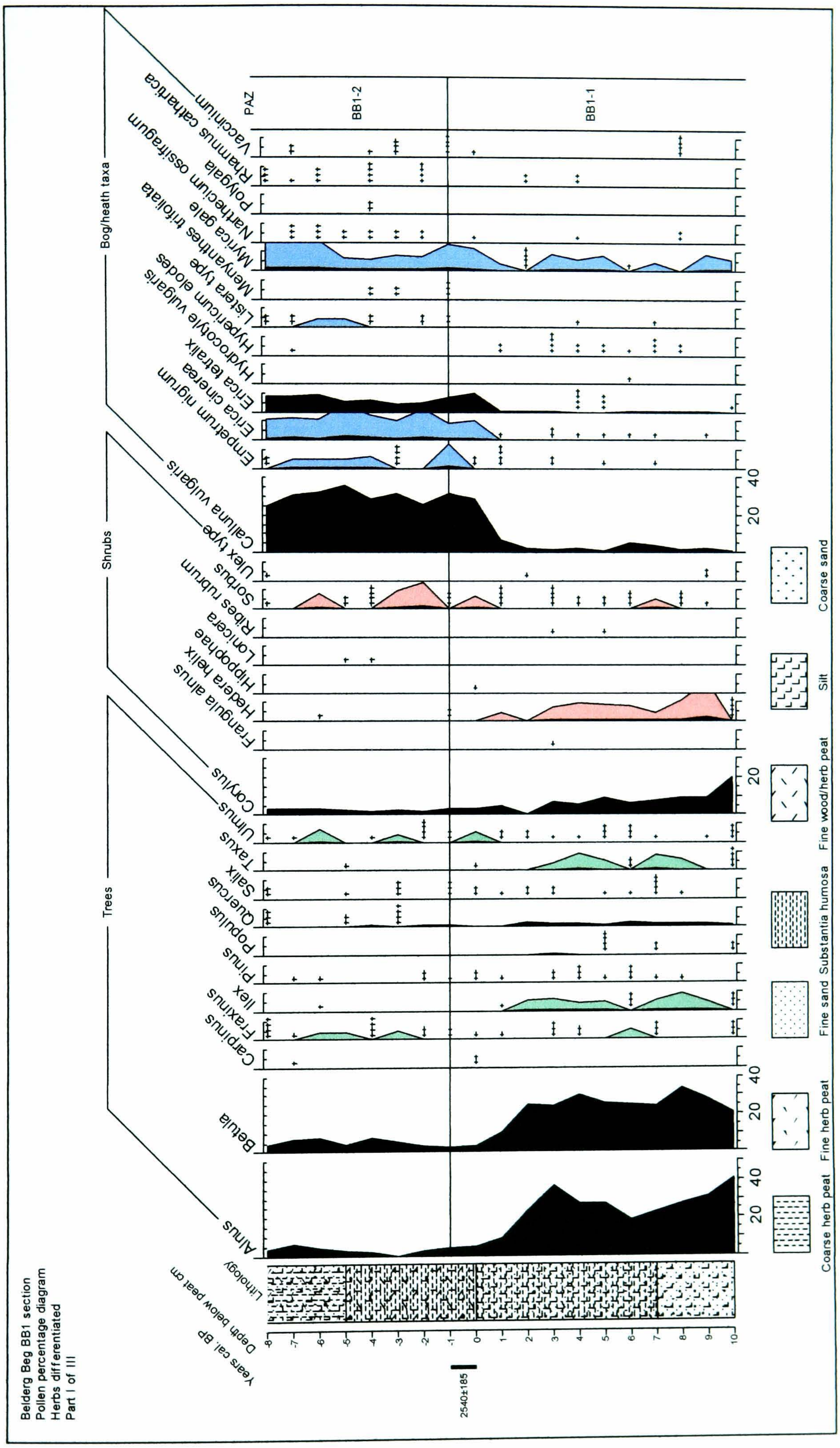


Figure 6.5b: Pollen percentage diagram, BB1 section (continued)

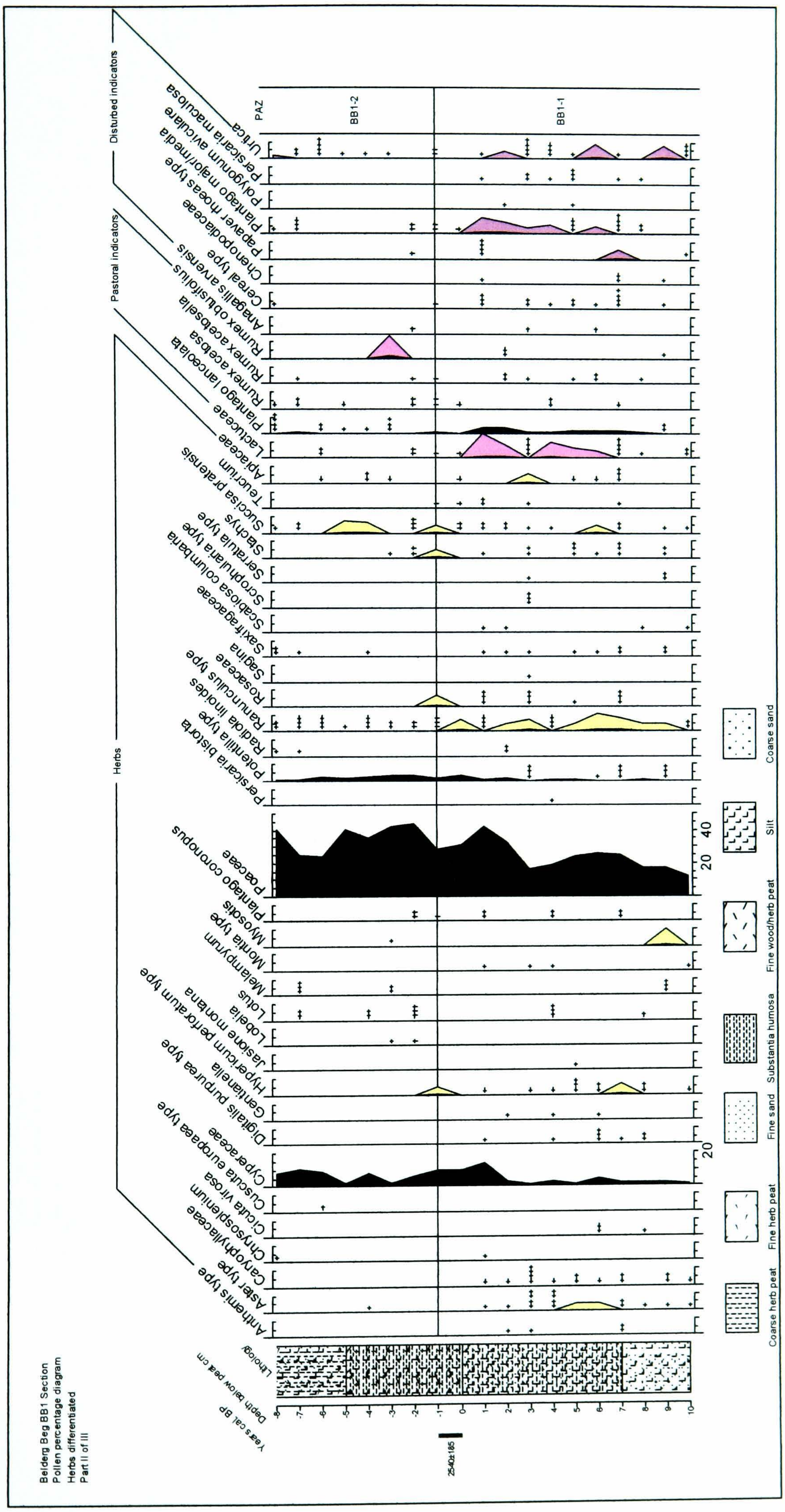


Figure 6.5c: Pollen percentage diagram, BB1 section (continued)

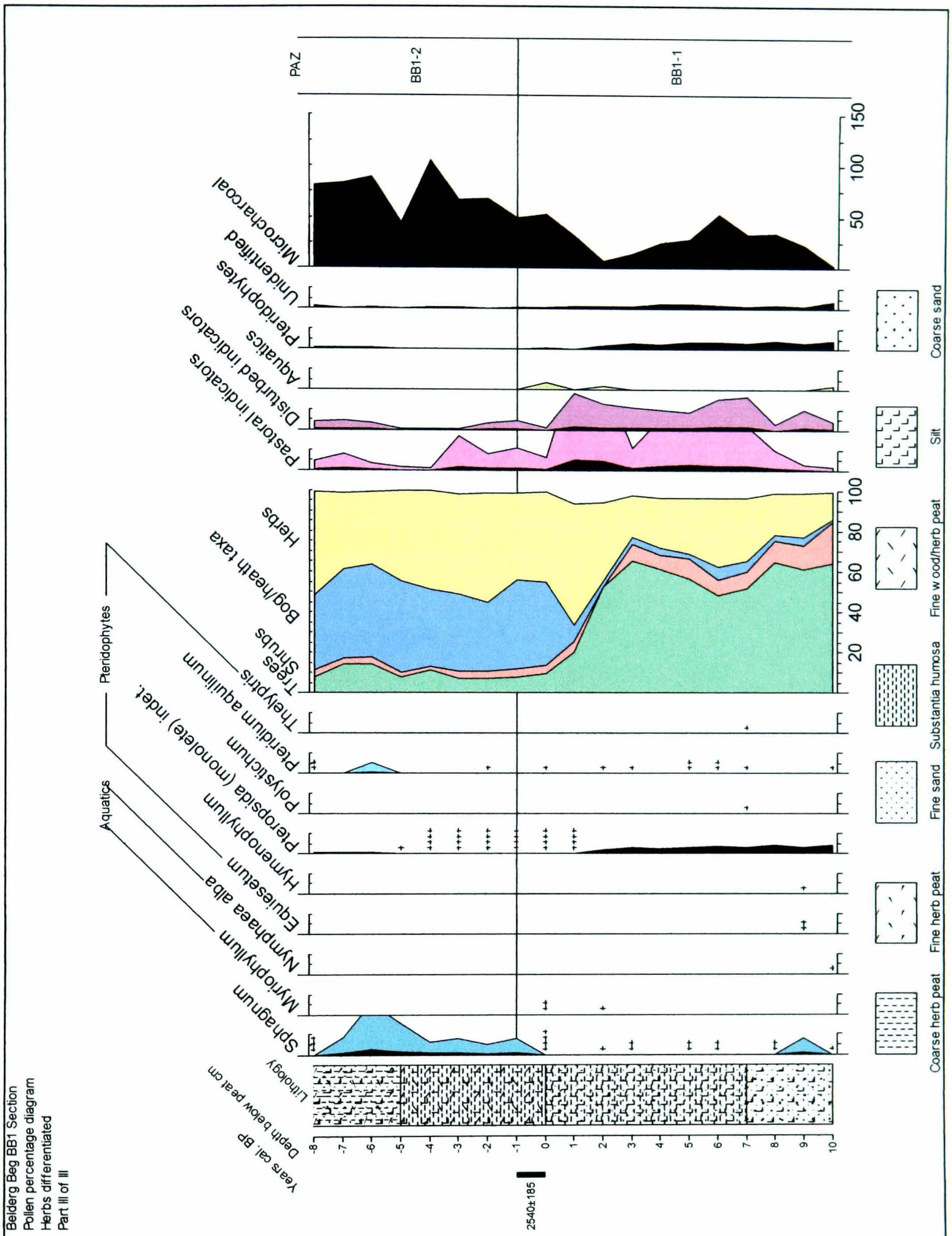


Figure 6.6: Pollen concentration diagram, BB1 section (selected taxa)

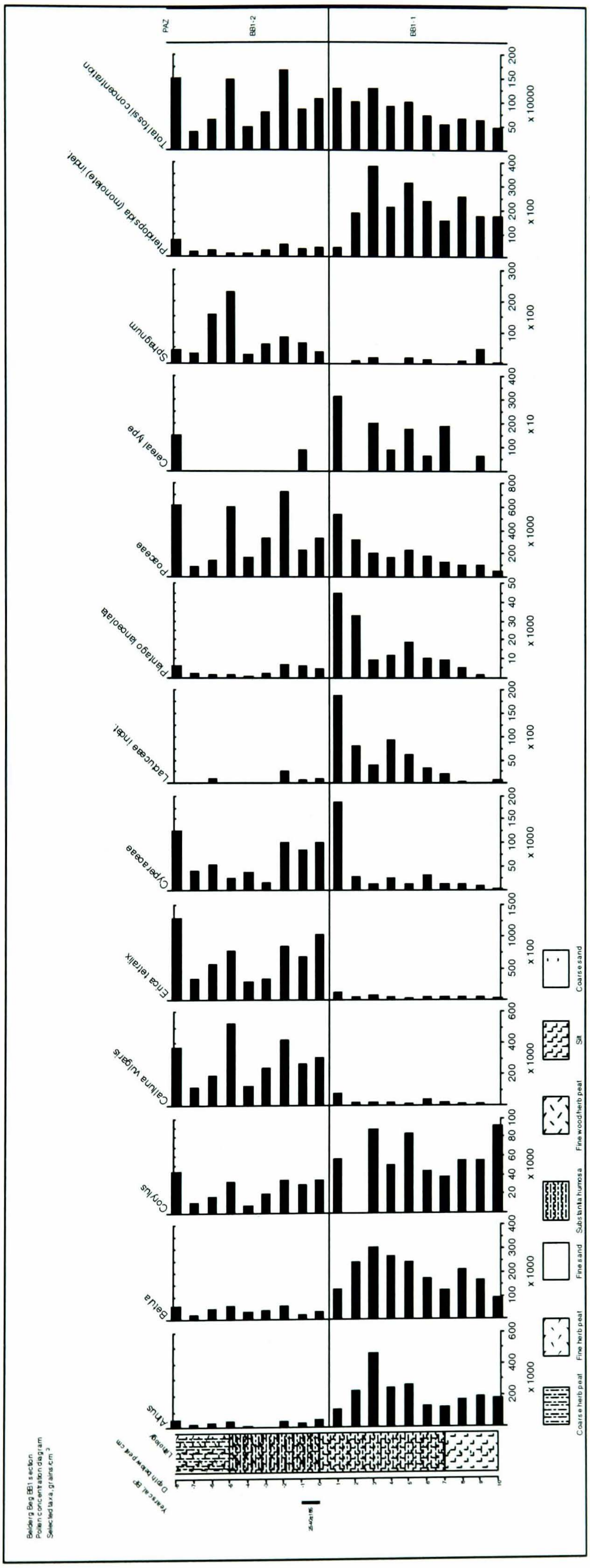
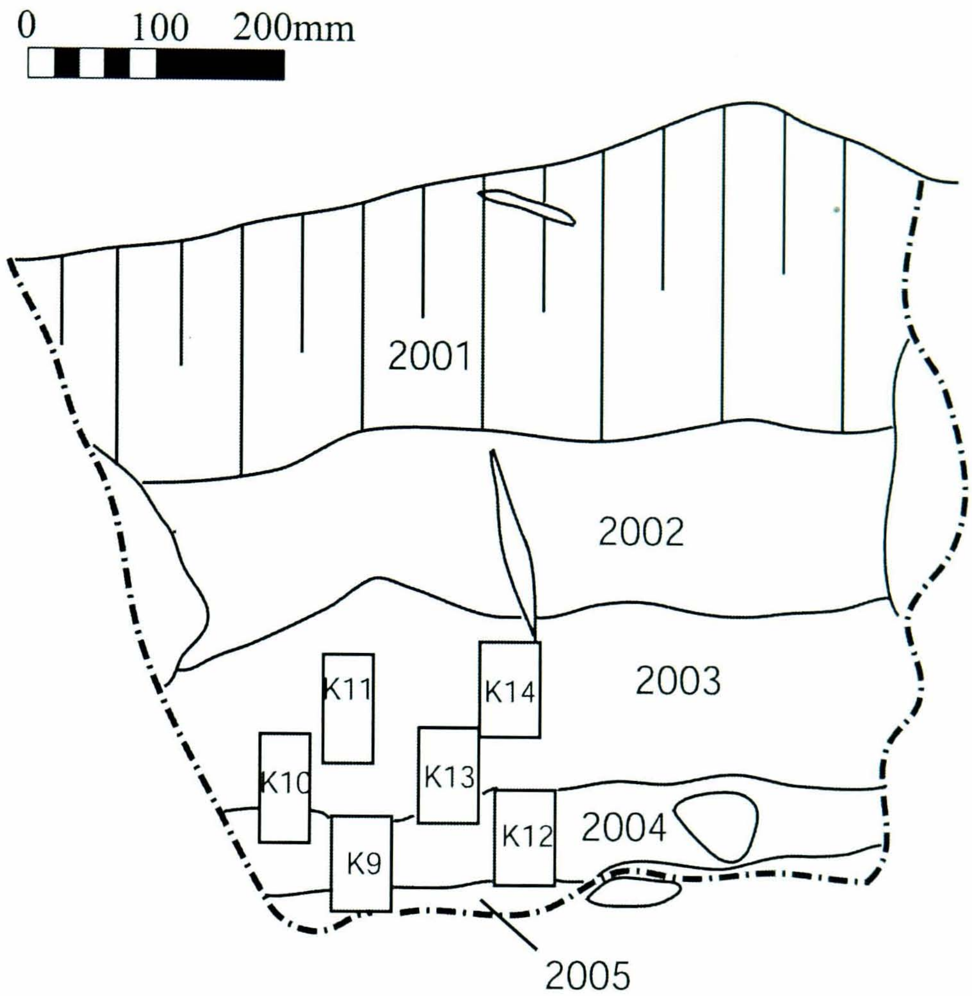
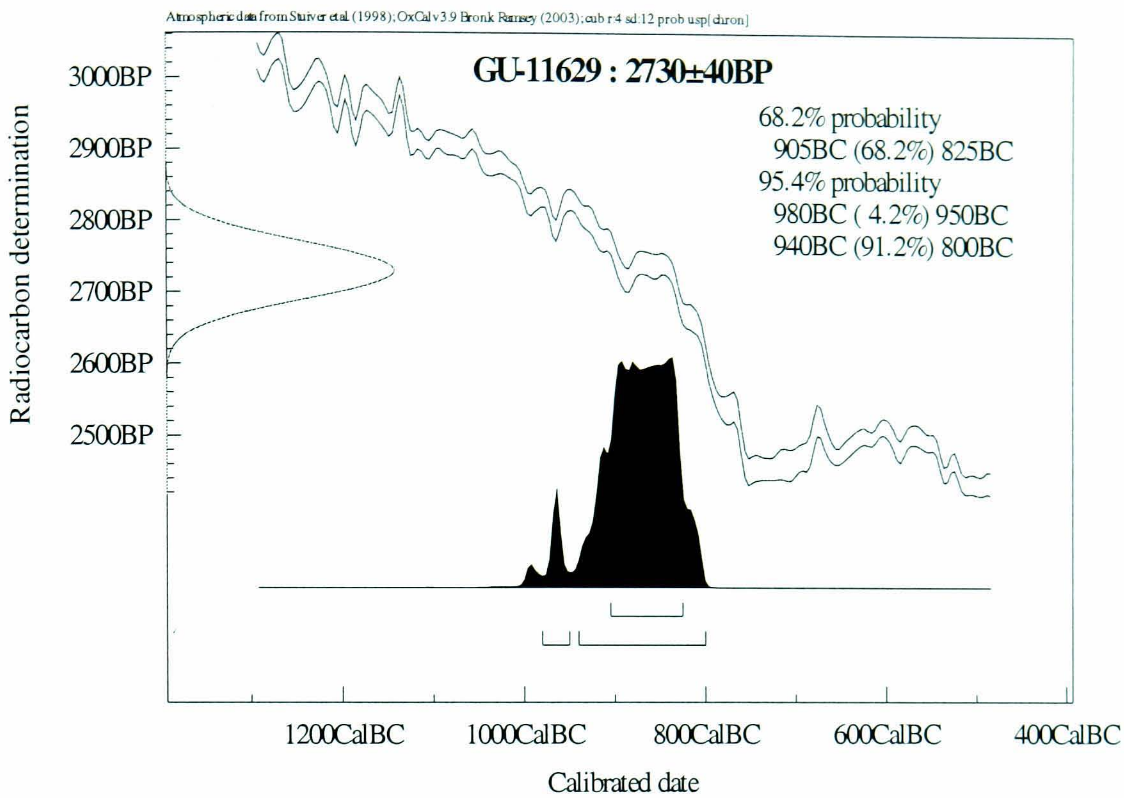


Figure 6.7: Section drawing of BB2 with locations of Kubiena sampling tins



Context	Description
2001	Acrotelm. N(f)0, N2, S0, E0, Si2 / H1/ Tl0.5, Th1, Dl0.5, Dh0.5, Ag0.5, Gmin1
2002	Dark brown moderately humified fibrous peat. N(f)2, N3, S2, E1, Si1 / H1.5 / Tl0.5, Th0.5, Dh1, Dg1, Sh1
2003	Amorphous, very well humified silty peat. N(f)4, N3, S0, E3, Si1/ H3 / Sh2, Dg1, Ga1
2004	Moderately organic silty sand. Firm consistence with frequent gravel & cobble inclusions. Organic matter well humified. Gs2, Ga1, Sh1
2005	Inorganic loose medium sand. Cobble clasts – clast supported in places. Vertical extent unknown.

Figure 6.8: Calibration details for GU-11629



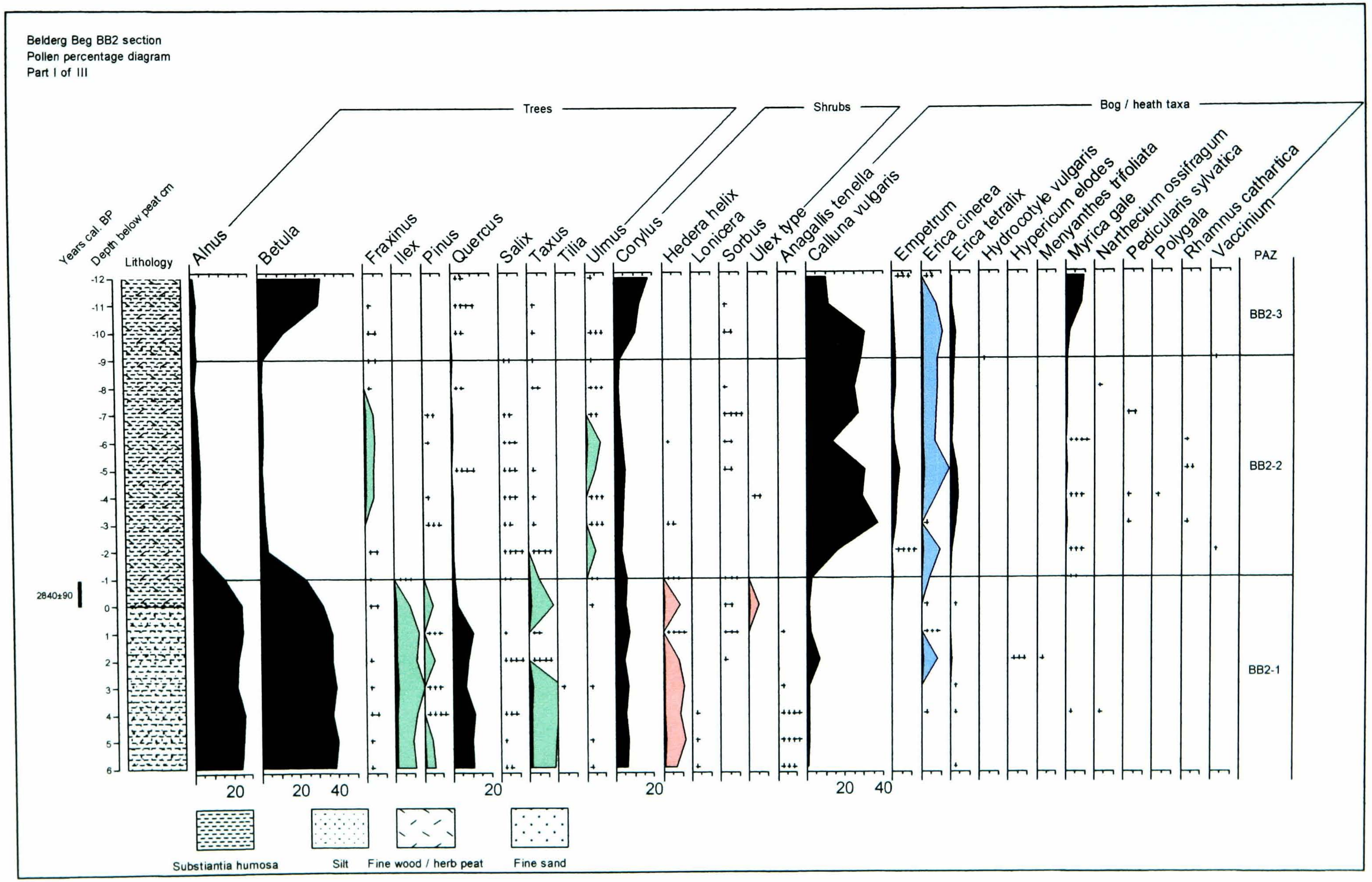


Figure 6.9a: Pollen percentage diagram, BB2 section

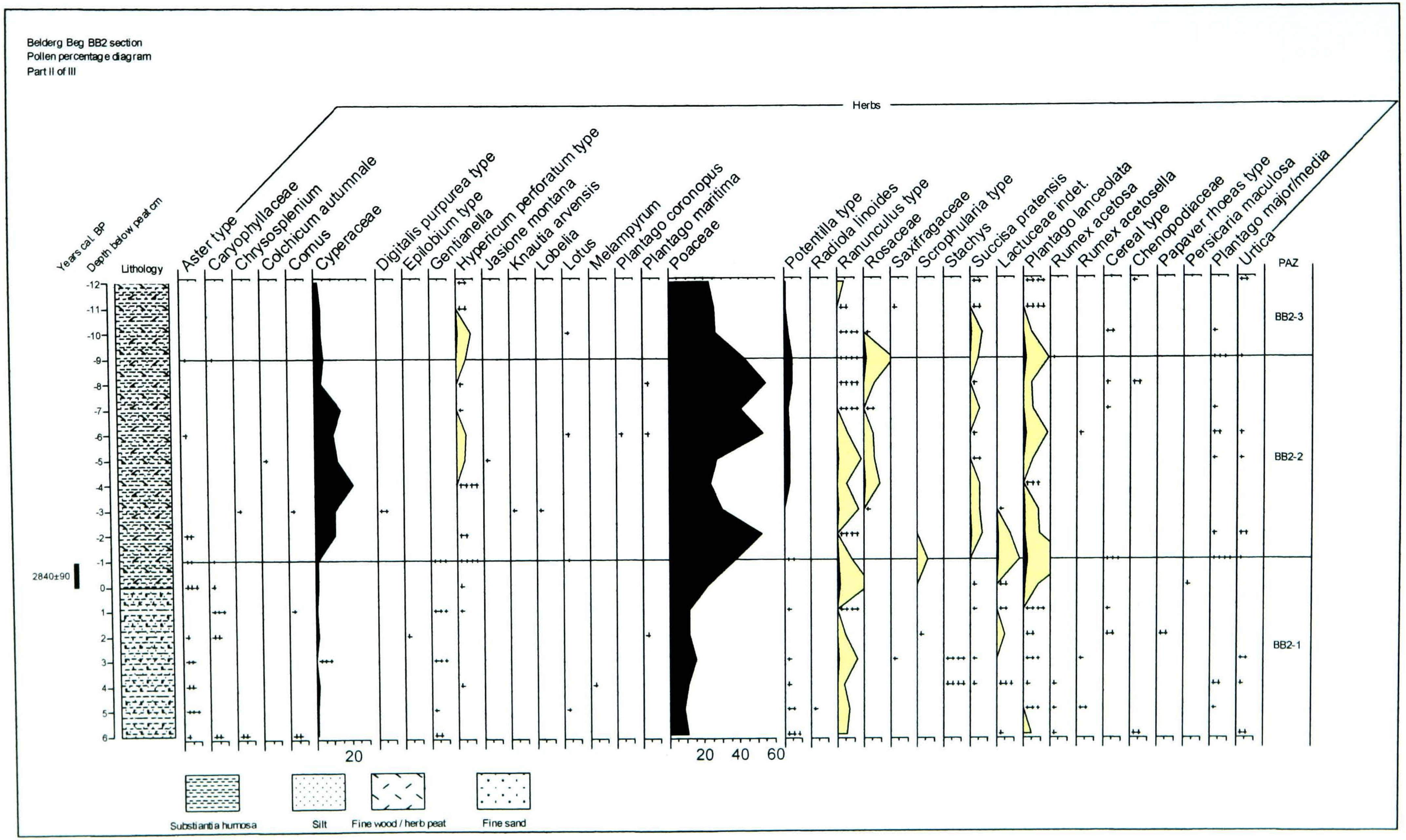


Figure 6.9b: Pollen percentage diagram, BB2 section (continued)

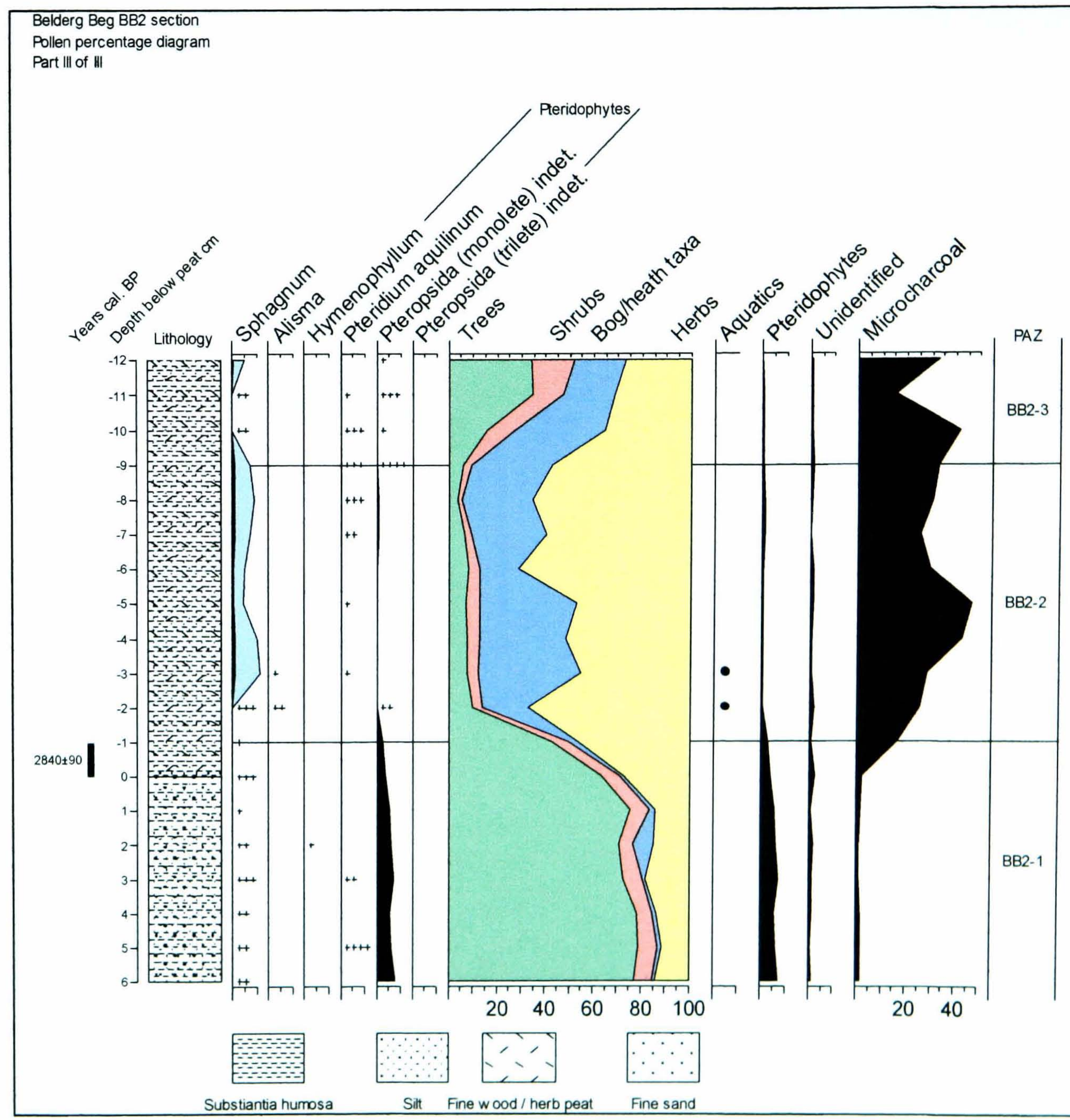


Figure 6.9c: Pollen percentage diagram, BB2 section (continued)

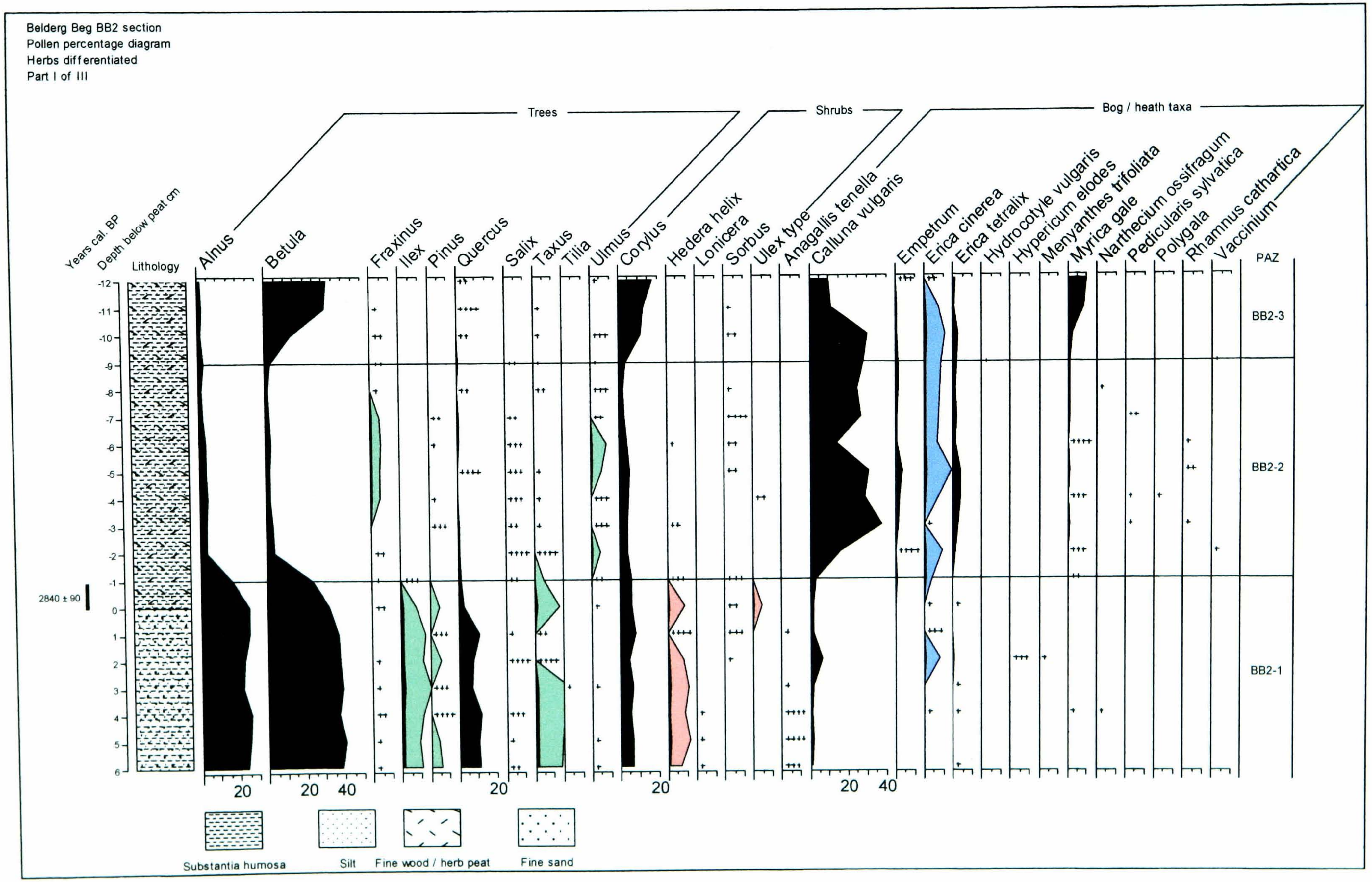


Figure 6.10a: Pollen percentage diagram, BB2 section

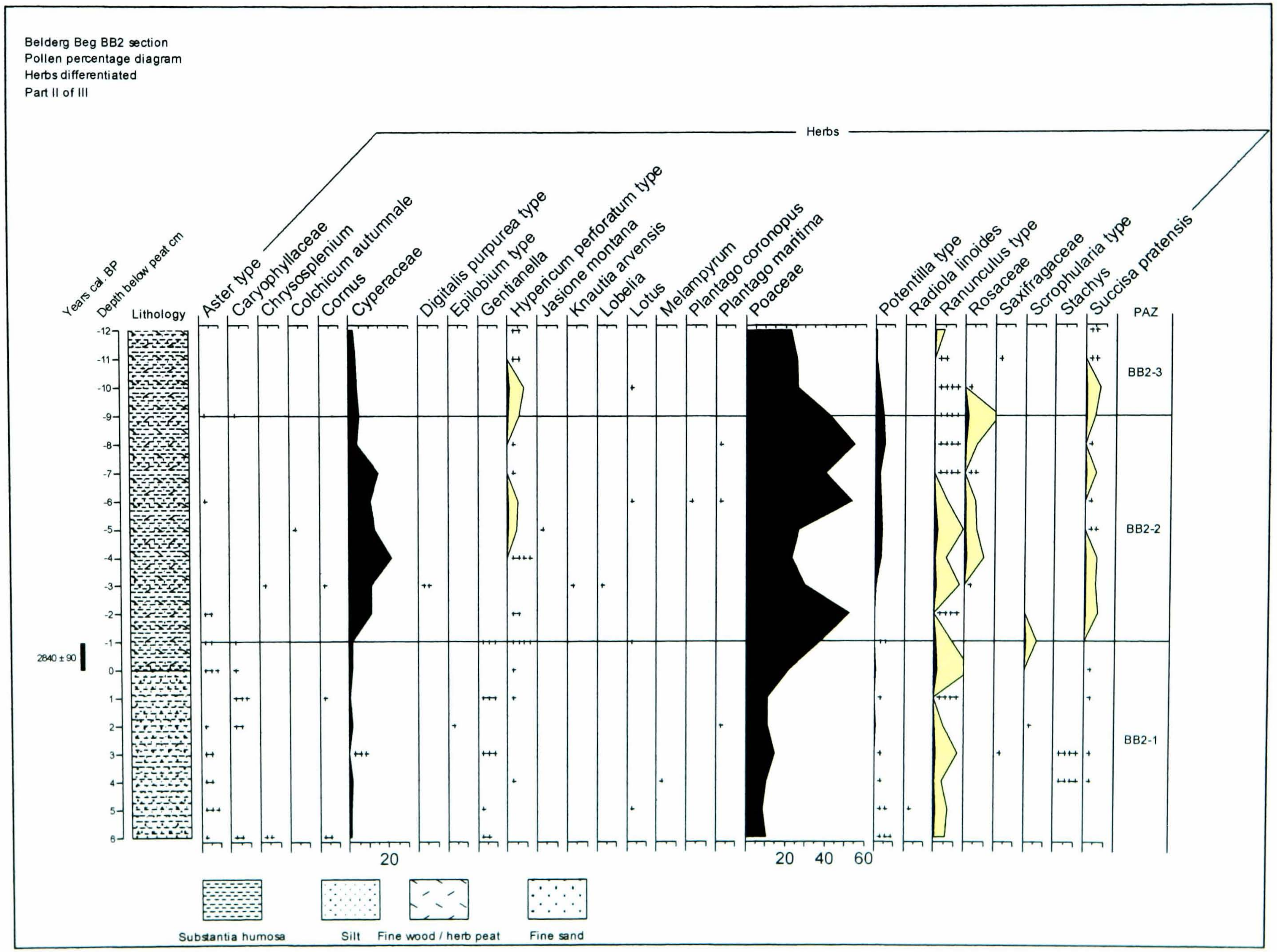


Figure 6.10b: Pollen percentage diagram, BB2 section (continued)

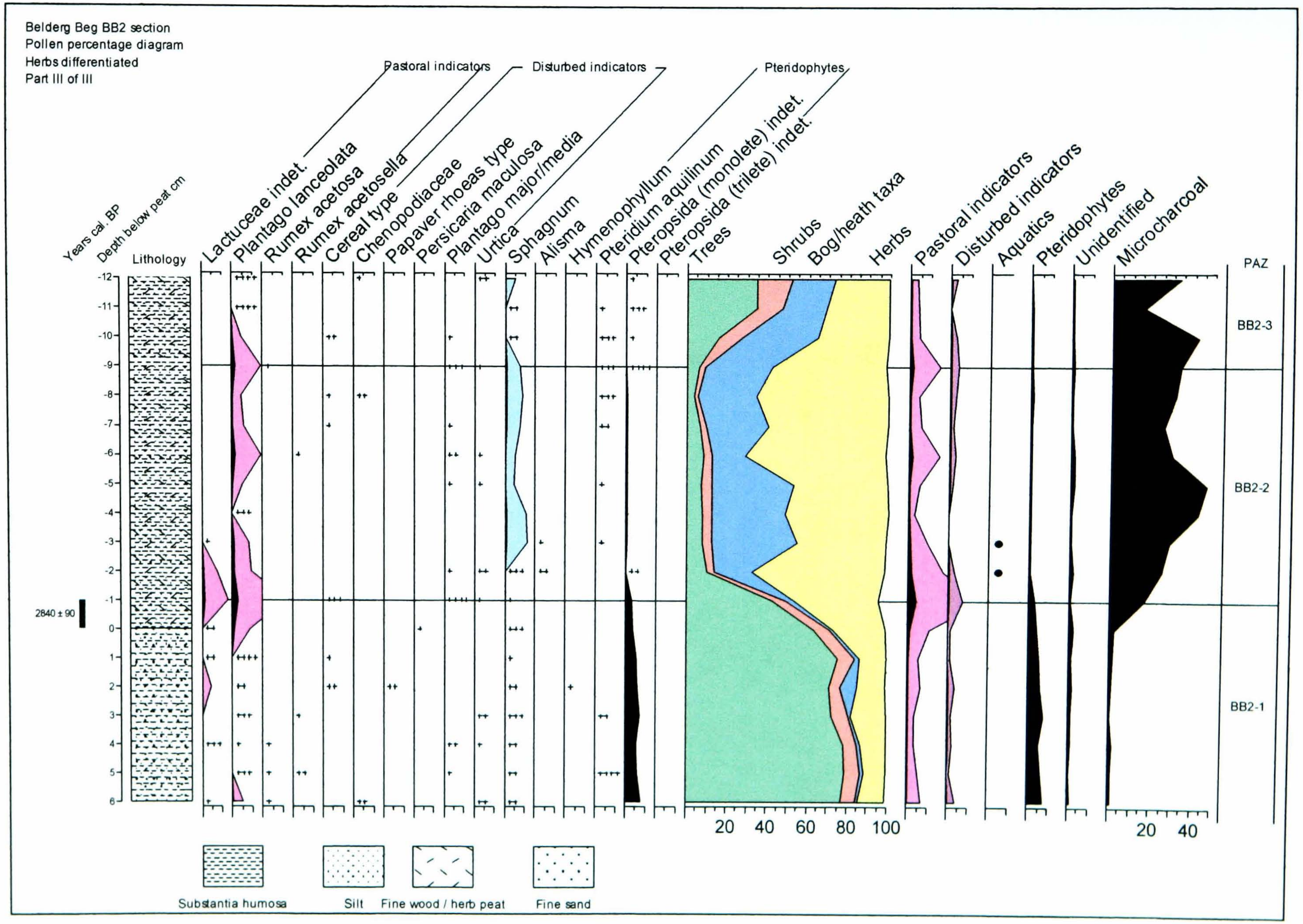
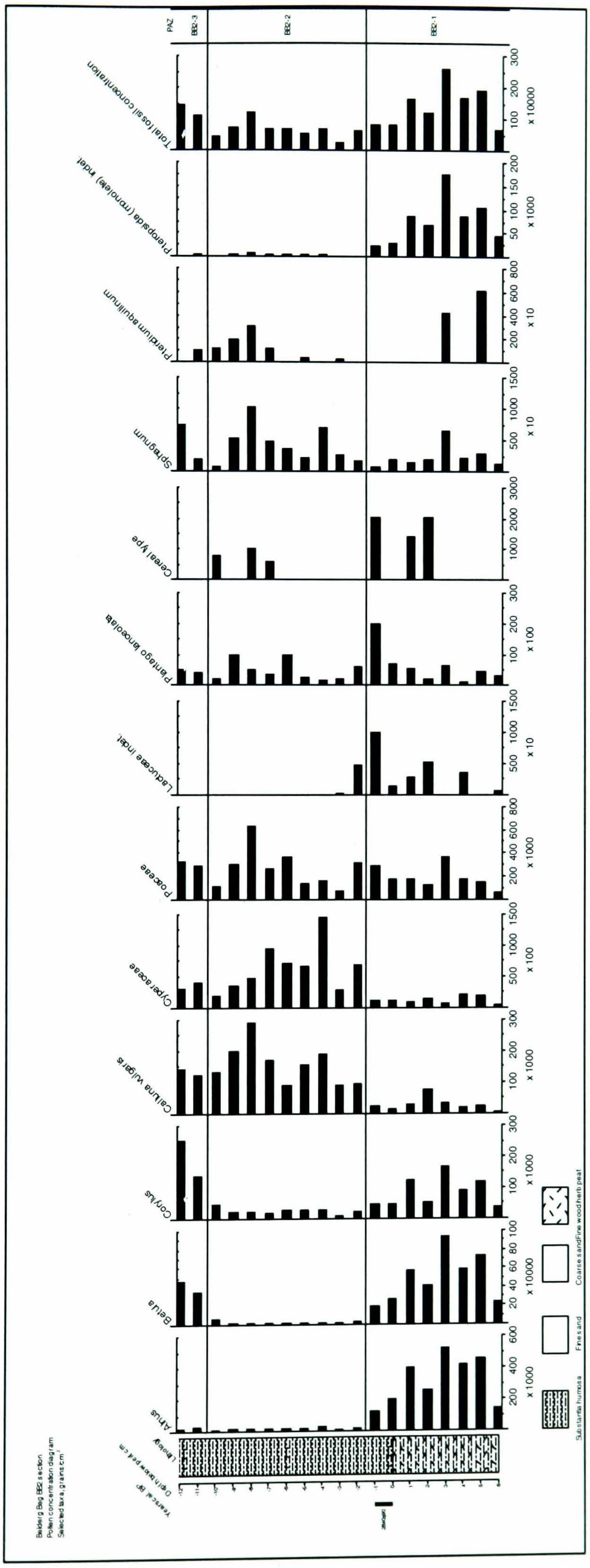


Figure 6.10c: Pollen percentage diagram, BB2 section (continued)

Figure 6.11: Pollen concentration diagram, BB2 section (selected taxa)



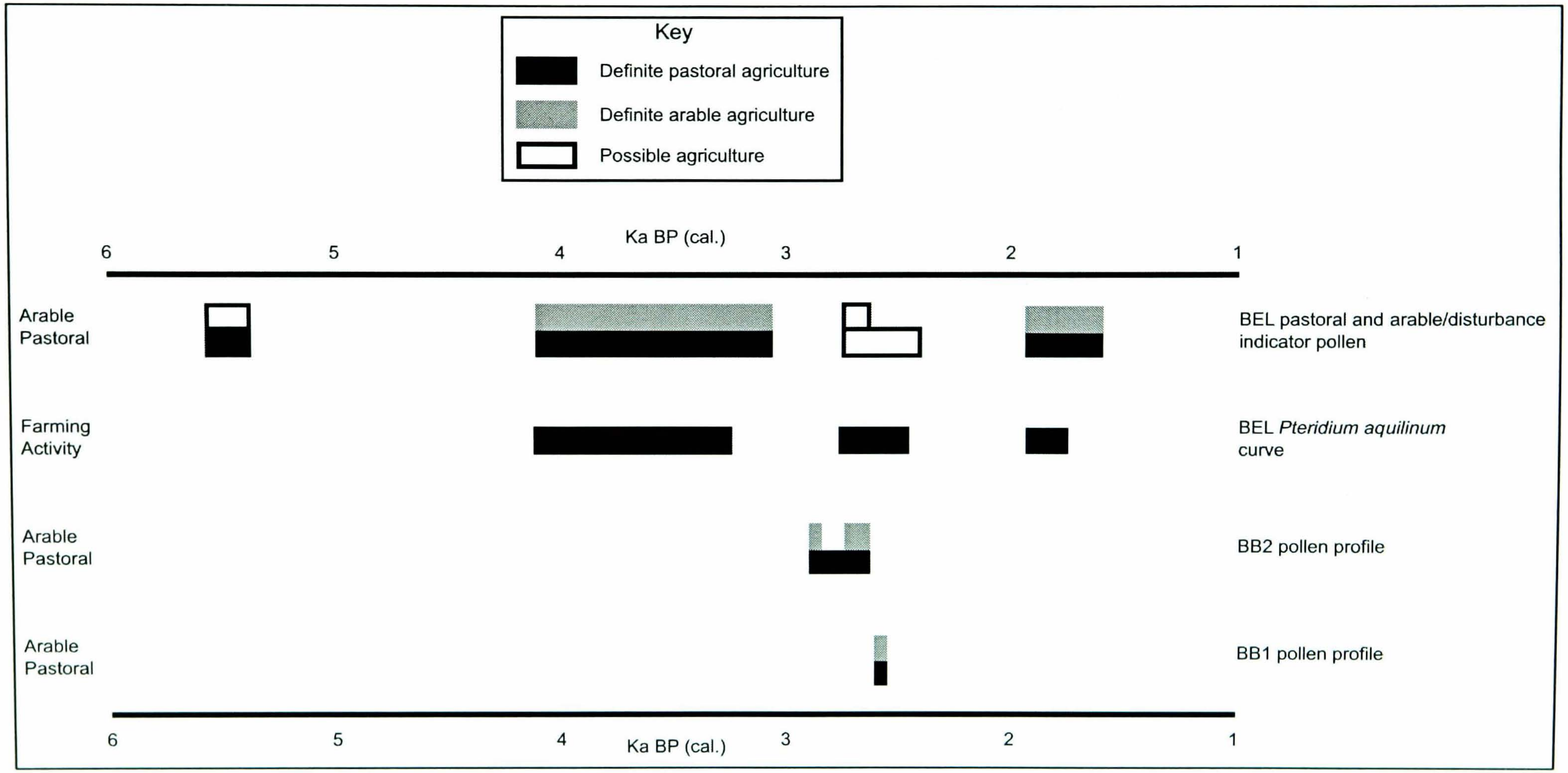


Figure 7.1: Graphical representation of settlement and agricultural chronology at Belderg Beg

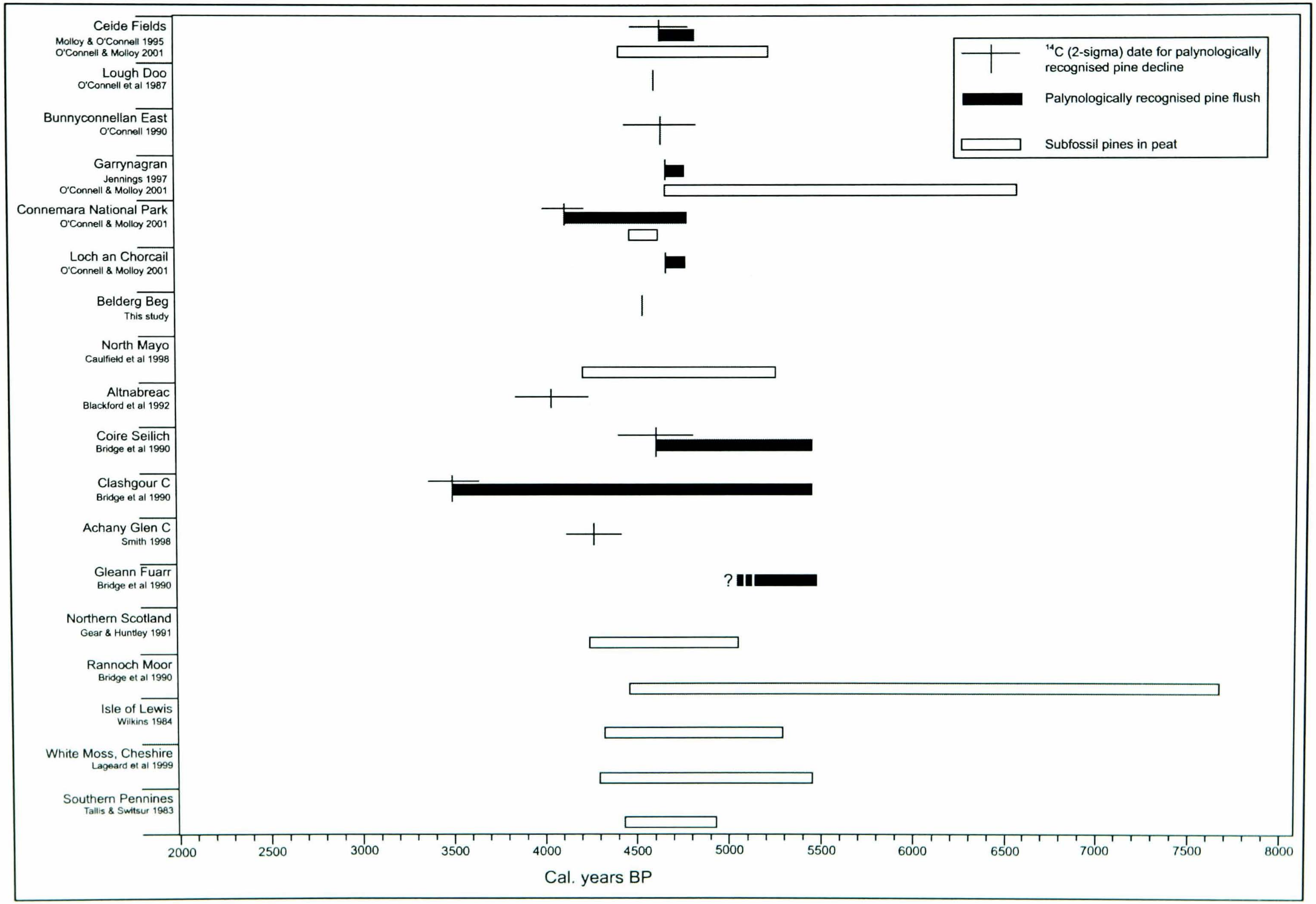
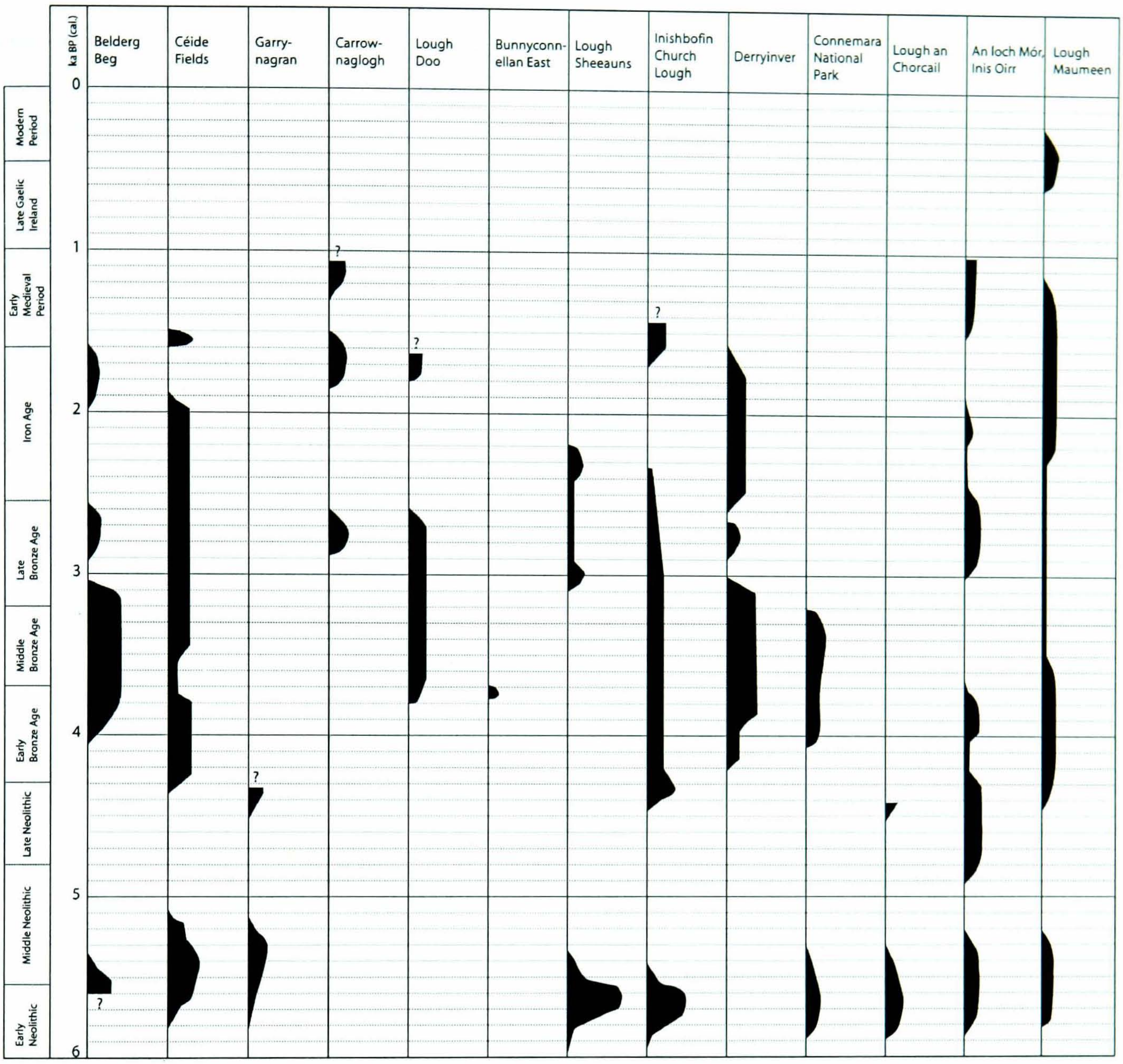


Figure 7.2: Details of the *Pinus* expansion and decline in Atlantic Britain and Ireland.

Figure 7.3: Graphical representation of the chronology of agricultural activity at major Neolithic and Bronze Age sites of North Mayo and western Galway



<u>Locations</u>

County Mayo: Belderg Beg, Céide Fields, Garrynagran, Carrownaglogh, Lough Doo, Bunnyconnellan East.

County Galway: Lough Sheeauns, Inishbofin Church Lough, Derryinver, Connemara National Park, Lough an Chorcail, An Loch Mór, Lough Maumeen.

<u>Sources</u>

Céide Fields: Molloy & O'Connell 1995; Garrynagran & Lough an Chorcail: O'Connell & Molloy 2001; Carrownaglogh: O'Connell 1986; Lough Doo: O'Connell *et al* 1987; Bunnyconnellan East: O'Connell 1990b; Lough Sheeauns & Connemara National Park: O'Connell *et al* 1988; Inishbofin Church Lough: O'Connell. & Ní Ghráinne 1994; Derryinver: Molloy & O'Connell 1993; An Loch Mór: Molloy & O'Connell 2004; Lough Maumeen: Huang 2002.

Table 2.1: Provisional Late Quaternary Irish climate stages (After Coxon 1993; Bell & Walker 1997, 13; Woodman *et al* 1997, 132; Mitchell & Ryan 2001, 37).

<table>
<tr><th>Ka BP</th><th colspan="2">Mainland Britain</th><th colspan="2">Ireland</th><th>Cold / Temperate</th><th>Marine OI stage</th></tr>
<tr><td>10 – 0</td><td colspan="2">Flandrian</td><td colspan="2">Littletonian</td><td>T</td><td rowspan="3">1</td></tr>
<tr><td>11 - 10</td><td rowspan="2">Lateglacial</td><td>Loch Lomond stadial</td><td rowspan="2">Lateglacial</td><td>Nahanagan stadial</td><td>C</td></tr>
<tr><td>13 - 11</td><td>Windermere interstadial</td><td>Woodgrange interstadial</td><td>T</td></tr>
<tr><td>35 – 13</td><td colspan="2" rowspan="4">Devensian glacial</td><td rowspan="4">Midlandian glacial</td><td>Derryvee stadial</td><td>C</td><td>2</td></tr>
<tr><td>65 – 35</td><td>Aghnadarraghian interstadial</td><td>T</td><td>3</td></tr>
<tr><td>79 - 65</td><td>Fermanagh stadial</td><td>C</td><td>4</td></tr>
<tr><td>120 - 79</td><td>Kilnefora interstadial</td><td>T</td><td>5a-d</td></tr>
<tr><td>130 -120</td><td colspan="2">Ipswichian interglacial</td><td colspan="2">?Eemian interglacial</td><td>T</td><td>5e</td></tr>
</table>

Table 5.1: AMS radiocarbon assay details of all submitted samples from transect cores

GU no	SUERC no	Core	Depth & thickness of sample	Material sampled	Fraction assayed	^{14}C age BP ± 1σ	$\Delta^{13}C$ ‰	Calibrated range ± 2σ	Mid-point cal. BP
11634	2055	BEL	277-278cm	Very well humified dark brown/black **amorphous silty peat**	Humic acid	4775 ± 35	-29.2	5330-5600	5465
12211	4028	W2	144-146cm	Dark grey brown organic rich mud with common highly decomposed plant remains and abundant silt particles.	Humic acid (fine fraction)	4545 ± 35	-28.9	5040-5320	5180
12616	4961	W2	144-146cm		Humin (fine fraction)	4640 ± 35	-29.3	5300-5470	5385
12212	4029	W21 (P2)	80-82cm	Light brown brown humified amorphous peat with common herb stems and rare broken wood fragments.	Humic acid(fine fraction)	3715 ± 35	-28.1	3920-4160	4040
12617	4962	W21 (P2)	80-82cm		Humin (fine fraction)	3625 ± 35	-29.0	3830-4080	3955
12725	5757	W7	90-92cm	Dark grey brown organic rich mud with common highly decomposed plant remains and abundant silt particles.	Humic acid (fine fraction)	4345 ± 35	-28.1	4830-5040	4935
12726	5758	W8	66-68cm	Brown amorphous structureless peat.	Humic acid (fine fraction)	4335 ± 35	-28.6	4830-5030	4930
12727	5759	W21 (P1)	38-40cm	Dark brown humified amorphous peat with common herb stems, rare broken wood fragments and common silt and fine sand throughout.	Humic acid (fine fraction)	2770 ± 40	-28.6	2770-2950	2860
12728	5760	N10	29-31cm	Very well humified brown herb peat with very rare silt.	Humic acid (fine fraction)	2070 ± 35	-29.0	1930-2130	2030

Table 5.2a: Data required to calculate rates of peat up Belderg Beg hillslope

core	surface height (m OD)	core depth (m)	base height (m OD)	distance from BEL (m)	basal peat age midpoint cal. BP
BEL	28.7	3	25.7	0	5465
W2	28.18	1.7	26.48	27	5180
W7	29.53	0.95	28.58	66.5	4935
W8	29.83	0.87	28.96	74.3	4930
W21	34.04	0.85	33.19	137.7	4040
N10	38.35	0.4	37.95	210.7	2030

Table 5.2b: Rates of peat spread up Belderg Beg hillslope

stage	relative height difference (m) = dy	relative distance (m) = dx	gradient (dy/dx)	age difference (cal. years)	peat spread rate m/cal. year
BEL-W2	0.78	27	0.029	285	0.095
W2-W7	2.1	39.5	0.053	245	0.161
W7-W8	0.38	7.8	0.049	n/a	n/a
W8-W21	4.23	63.4	0.067	890	0.071
W21-N10	4.76	73	0.065	2010	0.036
Mean values			0.053		0.091

Table 5.3: Sediment stratigraphy of BEL core

Depth cm	Description
0-40	Poorly humified red/brown fine fibrous herbaceous peat. Abundant fine herb fragments, frequent sedge fragments. Nig. 1, Str. 3, Sicc. 3, Elas. 3; Humo. 0; Th3, Dh1.
40-45	Dark red/brown fibrous herbaceous peat with very rare roundwood fragments. Nig. 2, Str. 4, Sicc. ,2 Elas. 3; Humo. 1; Th3, Dh1, Tl+.
45-55	Dark brown well humified herbaceous peat with abundant fine herb fragments. Nig. 4, Str. 4, Sicc. 2, Elas. 3; Humo. 3; Th4.
55-70	Dark brown well humified herbaceous peat with abundant fine herb fragments and rare ericaceous fragments. Nig. 4, Str. 4, Sicc. 1, Elas. 2; Humo. 4; Th3, $Tl_{erica}1$.
70-80	Moderately humified dark brown ericaceous peat. Common fine herb fragments. Nig.4 , Str. 4, Sicc. 1, Elas. 2; Humo. 3; $Tl_{erica}2$, Th1, Sh1.
80-90	Dark brown moderately humified fine fibrous herbaceous peat with abundant fine herb fragments. Occasional ericaceous fragments. Rare roundwood twigs. Nig. 4, Str. 4, Sicc. 1, Elas. 1; Humo. 3; Th2, Dh1, $Tl_{erica}1$, Tl+.
90-96	Compressed large wood fragments. Nig. 2, Str. 1, Sicc. 2, Elas. 1; Humo. 1; Tl3, Dh1.
96-115	Dark brown moderately humified fine fibrous herbaceous peat with abundant herb fragments and rare ericaceous fragments. Nig. 4, Str. 4, Sicc. 2, Elas. 2; Humo. 2; Th2.5, Dh1, $Tl_{erica}0.5$.
115-135	Dark brown moderately humified fine fibrous herbaceous peat with abundant herb fragments. Nig.3 , Str. 4, Sicc. 2, Elas. 2; Humo. 2; Th3, Dh1, Sh1.
135-180	Dark brown moderately humified fine fibrous herbaceous peat with abundant herb fragments and rare ericaceous fragments. Nig. 3, Str. 4, Sicc. 2, Elas. 2; Humo. 3; Th2, Dh1, Tl0.5, Sh0.5.
180-200	Mid-brown poorly humified fibrous wood peat with common large roundwood twigs and common fine fibrous herb fragments. Nig. 2, Str.2 , Sicc. 2, Elas. 1; Humo. 1; Tl3, Th1, Sh+.
200-219	Dark brown moderately humified wood peat with abundant wood fragments including small fragments and rare deciduous roundwood pieces. Nig.3 , Str. 2, Sicc. 2, Elas. 1; Humo.2 ; Tl3, Sh1.
219-224	Deciduous tree fragment filling chamber. Nig. 1, Str. 0, Sicc.1 , Elas. 0; Humo. 2; Sh4 [stirpes indet. 4].
224-268	Dark brown moderately humified wood peat with abundant wood fragments including small fragments and rare deciduous roundwood pieces. Nig. 4, Str. 2, Sicc. 2, Elas. 1; Humo. 3; Tl3, Sh1.
268-280	Dark grey brown organic deposit with common highly decomposed plant remains and abundant silt particles. Nig. 4, Str. 0, Sicc. 3, Elas. 0; Humo. 4; Sh2.5, Th0.5, AG1.
280-285	Yellowish brown coarse sand, well sorted, no organic matter. Nig. 0, Str. 4, Sicc. 3, Elas. 0; Humo. 0; Gmin4.
285-300	Grey/brown till Nig. 0, Str. 2, Sicc. 3, Elas. 0; Humo. 0; Gmin3, Gmaj1.

Described using system of Aaby & Berglund (1986).

Table 5.4: AMS Radiocarbon assay details of all submitted samples from BEL core

GU no.	SUERC no	Core	Depth & thickness of sample	Material sampled	Fraction assayed	^{14}C age BP ± 1σ	$\Delta^{13}C$ ‰	Calibrated range ± 2σ	Mid-point cal. BP
11630	2048	BEL	39-40cm	Moderately humified silty pseudo-fibrous peat.	Humic acid	1565 ± 35	-28.6	1350-1530	1440
11631	2049	BEL	130-131cm	Dark brown pseudo fibrous moderately humified peat	Humic acid	2830 ± 35	-28.8	2840-3080	2960
11632	2053	BEL	199-200cm	Well humified dark brown pseudo-fibrous peat	Humic acid	3765 ± 35	-29.3	3980-4240	4110
11633	2054	BEL	259-260cm	Pseudo-fibrous woody peat, moderately-well humified with numerous ligneous fragments	Humic acid	4350 ± 35	-28.4	4830-5040	4935
11634	2055	BEL	277-278cm	Very well humified dark brown/black amorphous silty peat	Humic acid	4775 ± 35	-29.2	5330-5600	5465

Table 5.5: Details of cereal-type pollen grains from BEL core

Depth cm	*	Grain dia. µm	Annulus dia. µm	Pore dia. µm	Surface	Notes	Pollen type	Plate?
4		50	10	5	Scabrate		*Avena-Triticum?*	5.1
8	1	47.5	10	5	Scabrate		*Avena-Triticum?*	
8	2	38	10	5	Scabrate		*Hordeum*	
12		52.5			Scabrate	Split - pore not measurable	*Avena-Triticum?*	
16		40	10	5	Scabrate		*Hordeum*	5.2
20		40	8	5	Scabrate		*Hordeum*	5.3
28		37.5	10	5	Verrucate		*Hordeum?*	5.4
56		37.5	8	5	Scabrate	Degraded	*Hordeum*	
92		38	9	4	Scabrate		*Hordeum*	5.5
116		40	8	3	Scabrate		*Hordeum*	
138		40	9	4	Scabrate	Pore part concealed	*Hordeum*	5.6
140		38	10	5	Scabrate		*Hordeum*	
150		40	9	5	Scabrate		*Hordeum*	5.7
152		40	10	5	Scabrate		*Hordeum*	5.8
154	1	42	11	5	Scabrate			5.9
154	2	38	10	4	Scabrate		*Hordeum*	5.10
156	1	41	10	4	Verrucate		*Avena-Triticum?*	5.11
156	2	38	8	5	Scabrate		*Hordeum*	5.12
158		37.5	10	4	Scabrate	Part concealed	*Hordeum*	5.13
166		37.5	10	5	Scabrate		*Hordeum*	5.14
172		37.5	9	5	Scabrate		*Hordeum*	5.15
178	1	37.5	9	4	Scabrate		*Hordeum*	5.16
178	2	38			Scabrate	Pore concealed	*Hordeum*	
196		37.5	9	5	Scabrate		*Hordeum*	5.17

Table 6.1: Sediment stratigraphy of BB1 section

Context	Description
1001	Acrotelm. N(f)4, N3, S0, E0, Si2 / H1/ Tl0.5, Th1, Dl0.5, Dh0.5, Ag0.5, Gmin1
1002	Poorly humified fibrous peat. N(f)3, N3, S0, E0, Si2 / H1 / Th1, Dh1, Ag1, Ga1 10YR 2/1 black
1003	Amorphous, very well humified peat. N(f)4, N4, S0, E2, Si2.5 / H3 / Dg1, Sh2, Ag1 5YR 2/1 black
1004	Compact highly organic soil. N(f)2.5, N2, S0, E1, Si3 / H3 / Sh1, Ag2, Ga1 10YR 2/2 very dark brown
1005	Moderately organic medium sand. Weak consistence. Frequent charcoal and coarse pebble inclusions. Gs2, Ga1, Ag1 7.5YR 2.5/2 very dark brown
1006	Loose inorganic silty sand. Pebble inclusions. Vertical extent unknown. 2.5Y 3/2 very dark grayish brown

Described using system of Aaby & Berglund (1986).

Table 6.2: AMS Radiocarbon assay details of all submitted samples from BB sections

GU no	SUERC no	Section	Depth & thickness of sample	Material sampled	Fraction assayed	^{14}C age BP ± 1σ	$\Delta^{13}C$ ‰	Calibrated range ± 2σ	Mid-point cal. BP
11628	2046	BB1	(K7) 1-2cm	Amorphous, very well humified silty peat	Humic acid	2450 ± 35	-31.4	2350-2720	2535
11629	2047	BB2	(K13) 7-8cm	Amorphous, very well humified silty peat	Humic acid	2730 ± 40	-29.0	2750-2930	2840

Table 6.3: Location of BB1 pollen spectra with reference to Kubiena tin sample and context

Kubiena tin	Depth in tin (cm)	Context	Depth below basal peat (cm)
K8	0-1	1002	-8
	1-2		-7
	2-3		-6
	3-4		-5
	4-5	1003	-4
	5-6		-3
	6-7		-2
	7-8		-1
K7	1-2		0
	2-3	1004	1
	3-4		2
	4-5		3
	5-6		4
	6-7		5
K6	1-2		6
	2-3		7
	3-4	1005	8
	4-5		9
	5-6		10

The soil-peat interface was used as the reference point (0cm) because it was the only fixed point in the BB sections. The surface is artificial, resulting from excavation, and the base was not fixed.

By reference to this table, each spectrum from the pollen profile (Figures 6.4, 6.5 and 6.6) can be related to both a context and a Kubiena tin sample.

Table 6.4: Details of cereal-type pollen grains from BB1 section

Depth below peat cm	*	Grain dia. µm	Annulus dia. µm	Pore dia. µm	Surface	Notes	Pollen type	Plate?
-8		42.5	10	3	scabrate		*Hordeum*	
-1	1	40	10	3.75	scabrate		*Hordeum*	
-1	2	37.5	8	4	scabrate	same plate	*Hordeum*	6.1
-1	3	40	8	4	scabrate		*Hordeum*	
-1	4	40	9	5	scabrate		*Hordeum*	6.2
1	1	37.5	10	4	scabrate		*Hordeum*	6.3
1	2	42.5	10	3	psilate	split	*Hordeum*	
1	3	40	10	5	scabrate		*Hordeum*	
3	1	45	10	3	scabrate		*Hordeum*	6.4
3	2	45	10	5	scabrate		*Hordeum*	6.5
3	3	42.5	8	4	scabrate		*Hordeum*	
4		37.5	9	4	scabrate		*Hordeum*	
5	1	45	10	4	scabrate		*Hordeum*	
5	2	42.5	9	4	scabrate		*Hordeum*	6.6
6		37.5	10	3	scabrate	degraded & crumpled	*Hordeum*	
7	1	42.5	10	4	scabrate		*Hordeum*	6.7
7	2	40	10	3	scabrate		*Hordeum*	
7	3	40	9	4	scabrate		*Hordeum*	6.8
7	4	44	9	4	scabrate		*Hordeum*	6.9
9		40	8	4	scabrate	split	*Hordeum*	

Table 6.5: Features noted in thin section soil micromorphological analysis of BB1 sediments

	COARSE MINERAL MATERIAL (>10µm)														COARSE ORGANIC MATERIAL (>5 cells)			FINE ORGANIC MATERIAL (<5 cells)					PEDOFEATURES					
Section	Quartz	Feldspar	Biotite	Garnet	$CaCO_3$	Muscovite	Hornblende	Compound	Sandstones	Siltstones	Phytoliths	Diatoms	Heated mineral	FINE MINERAL MATERIAL (<10µm)	Fungal spores	Lignified tissue	Parenchymatic tissue	Amorphous (black)	Amorphous (yellow/orange)	Amorphous (red/brown)	Cell residues	Carbonised material	Textural (silty clay)	Organic coatings	Amorphous & crypto crystalline infills + oatings	Excremental (mammilate)	Excremental (spheroidal)	Depletion
K4 1002	•													Organo-mineral Red PPL Brown & grey/brown OIL		••	••		•	••		+						
K4 1003	•					+					+		+	Organo-mineral Red/brown PPL Red/brown & dark brown OIL	•	•••			••	••	•	+						
K3 1004	••	+				+		•	•	•	•	+	+	Organo-mineral Brown, red/brown & dark brown PPL Red/brown & dark brown OIL		•	•		•	•		•		+	+			•
K1 & K2 1005	••••	+				•	•	•	•	•				Organo-mineral Brown & grey-brown OIL Brown PPL		+	•		•			•	•			•	•	+
K1 1006	•••	•	+	+		•	+	•	•	•				Organo-mineral Brown OIL Brown & Brown PPL		•	•		•	•		+		•		+	+	

Section	MICROSTRUCTURE	COARSE MATERIAL ARRANGEMENT	GROUNDMASS B FABRIC	RELATED DISTRIBUTION
K4 1002	Angular blocky		Undifferentiated	
K4 1003	Spongy	Moderately sorted	Undifferentiated	Porphyric
K3 1004	Intergrain channel	Unsorted, random	Crystallitic to speckled	Porphyric
K1 & K2 1005	Vughy (furrow fill)	Poorly sorted, random	Crystallitic	Porphyric
K1 1006	Intergrain channel	Poorly sorted, random	Speckled to stipple-speckled	Close porphyric

Frequency class refers to the appropriate area of section (Bullock et al 1985), •: very few; ••: few; •••: frequent / common; ••••: dominant/very dominant.
Frequency class for textural pedofeatures (Bullock et al 1985), • rare; ••: occasional; •••: many.

Table 6.6: Main micromorphological features of BB1 section (relevant contexts only).

Context	Micromorphogical feature	Interpretation
1003	Largely consists of organic material	Peat
	Spongy microstructure, undifferentiated groundmass B fabric	Undisturbed, in situ
1004	Rounded quartz grains	Worked/weathered
	Red/brown fine organo-mineral fraction (OIL&PPL)	Ash inclusions
	Rubified minerals (OIL)	Ash inclusions
	Organic coatings	Peat growth underway
	Patches of accumulated phytoliths and silicaceous material	Soil amendment by addition
	Yellowish patches of fine material (PPL)	Leaching, iron movement
	Calcium-iron-phosphate accumulations & infills	Decomposed & recrystallised bone
	High organic component, spongy microstructure	Peat growth underway
	Fines lenses of sand/silt and fine microaggregates	Ard cultivation
1005	Subrounded quartz grains	Some working
	Excremental pedofeatures	Soil fauna activity
	Dusty coatings & infills	Cultivation
	Light yellow patches of fine material (PPL)	Leaching
	Fines lenses of sand/silt and fine microaggregates	Ard cultivation
	Some rubified minerals (OIL)	Possible ash inclusion
1006	Poorly sorted subangular quartz	Quartz/schist bedrock forming soil
	Excremental pedofeatures	Soil fauna activity

Table 6.7: Sediment stratigraphy of BB2 section

Context	Description
2001	Acrotelm. N(f)0, N2, S0, E0, Si2 / H1/ Tl0.5, Th1, Dl0.5, Dh0.5, Ag0.5, Gmin1
2002	Dark brown moderately humified fibrous peat. N(f)2, N3, S2, E1, Si1 / H1.5 / Tl0.5, Th0.5, Dh1, Dg1, Sh1 10YR 2/1 black
2003	Amorphous, very well humified peat. N(f)4, N3, S0, E3, Si1/ H3 / Sh2, Dg1, Ag1 5YR 2.5/1 black
2004	Moderately organic silty sand. Firm consistence with frequent gravel & cobble inclusions. Organic matter well humified. Gs2, Ga1, Sh1 10YR 2/2 very dark brown
2005	Inorganic loose medium sand. Cobble clasts – clast supported in places. Vertical extent unknown. 10YR 3/2 very dark grayish brown

Described using system of Aaby & Berglund (1986).

Table 6.8: Location of BB2 pollen spectra with reference to Kubiena tin sample and context

Kubiena tin	Depth in tin (cm)	Context	Depth below basal peat (cm)
K14	0-1	2003	-12
	1-2		-11
	2-3		-10
	3-4		-9
	4-5		-8
	5-6		-7
	6-7		-6
	7-8		-5
K13	1-2		-4
	2-3		-3
	3-4		-2
	4-5		-1
	5-6		0
K12	1-2	2004	1
	2-3		2
	3-4		3
	4-5		4
	5-6		5
	6-7		6

The soil-peat interface was used as the reference point (0cm) because it was the only fixed point in the BB sections. The surface is artificial, resulting from excavation, and the base was not fixed.

By reference to this table, each spectrum from the pollen profile (Figures 6.9, 6.10 and 6.11) can be related to both a context and a Kubiena tin sample.

Table 6.9: Details of cereal-type pollen grains from BB2

Depth below peat cm	*	Grain dia. µm	Annulus dia. µm	Pore dia. µm	Surface	Notes	Pollen type	Plate?
-10	1	45	10	4	verrucate		*Avena-Triticum*	6.21
-10	2	42.5	8	4	scabrate		*Hordeum*	6.22
-8		40	9	4	scabrate		*Hordeum*	6.23
-7		47.5	12.5	7	verrucate		*Avena-Triticum*	
-1	1	40	10	4	scabrate		*Hordeum*	
-1	2	40	10	4	scabrate		*Hordeum*	6.24
-1	3	38	9	4	scabrate		*Hordeum*	
1		48	10	5	scabrate		*Avena-Triticum?*	
2	1	42.5			scabrate	Crumpled – pore not measurable	*Hordeum*	
2	2	42.5	10	4	scabrate		*Hordeum*	

Table 6.10: Features noted in thin section soil micromorphological analysis of BB2 sediments

Section	COARSE MINERAL MATERIAL (>10µm)														COARSE ORGANIC MATERIAL (>5 cells)			FINE ORGANIC MATERIAL (<5 cells)					PEDOFEATURES					
	Quartz	Feldspar	Biotite	Garnet	$CaCO_3$	Muscovite	Hornblende	Compound	Sandstones	Siltstones	Phytoliths	Diatoms	Heated stone	FINE MINERAL MATERIAL (<10µm)	Fungal spores	Lignified tissue	Parenchymatic tissue	Amorphous (black)	Amorphous (yellow/orange)	Amorphous (red/brown)	Cell residues	Carbonised material	Textural (silty clay	Organic coatings	Amorphous & crypto crystalline infills + coatings	Excremental (mammilate)	Excremental (spheroidal)	Depletion
K10 & K11 2003	+													Organo-mineral Brown & red-brown PPL Red, brown & dark brown OIL	•	•••	•		•		•	••						
K9 2004	•••	+			+	•		•		+				Organo-mineral Brown & red-brown PPL Brown & dark brown OIL		••	•					•	•			•	•	
K9 2005	•••	+				•		•		+				Organo-mineral Brown PPL Brown & light brown OIL		••			••							•	•	

Section	MICROSTRUCTURE	COARSE MATERIAL ARRANGEMENT	GROUNDMASS B FABRIC	RELATED DISTRIBUTION
K10 & K11 2003	Prismatic / angular blocky		Undifferentiated	
K9 2004	Complex – channel & vughy	Poorly sorted Random	Speckled	Open porphyric
K9 2005	Intergrain channel	Moderately sorted	Mosaic speckled	Porphyric

Frequency class refers to the appropriate area of section (Bullock et al 1985), •: very few; ••: few; •••: frequent / common; ••••: dominant/very dominant.
Frequency class for textural pedofeatures (Bullock et al 1985), • rare; ••: occasional; •••: many.

Table 6.11: Main micromorphological features of BB2 section (relevant contexts only).

Context	Micromorphogical feature	Interpretation
2003	Largely consists of organic material	Peat
	Angular blocky microstructure, undifferentiated groundmass B fabric	Wetting / drying
	Few carbonised particles	Burning activity in area
2004	Subrounded/subangular quartz grains	Worked/weathered
	Brown fine organo-mineral fraction (OIL&PPL); red-brown in PPL	Possible ash inclusions
	Excremental pedofeatures	Soil fauna activity
	Highly organic	Peat formation underway
	Channel / vughy microstructure	Cultivation / grassland
2005	Subangular quartz grains	Schist bedrock forming soil
	Excremental pedofeatures	Soil fauna activity
	Brown/light brown fine organo-mineral fraction (PPL & OIL)	Some leaching, no addition or amendment
	Intergrain channel microstructure	Grassland

Table 7.1: Schematic display of results and interpretation of palaeoenvironmental and archaeological investigations at Belderg Beg.

Period	Date cal. BP	Geochemistry	Humification	Archaeology, palynology, AMS dating: Area	Archaeology, palynology, AMS dating: Event
Middle Neolithic 5500-4800 cal. BP	5465	BEL – detrital mud peat		BEL	Peat initiation
				Neolithic fields	Mixed agriculture
	5375			Neolithic fields (walls 1, 2, 4)	Abandoned. Woodland grows on peat downslope of fields.
	5300		Increasing wetness	W2	Peat initiation
	5170	BEL – fen peat			
	4900	Fen carr spread – isolation from freshwater	Peak in wetness	W7 & W8	Peat initiation
Late Neolithic 4800-4300 cal. BP	4850		Increasing dryness		
	4520	Increasing oceanicity	Peak in wetness	(BEL)	Pine decline
Early Bronze Age 4300-3700 cal. BP	4100			W21	Peat initiation
	4100-4000			(BEL)	Temporary clearance
	3950			(BEL)	Clearance, agriculture
	3775		Shift to drier conditions		

Period	Date cal. BP	Geochemistry	Humification	Archaeology, palynology, AMS dating	
				Area	Event
Middle Bronze Age 3700 – 3200 cal. BP	3440	Maximum oceanic influence		Wall 3 / fence	2 oak stumps dated
Late Bronze Age 3200 – 2550 cal. BP	3400			Round house	Construction – timber dated
	3050			(BEL)	Contraction of agriculture
	3000		Peak in dryness		
	2850			BB2	Peat initiation, agricultural contraction/cessation
				W21	Soil erosion recorded
	2750-2700			BB2	Cereals recorded
	c. 2550			BB1	Abandonment & peat initiation
Iron Age 2550 – 1600 Cal. BP	c. 2450			Roundhouse	Charcoal dated
	c. 2275			Roundhouse	Charcoal dated
	2030			N10	Peat initiation
	1935			(BEL)	Mixed farming
Early Medieval 1600 - 1200 cal. BP	1600			(BEL)	Abandonment
	1100			(BEL)	Mixed farming – low level
	c. 700 – 0 ?			(BEL)	Mixed farming – more intensive

Table 7.2: Integration of palaeoenvironment and archaeology at Belderg Beg with other sites in North Mayo, 10000 – 1500 cal. BP.

Period	Date cal. BP	Belderg Beg		Céide Fields		Garrynagran	Achill Island
		Area	Event	Archaeology	Environment	Event	Event
Mesolithic 10000 – 6000 cal. BP	10000 - 9000				Peat initiation		
	9000				Hiatus in peat growth		
Early Neolithic 6000-5500 cal. BP	5950				Wet conditions	*Ulmus* decline	
	5840				*Ulmus* decline		
	5800			Clearance, mixed agriculture	Wet conditions (caused by increased runoff?	Mixed agriculture	
Middle Neolithic 5500-4800 cal. BP	5465	BEL	Peat initiation				
		Fields	Mixed agriculture				
	5375	Fields	Abandoned. Woodland grows on peat downslope of fields	Less intensive pastoral agriculture	Some drying of surface		
	5300	W2	Peat initiation				Dry bog surface
		Increasing wetness					
	5170	Fen peat spread		Abandonment	Increasing wetness		Extreme storminess
	4900	W7 & W8	Peat initiation				
		Peak in wetness					

Period	Date cal. BP	Belderg Beg		Céide Fields		Garrynagran	Achill Island
		Area	Event	Archaeology	Environment	Event	Event
	4850	Increasing dryness					
Late Neolithic 4800-4300 cal. BP	4800				Elevated pine pollen values		
	4750					Elevated pine pollen values	
	4650				Pine decline	Pine decline	
	4520	(BEL)	Pine decline				
Early Bronze Age 4300-3700 cal. BP	4350			Clearance, pastoral agriculture	Wet mire surface		
	4100	W21	Peat initiation				
	4100-4000	(BEL)	Temporary clearance				
	3950	(BEL)	Clearance, mixed agriculture				
	3775	Increasing dryness					
	3700			Decline in human activity			

Period	Date cal. BP	Belderg Beg		Céide Fields		Garrynagran	Achill Island
		Area	Event	Archaeology	Environment	Event	Event
Middle Bronze Age 3700 – 3200 cal. BP	3500			Mixed agriculture	Dry mire surface		
	3440	Wall 3 / fence	2 oak stumps added				
	3400	Roundhouse	Construction - timber				
Late Bronze Age 3200 – 2550 cal. BP	3050	(BEL)	Contraction of agriculture				
	3000	Peak in dryness					
	2850	BB2	Peat initiation, agricultural cessation/contraction				
		W21	Soil erosion recorded				
	2750-2700	BB2	Cereals recorded				
	2550	BB1	Abandonment & peat initiation				
Iron Age 2550 – 1600 Cal. BP	c. 2450	Roundhouse	Charcoal dated				
	c. 2275	Roundhouse	Charcoal dated				
	2030	N10	Peat initiation				
	1930	(BEL)	Clearance & mixed farming	Abandonment. Regeneration of trees & shrubs			
Early Medieval period 1600 - 1200 cal. BP	1640	BEL	Abandonment	Clearance & farming	Wetter mire surface		
	1520						

Plate 3.1: Area surrounding BEL sampling site facing approximately west.

Plate 3.2: Enclosure 5 (Neolithic) – see Figure 2.8 for location. Facing approximately west.

Plate 3.3: Wall 4 viewed from western end. See Figure 2.8 for location.

Plate 3.4: Roundhouse viewed roughly to east. See Figure 2.8 for location.

Plate 3.5: Wall 3 viewed from southern end. See Figure 2.8 for location.

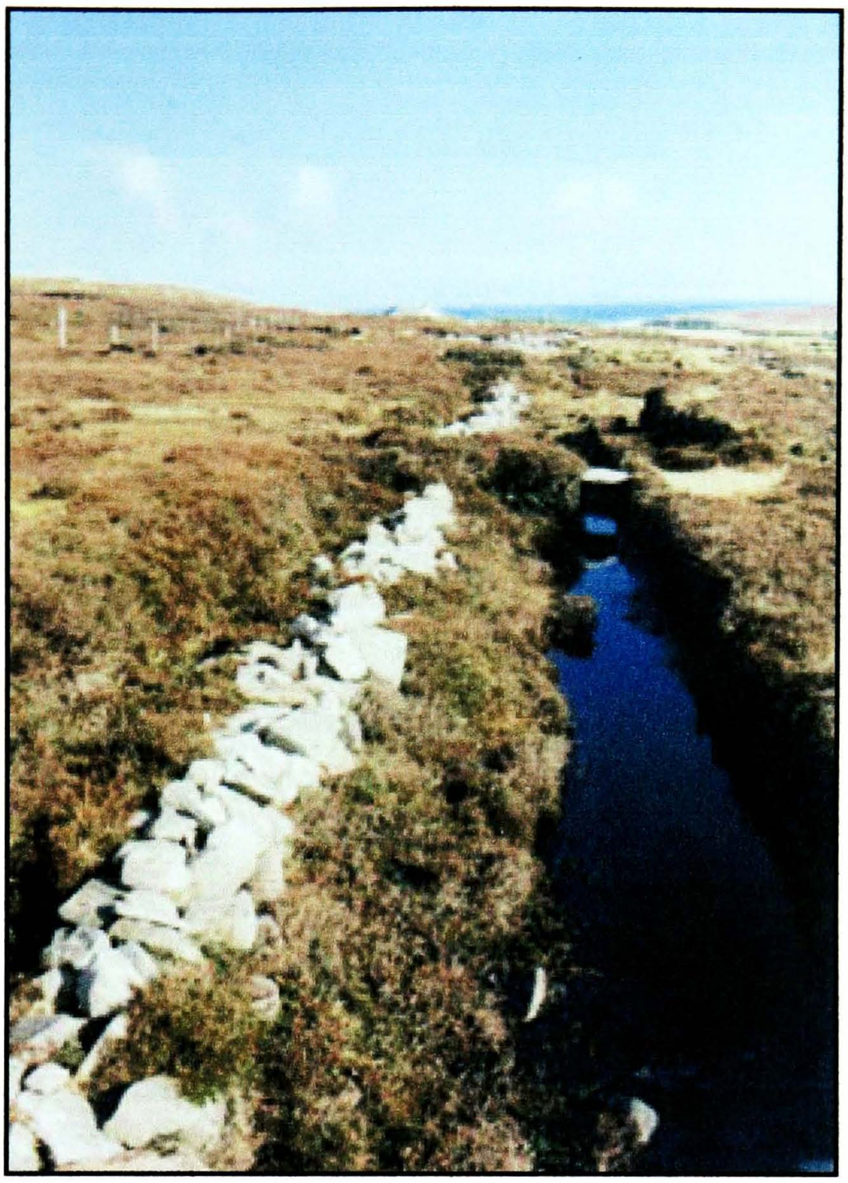


Plate 3.6: Area of ridge-and-furrow adjacent to roundhouse viewed roughly to the east.

Plate 3.7: Area of ridge-and-furrow adjacent to roundhouse viewed roughly to north. See Figure 3.4 for location.

Plate 4.1: BB1 section prior to sampling

Plate 4.2: BB2 section prior to sampling

Plate 4.3: BEL location during sampling

Plate 4.4: BB1 section during sampling

Plates 5:1-5.12: Cereal-type pollen grains from BEL core

Plate 5.1: BEL 4cm

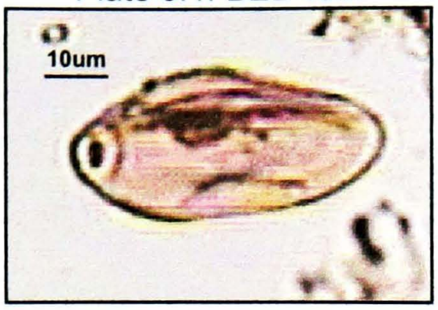


Plate 5.2: BEL 16cm

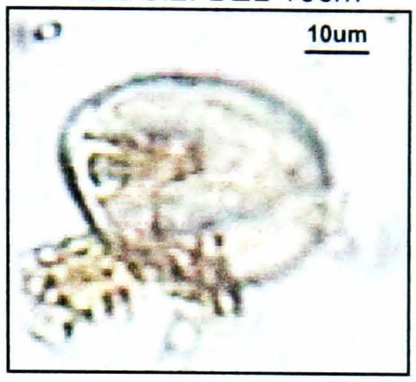


Plate 5.3: BEL 20cm

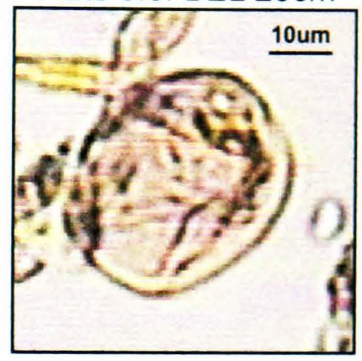


Plate 5.4: BEL 28cm

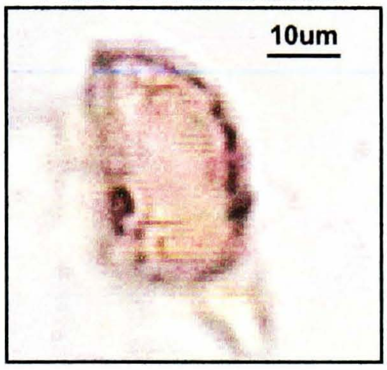


Plate 5.5: BEL 92cm

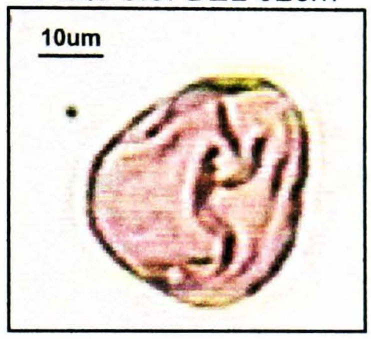


Plate 5.6: BEL 138cm

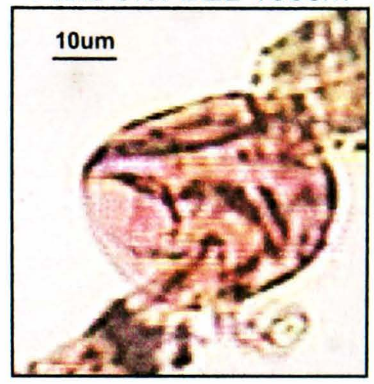


Plate 5.7: BEL 150cm

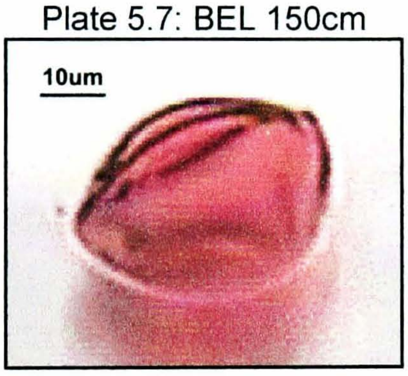


Plate 5.8: BEL 152cm

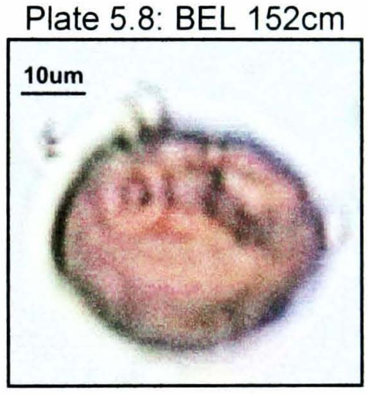


Plate 5.9: BEL 154cm (1)

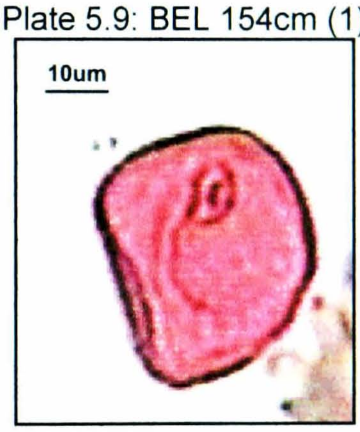


Plate 5.10: BEL 154cm (2)

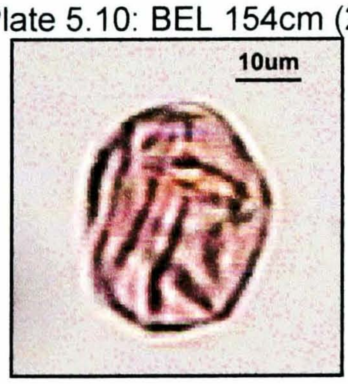


Plate 5.11: BEL 156cm (1)

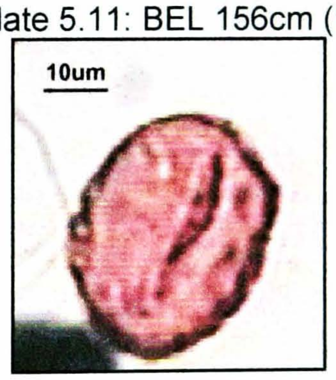
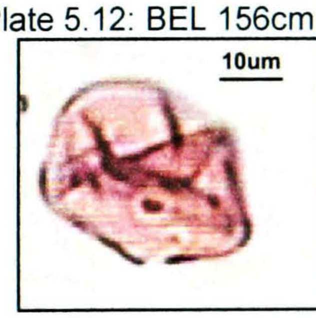


Plate 5.12: BEL 156cm (2)



Plates 5.13 – 5.17: Selected cereal pollen from BEL core

Plate 5.13: BEL 158cm

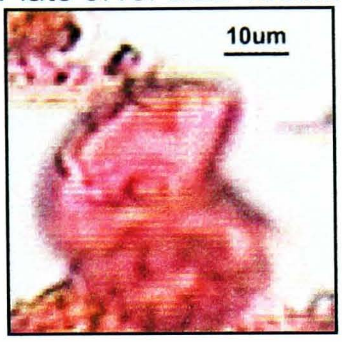


Plate 5.14: BEL 166cm

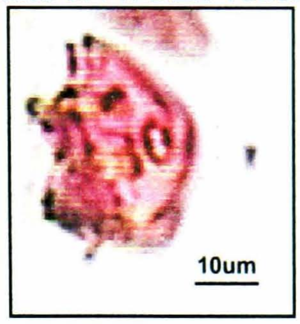


Plate 5.15: BEL 172cm

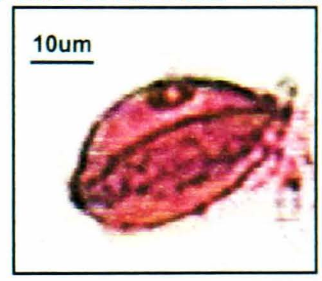


Plate 5.16: BEL 178cm

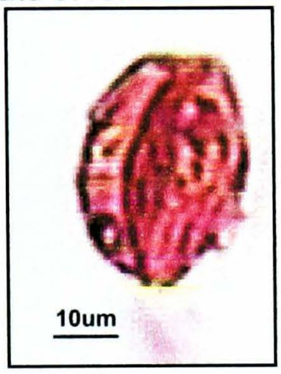
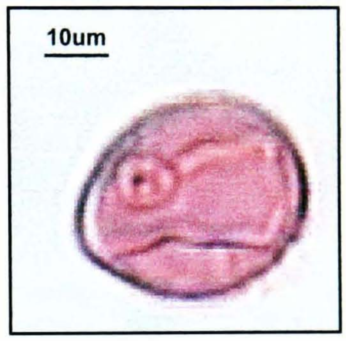


Plate 5.17: BEL 196cm



Plates 6.1-6.9: Cereal-type pollen grains from BB1 section

Plate 6.1: BB1 -1cm (2&3)

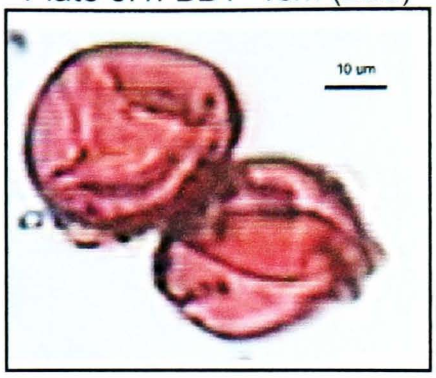


Plate 6.2: BB1 -1cm (4)

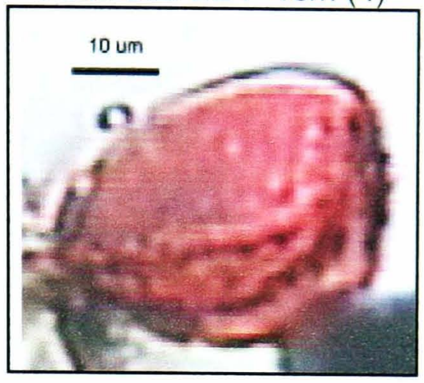


Plate 6.3: BB1 1cm (1)

Plate 6.4: BB1 3cm (1)

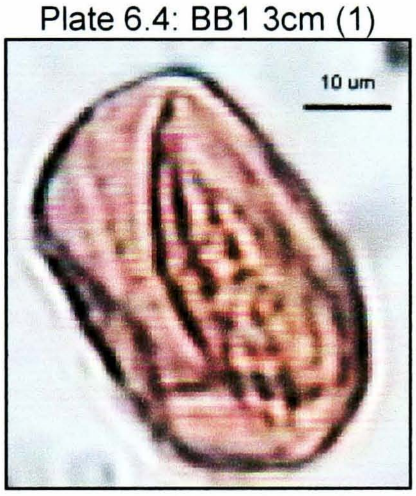


Plate 6.5: BB1 3cm (2)

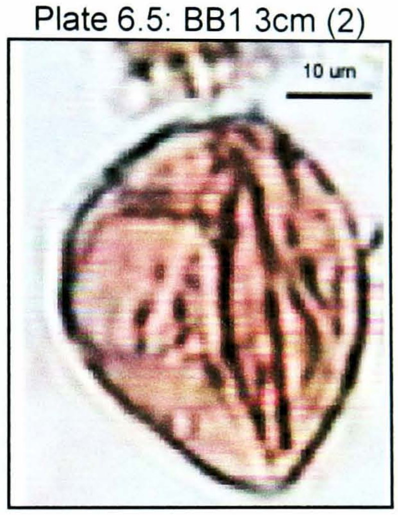


Plate 6.6: BB1 5cm (2)

Plate 6.7: BB1 7cm (1)

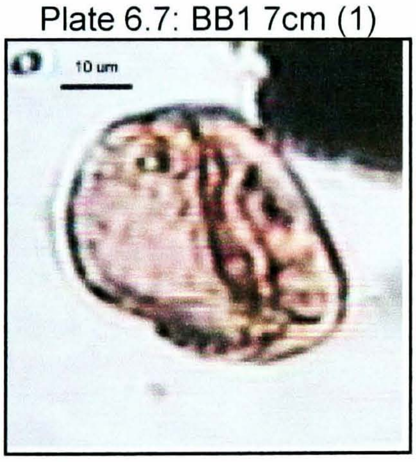


Plate 6.8: BB1 7cm (3)

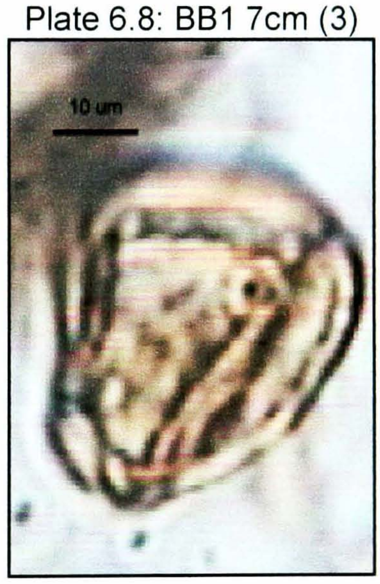


Plate 6.9: BB1 7cm (4)

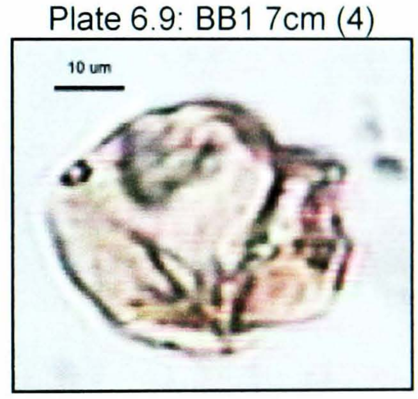
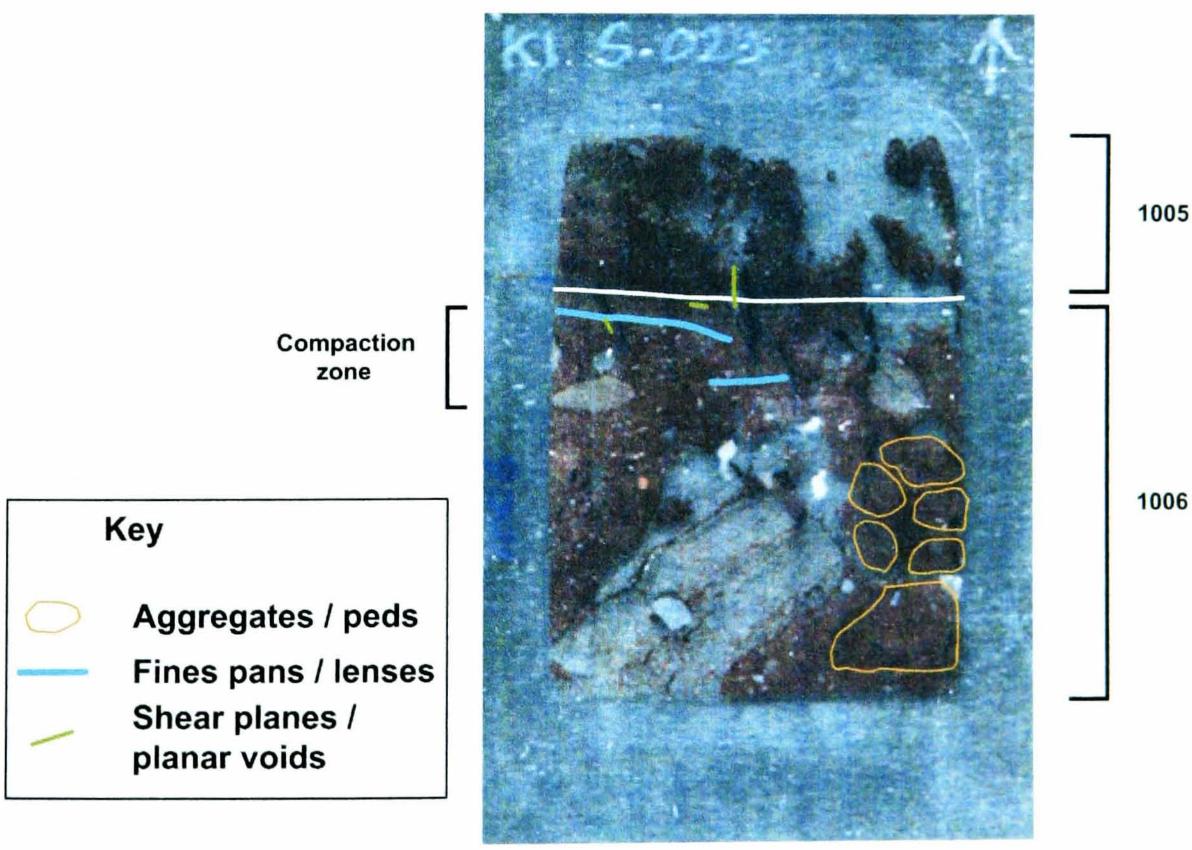


Plate 6.10a: Thin section from Kubiena tin K1

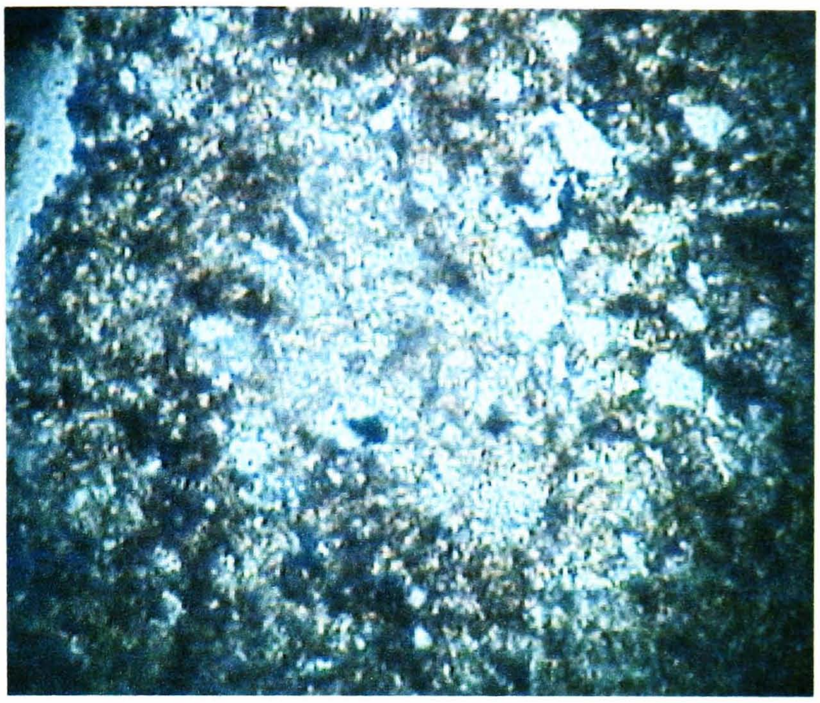
55mm

Plate 6.10b: K1 illustrated



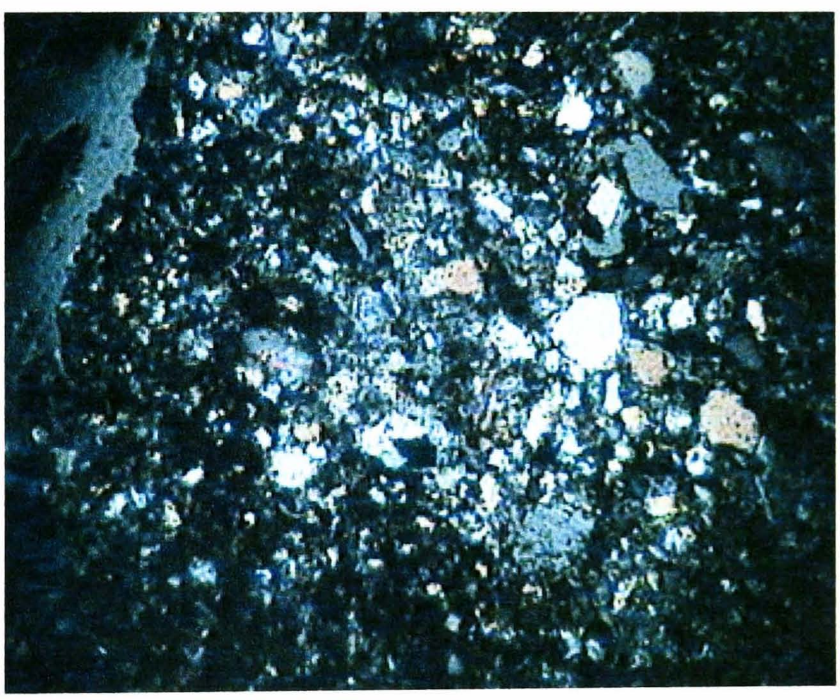
55mm

Plate 6.11a: Part of fines accumulation in 1006 (PPL)



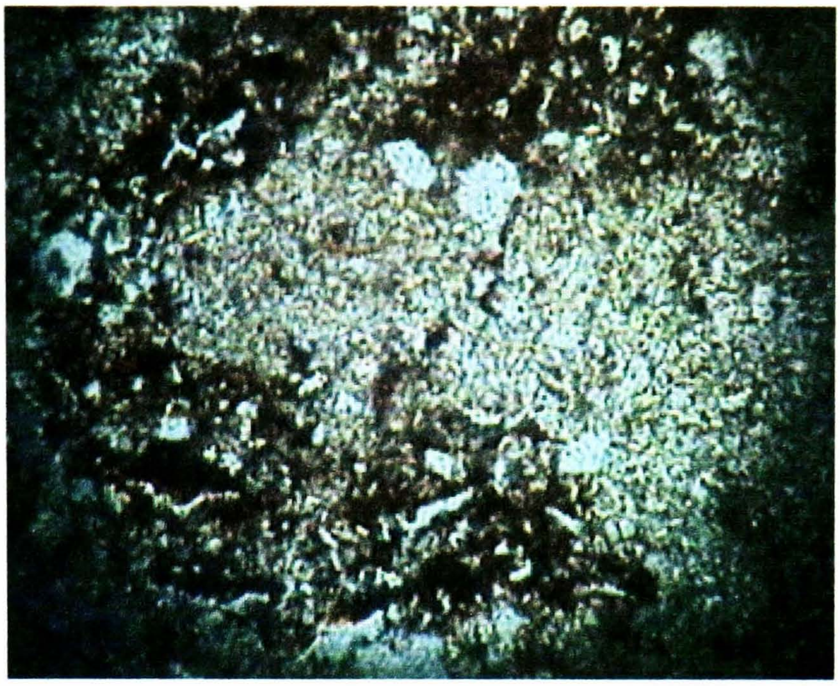
1mm

Plate 6.11b: Part of fines accumulation in 1006 (XPL)



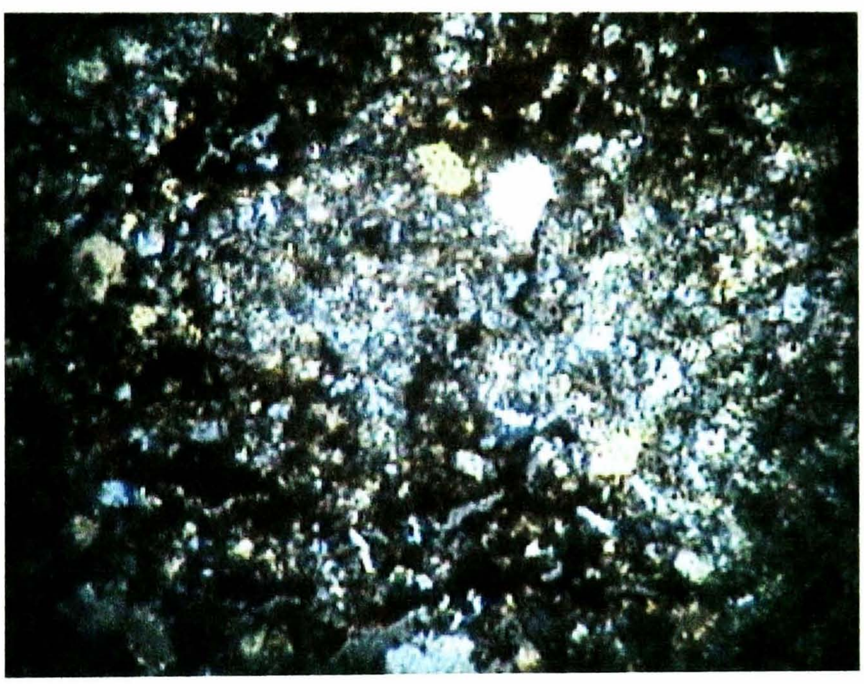
1mm

Plate 6.12a: Part of fines pan in 1006 (PPL)



1mm

Plate 6.12b: Part of fines pan in 1006 (XPL)

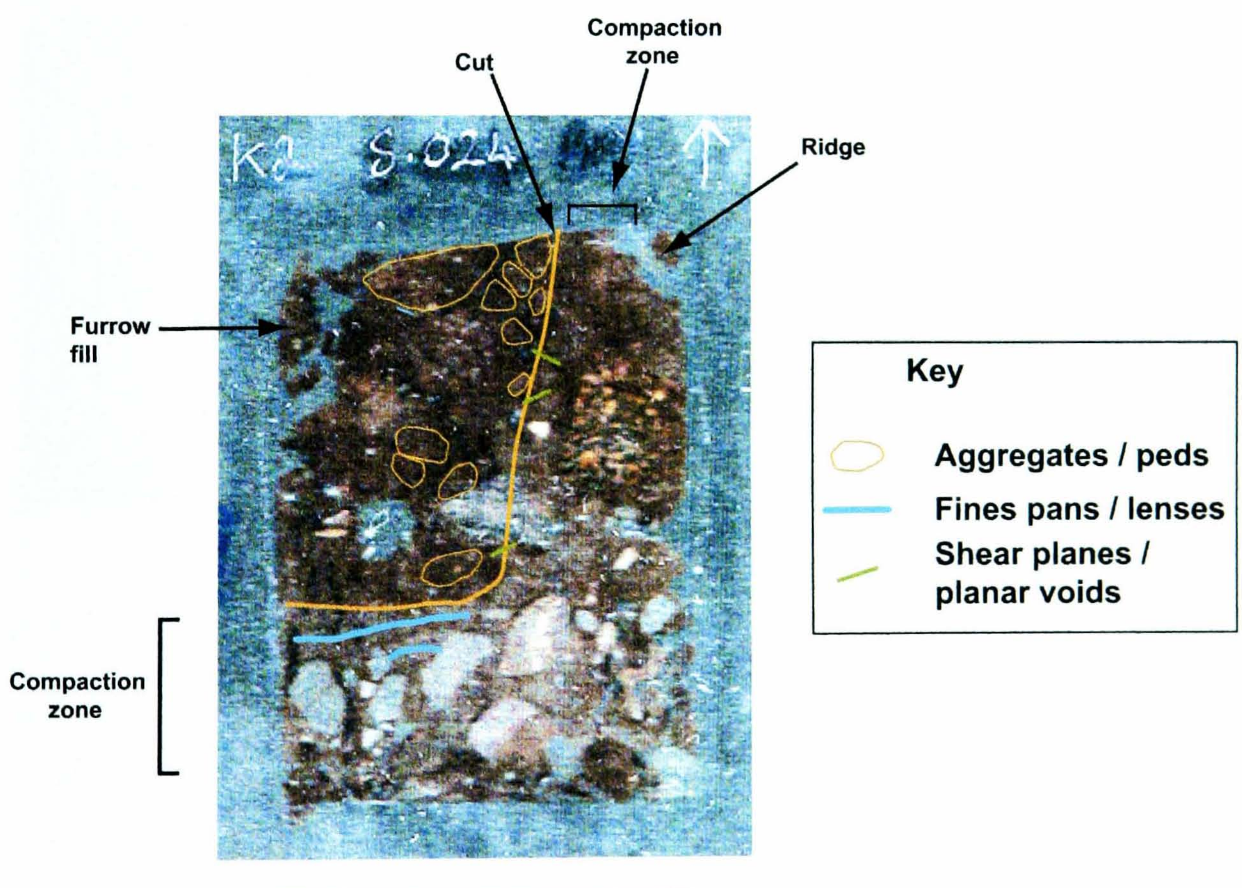


1mm

Plate 6.13a: Thin section from Kubiena tin K2

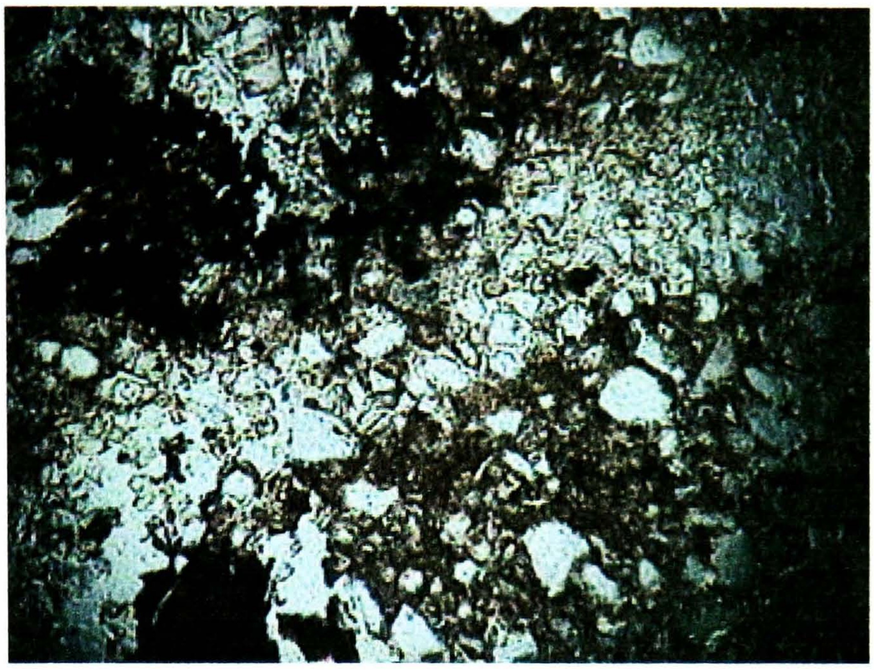
55mm

Figure 6.13b: K2 annotated



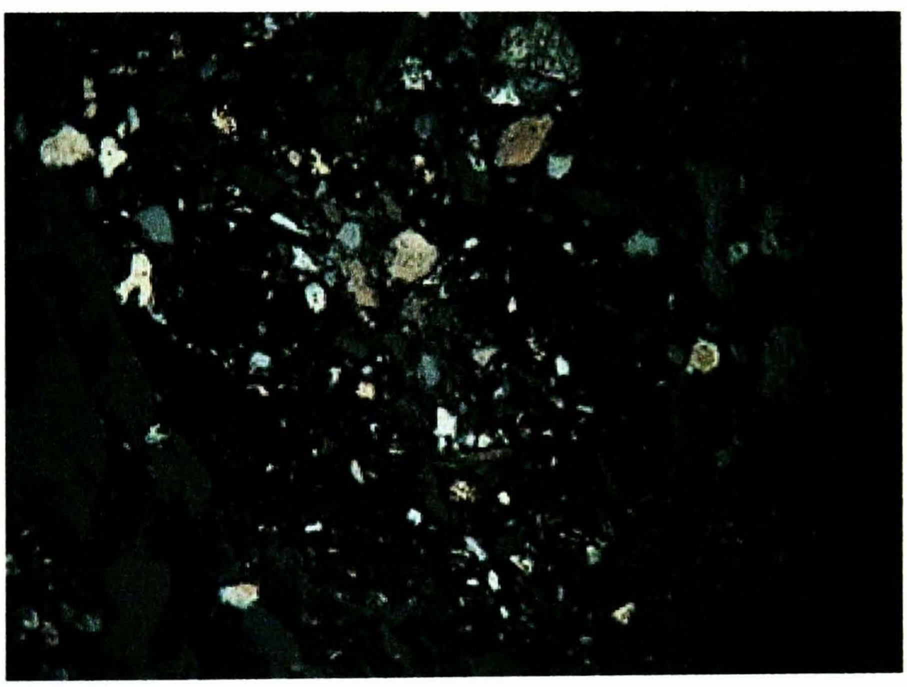
55mm

Plate 6.14a: Fines lens in furrow fill of 1005 (PPL)



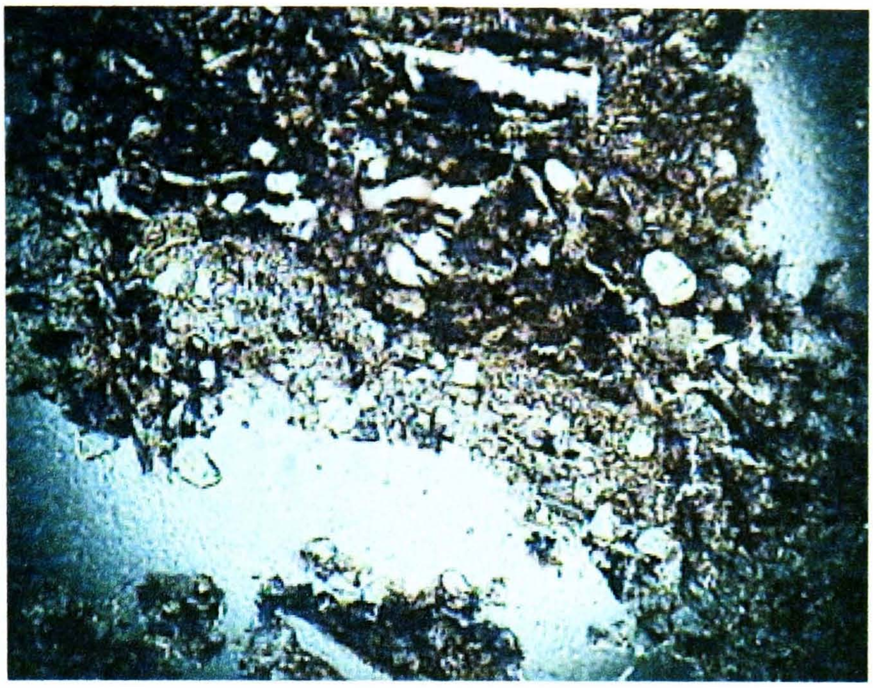
1mm

Plate 6.14b: Fines lens in furrow fill of 1006 (XPL)



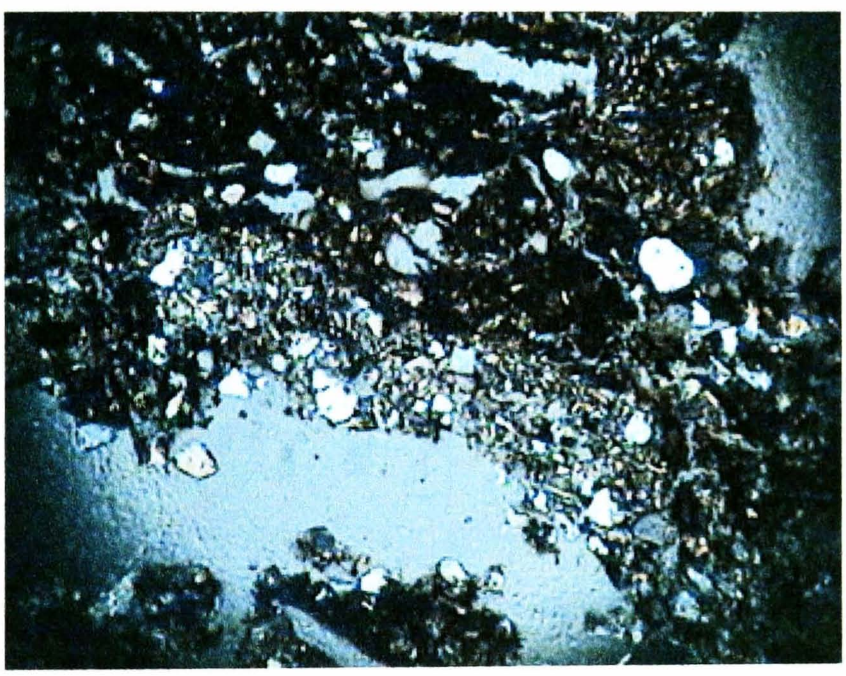
1mm

Plate 6.15a: Fines lens in basal furrow fill of 1005 (PPL)



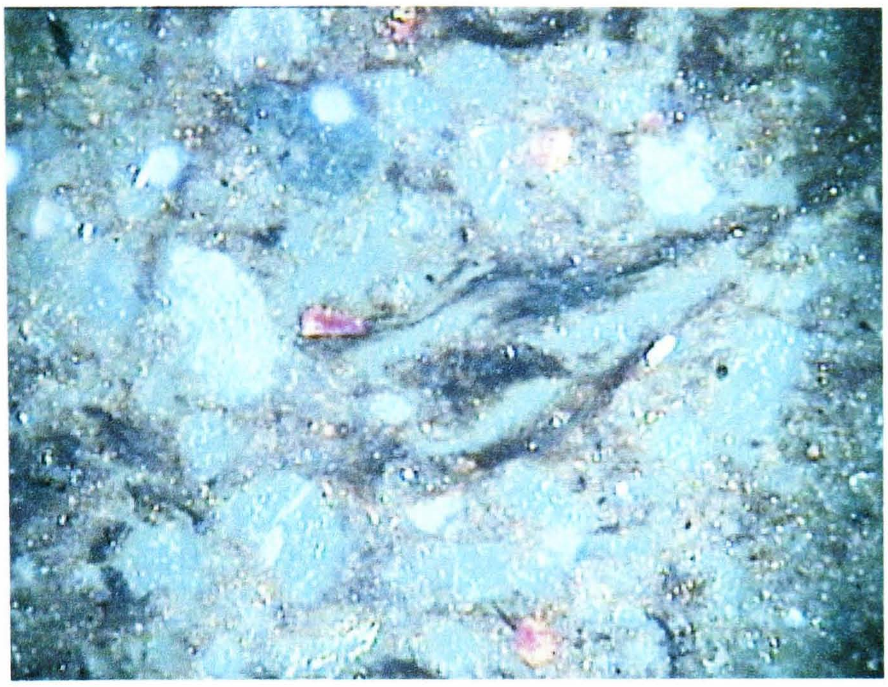
1mm

Plate 6.15b: Fines lens in basal furrow fill of 1005 (XPL)



1mm

Plate 6.16: Rubified minerals in 1005 (OIL)



20mm

Plate 6.17a: Thin section from Kubiena tin K3

Plate 6.17b: K3 annotated

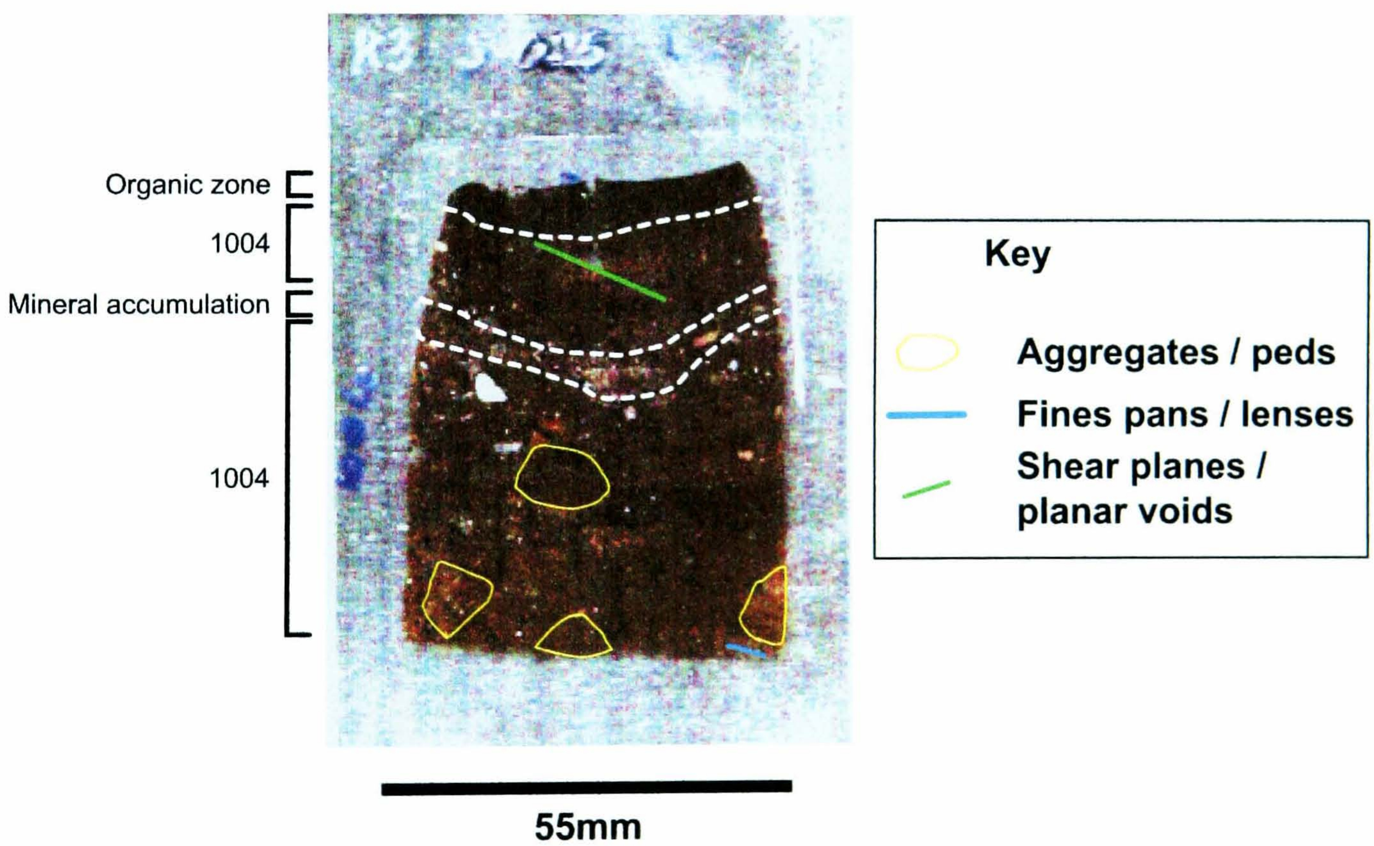
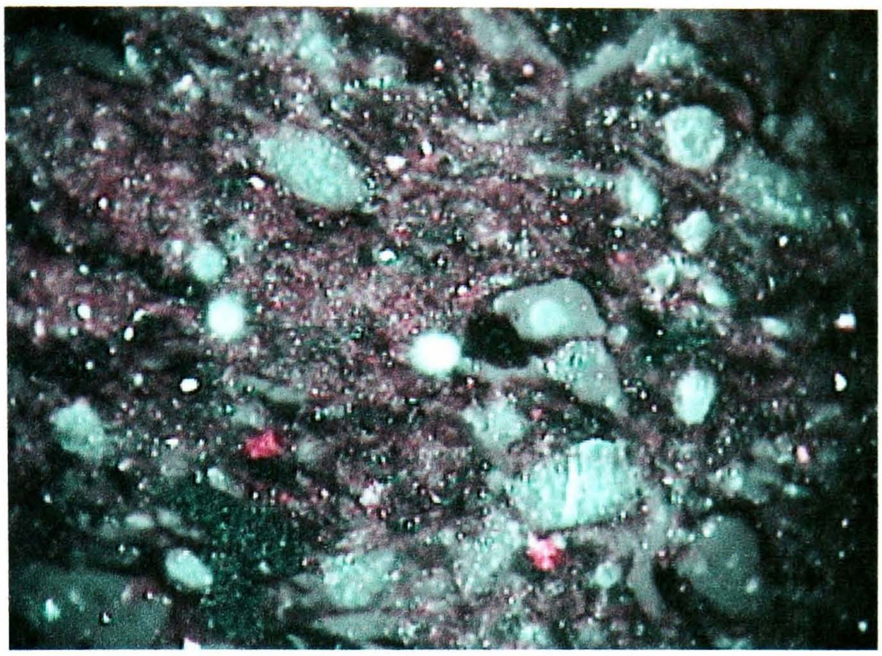
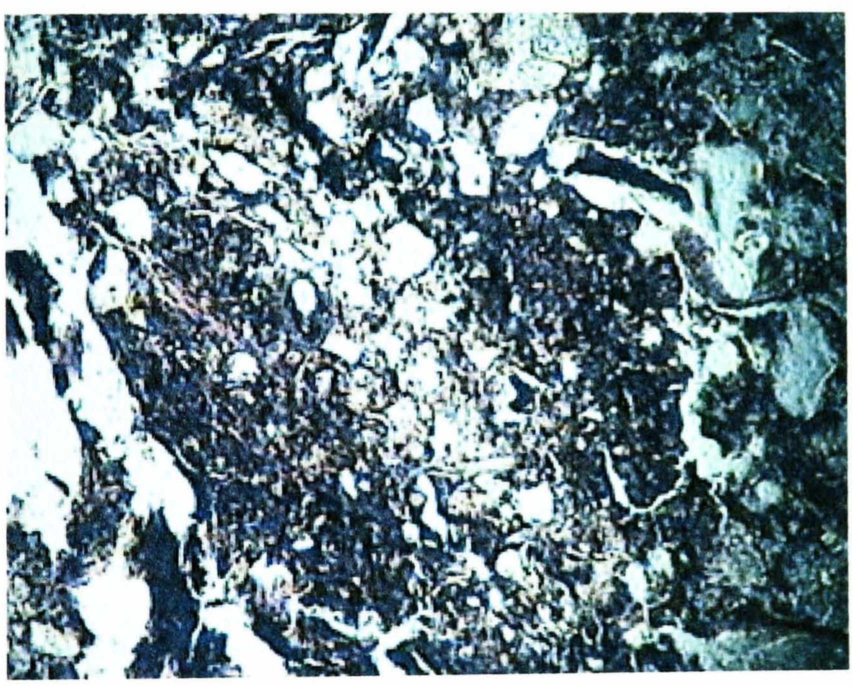


Plate 6.18: Rubified minerals in 1004 (OIL)



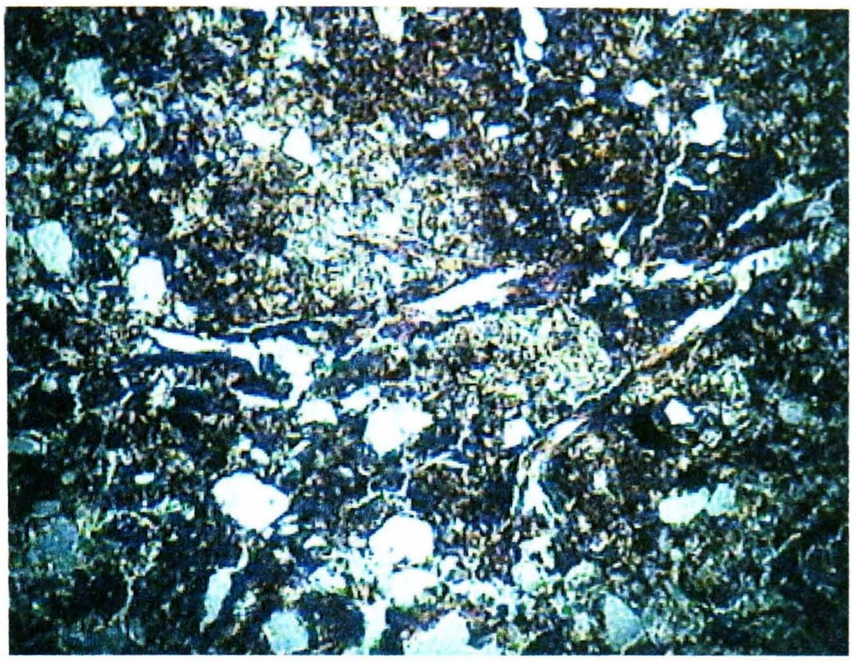
20mm

Plate 6.19: Fines lens in (upper) 1004 (PPL)



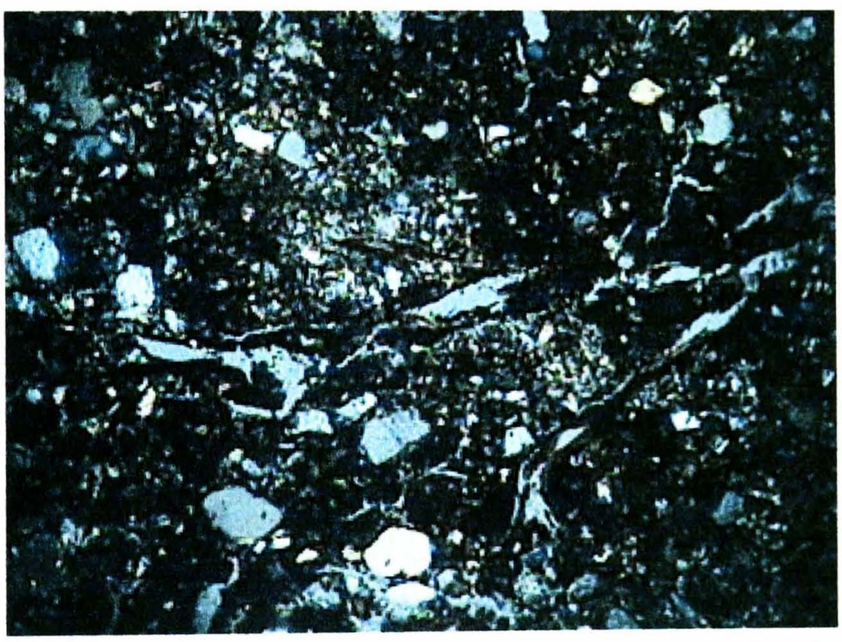
1mm

Plate 6.20a: Fines lens in (lower) 1004 (PPL)



1mm

Plate 6.20b: Fines lens in (lower) 1004 (XPL)



1mm

Plates 6.21 - 6.24: Cereal-type pollen grains from BB2 section

Plate 6.21: BB2 -10cm (1)

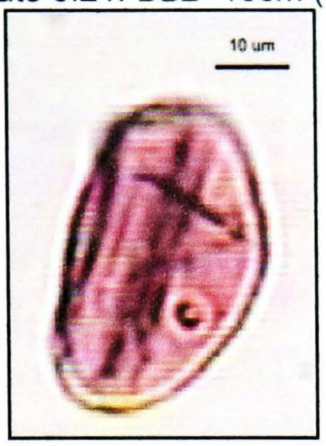


Plate 6.22: BB2 -10cm (2)

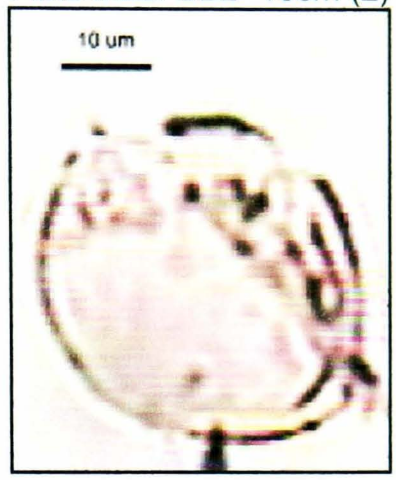


Plate 6.23: BB2 -8cm

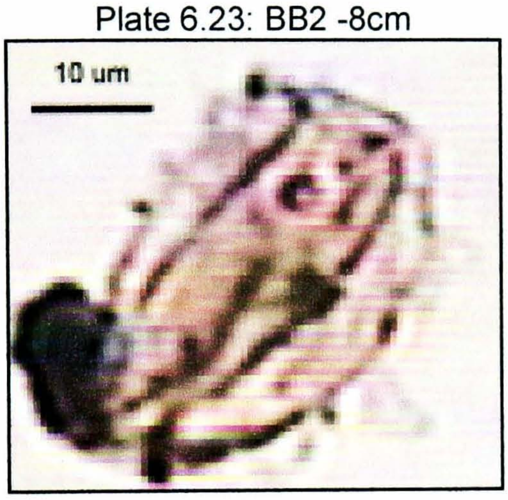
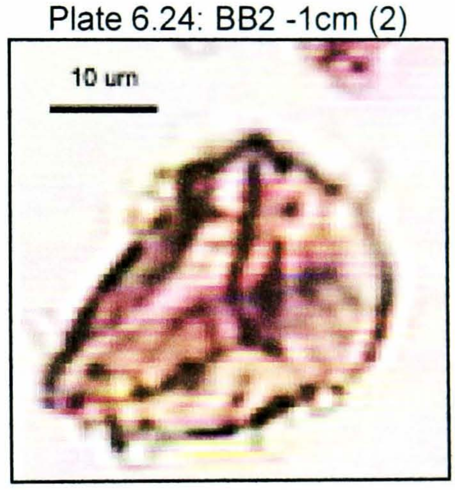


Plate 6.24: BB2 -1cm (2)



Appendix A

Radiocarbon assays quoted in the text

For further details and discussion of radiocarbon dating see Section 1.1.2. Assay details are arranged alphabetically by site name.

^{14}C lab. no	Age (bp)	Age (cal. BP/AD)¶	Material dated	Context	$\Delta^{13}C$	Source
Ballyveelish, Co. Tipperary						
GrN-11656	2810±90	2880±230	Charcoal	Ditch of square structure		Doody (1987a)
GrN-11657	3580±50	3880±190	Charcoal	Fragments in vessel		
GrN-11659	3485±40	3750±120	Charcoal	Wattle in ditch		
GrN-11445	2550±130	2625±325	Charcoal	Pit Site 2		
GrN-11658	2770±60	2885±135	Charcoal	Circular ditch		
Belderg Beg						
SI-1469	3835±85	4250±300	Oak stump	Growing in peat		Caulfield (1978)
SI-1470	4220±95	4725±345	Pine stump	Rooted on mineral soil		
SI-1471	3220±85	3440±200	Oak stake*	Extend stone wall onto shallow peat		
SI-1472	3210±85	3440±200	Oak stake*			
SI-1473	3170±85	3400±240	Wood*	From roundhouse		
SI-1474	2295±75	2400±350	Charcoal*	Associated with flint scrapers in roundhouse		
SI-1475	2905±75	3060±210	Charcoal*			
UCD-C60	3930±50	4355±175	Pine stump*			Caulfield *et al* (1998)
UCD-C31	4510±50	5145±175	Pine stump*	Rooted in mineral soil 5m from wall		
Bunnyconnellan East, Co. Mayo†						
	3410±70	3740±190	Peat	0-2cm		O'Connell (1990b)
	4090±40	4630±190	Peat	6-7cm		
Carrigdirty Rock, Co. Limerick						
GrN-20976	3330±25	3555±85	Wood	Sharpened post from ?house		O'Sullivan (1996)
Carrigillihy, Co. Cork						
GrN-12917	2810±50	2930±150	Charcoal	Refuse inside house		O'Kelly (1989)
GrN-12916	3100±50	3305±145	Charcoal	Twigs in pit inside house		
Carrownaglogh, Co. Mayo						
SI-1465	3425±85	3675±215	Charcoal	Hearth underlying wall at A†		O'Connell (1986)
SI-1466	3080±140	3250±400	Charcoal	Cultivation ridge at B†		
SI-1467	2620±75	2650±300	Peat	Overlying ridge sampled for SI-1466†		
GrN-13108	2390±35	2525±185	Peat	Overlying L2 furrow†		
GrN-13109	2435±35	2535±185	Peat	Overlying L3		

[14]C lab. no	Age (bp)	Age (cal. BP/AD)[¶]	Material dated	Context	$\Delta^{13}C$	Source
				furrow[†]		
GrN-13110	2465±35	2535±185	Peat	Overlying L7 ridge[†]		
SI-1468	3285±75	3525±165	Wood	Stake in peat at C[†]		
GrN-12301	1205±25	1140±90	Peat	-130cm, long monolith[† ‡]		
GrN-12302	2000±25	1850±60	Peat	-90cm, long monolith[† ‡]		
GrN-12303	2750±50	2855±95	Peat	-52cm, long monolith[† ‡]		
GrN-12304	3510±50	3770±140	Peat	-5cm, long monolith[† ‡]		
Céide Fields						
Dates from a monolith taken beside Behy tomb court cairn. Depths given are with respect to mineral ground/peat interface						
UB-158F	3930±105	4425±425	Peat (pt. fr.)	36-38cm		Smith *et al* (1973a)
UB-155	3630±70	3935±215	Peat[§]	30-34cm		
UB-153F	3890±110	4275±375	Peat (pt. fr.)	24-38cm		
Glenulra enclosure						
SI-1464	4460±115	5150±350	Charcoal	Enclosure within field system		Caulfield (1978)
Pollen profiles within Céide Fields GLU-IV core: Depths given relate to cm below modern day surface[†]						
GrN-21638	1820±50	1745±135	Peat	167-170cm		Molloy & O'Connell (1995)
GrN-21637	1940±50	1815±85	Peat	185-188cm		
GrN-21636	2890±50	3040±170	Peat	255-258cm		
GrN-21121	3310±60	3540±150	Peat	289-293cm		
GrN-21635	3510±50	3770±140	Peat	319-322cm		
GrN-21120	3890±60	4325±185	Peat	351-355cm		
GrN-21634	4070±60	4615±205	Peat	387-390cm		
GrN-21119	4110±60	4635±195	Peat	402-406cm		
GrN-21633	4470±60	5090±220	Peat	440-444cm		
GrN-21118	4550±60	5215±235	Peat	448-452cm		
GrN-21632	4500±60	5095±225	Peat	459-462cm		
GrN-21117	4840±60	5525±195	Peat	486-490cm		
GrN-21631	5170±60	5955±215	Peat	494-497cm		
GrN-21630	5100±80	5825±175	Peat	515-518cm		
BHY short monoliths: [‡]						
BHY IV[†]						
GrN-20030	2940±40	2550±190	Peat	-7 - -10		
GrN-20029	3630±40	3960±130	Peat	-1 - 0		
BHY V[†]						
Gd-6696	3450±80	3685±215	Peat	-8.5 - -7		
Gd-6694	3990±80	4500±350	Peat	0 – 1.5		
BHY VI[†]						
GrN-20028	3540±50	3830±150	Peat	-10 - -13		
GrN-20027	4080±50	4620±200	Peat	-5 - -8		
CF I monolith: [† ‡]						
GrN-20632	2250±50	2245±105	Peat	-7 - -8		
GrN-21116	2870±40	3010±150	Peat	-1 - -2		
GrN-20631	2760±40	2860±90	Peat	0 - -1		
Plough mark BHY (6) [†]						
GrN-20032	2390±40	2520±190	Peat	Plough fill		
BHY III: [† ‡]						
GrN-20031	3290±30	3540±100	Peat	-14.5 - -16.5		
Gd – 7147	3360±50	3580±120	Peat	-7 - -6		
Gd - 6693	4030±80	4550±300	Peat	-1 - 0		
GrN-23499	3090±30	3295±85	Peat[ß]	-17.5 - -16.5		O'Connell & Molloy (2001)
GrN-23498	3870±25	4285±125	Peat[ß]	-6 - -5		
GrN-23497	4110±40	4635±195	Peat[ß]	-1 - 0		
Chancellorsland, Co. Tipperary						

^{14}C lab. no	Age (bp)	Age (cal. BP/AD)¶	Material dated	Context	$\Delta^{13}C$	Source
UB-3723	3080±65	3260±190	?	Structure 5		Doody (1995)
UB-3626	3095±100	3275±325	?	Hut foundation trench		Doody (1993b)
UB-3627	3320±170	3525±475	?	Palisade trench		
UB-3628	2980±250	3150±700	?	Palisade trench		
GrA-5294	3340±40	3580±110	?	Ditch		Doody (1999)
GrA-5293	3160±40	3365±105	Charcoal	Perimeter stake		
Coney Island, Co. Armagh						
UB-43	3350±80	3610±220	Charcoal	Deposit with Bowl pottery		Smith *et al* (1971)
Corbally, Co. Kildare						
GrA-13697	4910±50	5620±130	Emmer grain	Post hole of house		A. Purcell (unpub.) in Milliken (2002)
GrA-13702	4880±50	5605±125	Emmer grain	Foundation trench of house		
GrA-13700	4900±50	5615±135	Emmer grain	Post hole of house		
Cullyhanna, Co. Armagh						
UB-688	3305±50	3545±145	Wood	Oak stake of enclosure on lake margin		Smith *et al* (1973b)
Curraghatoor, Co. Tipperary						
GrN-19562	2730±50	2850±100	Charcoal	?		Doody (1990)
GrN-11660	2840±35	2965±115	Charcoal	Pit inside round house		
GrN-16786	2845±40	2960±120	Charcoal	Refuse pit		
GrN-16787	3030±70	3185±195	Charcoal	Pit or posthole		
GrN-16785	2940±50	3105±165	Charcoal	Refuse pit		
GrN-16788	2865±35	3005±135	Charcoal	Pit or posthole		
GrN-16789	2850±35	2970±110	Charcoal	Pit or posthole		
Dalkey Island, Co. Dublin						
D-38	5300±170	6050±400	Charcoal	Shell midden		McAuley & Watts (1961)
OxA-4566	5050±90	5795±195	Sheep humerus		-19.6‰	Woodman *et al* (1997)
OxA-4567	3050±70	3200±200	Cattle ulna		-22.9‰	
OxA-4568	6870±90	7750±180	Pig scapula		-19.2‰	
OxA-4569	7250±100	8085±245	Seal/sheep rib		-13.9‰	
OxA-4570	5600±80	6385±185	Pig radius		-20.2‰	
OxA-4571	4820±75	5515±195	Cattle vertebra		-21.4‰	
OxA-4572	6410±110	7300±300	Seal phalanx		-11.4‰	
False Bay, Ballyconneely, Co. Galway						
?	3587±36	3945±135	Charcoal	Pit fill		McCormick *et al* (1996)
Ferriter's Cove, Co. Kerry						
OxA-4918	5545±65	6335±145	Human femur		-14.0‰	Woodman & O'Brien (1993)
OxA-5770	5590±60	6390±110	Human molar		-14.1‰	
OxA-3869	5510±70	6280±170	Cattle bone		-18.1‰	
GrN-18772	6300±140	7150±350	Charcoal		?	
Q-2641	5245±55	6045±135	Charcoal		?	
OxA-8775	5825±50	6620±130	Cattle bone		?	Woodman (2000)
Geevraun, 300m west of Belderg Beg						
UCD-C46	5710±90	6510±210	Peat	5cm above mineral soil		Caulfield *et al* (1998)
UCD-C47	4210±60	4720±150	Pine stump	45cm above		

^{14}C lab. no	Age (bp)	Age (cal. BP/AD)¶	Material dated	Context	Δ^{13}C	Source
				mineral soil		
Kilgreany Cave, Co. Waterford						
OxA-4269	5190±80	5960±220	Cattle tibia	Cave stratum	-22.5‰	Woodman *et al* (1997)
Lough Doo, Co. Mayo						
GrN-11739B	2800±100	2975±235	Lake sediment	59-65cm		O'Connell *et al* (1987)
GrN-11739	2510±50	2555±195	Lake sediment	65-80cm		
GrN-11738B	1510±120	1425±525	Lake sediment	164-169cm		
GrN-11738	1895±50	1830±120	Lake sediment	169-186cm		
GrN-11737	4610±60	5000±300	Lake sediment	221-231cm		
GrN-11737B	5020±230	5700±650	Lake sediment	231-237cm		
GrN-11736	6280±70	7205±215	Lake sediment	273-281cm		
GrN-11736B	6750±210	7625±425	Lake sediment	281-286cm		
Lough Eskragh, Co. Tyrone						
UB-1472	2590±45	2640±150	Wood	Oak plank from crannog A		Williams (1978)
UB-950	2360±45	2475±275	Wood	Vertical pile site C		
UB-965	2475±45	2540±190	Wood	Crannog A		
UB-2047	2690±45	2805±65	Wood	?		
UB-948	3105±80	3275±205	Wood	Site C horizontal timber		
GrN-14740	2165±25	2185±125	Wood	Dug-out canoe		Lanting & Brindley (1996)
Lyles Hill, Co. Antrim						
UB-3063	4775±125	5475±125	Barley	Hearth		Sheridan (2001)
Mannin 2, Ballyconneely, Co. Galway						
?	2799±28	2875±85	Charcoal	Midden		McCormick *et al* (1996)
?	2503±30	2605±145	Shell	Midden		
Meadowlands, Downpatrick, Co. Down						
UB-471	3575±70	3885±205	Charcoal	Occupation layer (lower)		Smith *et al* (1973a)
UB-472	3795±75	4200±220	Charcoal	Occupation layer (lower)		
UB-473	3265±80	3515±175	Charcoal	Occupation layer (upper)		
UB-474	3325±75	3555±175	Charcoal	Occupation layer (upper)		
Mooghaun, Co. Clare						
GrN-20490	2895±50	3040±170	Wood	Sealed by outer rampart		Grogan (1995)
Moynaugh Lough, Co. Meath						
GrN-11443	5270±60	6055±145	Charcoal	Lake mud		Bradley (1991)
OxA-4268	1660±70	AD 395±175	Charcoal		-22.5‰	Woodman *et al* (1997)
Rathlackan, Co. Mayo						
Beta-76588	4640±80	5325±275	Charcoal	Upper pit fill in tomb chamber 3		Byrne (n.d.)
Beta-76591	4570±90	5225±375	Charcoal	Deposit surrounding hearth in court		
Beta-76587	4520±80	5150±300	Charcoal	Spread on court surface		

^{14}C lab. no	Age (bp)	Age (cal. BP/AD)¶	Material dated	Context	$\Delta^{13}C$	Source
Beta-76589	4390±240	4950±700	Charcoal	Pit fill in tomb chamber 3		
Beta-76590	4130±80	4640±200	Charcoal	Silt in top of socket in tomb chamber 3		
Beta-76583	4110±90	4625±215	Charcoal	Spread on court surface		
Beta-76585	4090±70	4625±205	Charcoal	Deposit in tomb chamber 3 above basal stones		
Beta-76584	3640±80	3975±275	Charcoal	With secondary pottery in tomb chamber 3		
Beta-76586	3630±80	3925±235	Charcoal	With secondary pottery in tomb chamber 3		
Beta-48102	4110±60	4605±165	Charcoal	Hearth of house 10		
Beta-63836	4040±60	4575±275	Charcoal			
Rockmarshall Midden, Co. Louth						
OxA-4604	5705±75	6490±180	Human femur		-18.1‰	Hedges *et al* (1997)
Stoney Island, Co. Galway						
OxA-2758	6200±80	7075±205	Human bone	Bog body	-22.6‰	Hedges *et al* (1993)
OxA-2942	5270±80	6090±190	Human bone	Bog body	-21.2‰	
Sutton Shell Midden, Co. Dublin						
I5067	5250±100	6025±275	Charcoal	Shell midden		Mitchell (1972)
OxA-3691	6660±80	7545±125	?Cattle bone		-20.5‰	Woodman *et al* (1997)
OxA-3960	6560±75	7450±140	Recheck of OxA-3691		-23.5‰	
Tankardstown, Co. Limerick						
OxA-1476	4890±80	5600±300	Emmer grain	House 1		Hedges *et al* (1989)
OxA-1477	4840±80	5530±210	Emmer grain	House 1		

¶ Where necessary, all assays quoted from literature have been re-calibrated with OxCal version 3.9 (Bronk Ramsey 2003), using atmospheric data from Stuiver *et al* (1998). Here and in the text, the date given is mid-point of calibrated age range and ± value represents calibrated age range (end points at 95% [2σ] confidence level) divided by 2.

§ In this sample, the fine particulate fraction and the humic acid fraction were combined for dating. Humic acid samples from samples 24-28cm (=UB-153C) and 36-38cm (=UB-153C) gave dates of 3245±70 and 3750±85 bp respectively. The authors concluded that there was considerable movement of humic acid and that UB-155 therefore was too young.

β Additional dates for the BHY III profile were sought due to uncertainties with the initial dates. These new results confirmed the suspicions (based on palynological interpretations) that the original dates were inaccurate (Molloy & O'Connell 1995, 210; O'Connell & Molloy 2001, 101).

† See Figure 2.10 for locations.

* See Figure 2.8 for locations.

‡ Depth signifies distance from mineral soil, i.e. -130cm correlates to 130cm above mineral soil/peat horizon.

Appendix B

Belderg Beg site reports published in 'Excavations'

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1. Caulfield, S. 1971. Beldergbeg. ***Excavations 1971.***

BELDERGBEG

Pre-bog Field System

F982 410

A preliminary investigation of a pre-bog field system at Beldergbeg, Co. Mayo was begun in November 1971 and is continuing at present (February 1972). The site is four miles west of the Behy—Glenulra field complex and less than half a mile from Belderg harbour.

The excavation so far has revealed a number of small conjoined enclosures of irregular pattern. Flint knapping was carried out in these enclosures over a wide area. One site yielded a number of hammerstones and a large quantity of crushed quartz. In this same area a number of sherds of pottery were found around and under a loose stone. It appeared at first as if one vessel had been broken by the stone but reconstruction indicates at least two vessels, one a shouldered round bottomed vessel and the other an unshouldered vessel. A number of thumb scrapers of flint and a projectile head were also found.

One long stone wall at the western side of the site lies on approximately 20-30cm of peat. Following the line of this wall and in some cases directly under it, a number of pointed stakes 8-12cm in diameter were found. The stakes were in the peat and did not penetrate the underlying soil.

It is hoped to continue excavation on the site in the coming summer.

Mr. S. Caulfield, Department of Archaeology, University College Dublin

2. Caulfield, S. 1972. Beldergbeg. *Excavations 1972.*

BELDERGBEG

Neolithic Settlement

F985406

The excavation in Beldergbeg, Co. Mayo which was begun in November 1971 was resumed on July 4, 1972 and continued until August 29. The areas of the site which had produced finds in the first season's work were concentrated on. In one area which had an extensive spread of charcoal, about 15 flint scrapers, some small sherds of pottery and a cow's horn were found. The area which had previously yielded broken Neolithic pottery vessels produced further sherds of similar pottery. Further excavation in the area of the late wall which is built on a growth of peat confirmed the two periods of activity on the site.

Half of the circular earth and stone structure, 9m in diameter, was excavated. A wall trench immediately inside the enclosing bank shows that this is in all probability a house. Finds were rare but two broken saddle querns were found and a heat-shattered flint implement. The amount of charcoal within the enclosure in particular in the wall trench suggests that the structure was burnt down.

The most important result from this season's excavation was the evidence for prehistoric tillage which came from beside the circular enclosure. Plough marks indicating cross—ploughing were recovered over a 10m square area. Overlying the plough marks and extending over an area 20 x 20m was a pattern of ridges and furrows indicating subsequent spade cultivation. The plough marks are the first discovery of this phenomenon in Ireland and the pattern compares with the eight to ten examples known in Britain and the approximately 100 known from the continent. The apparently Neolithic date for the Beldergbeg plough marks makes this evidence of ploughing one of the earliest known in Europe. Its discovery in an open field where there is the opportunity to investigate the extent of the ploughing gives the discovery added significance. Ridge and furrow cultivation overlying plough marks is unparalleled elsewhere.

The main results of the 1972 season of excavation were therefore the evidence of prehistoric agriculture which was discovered. Apart from the obviously agricultural reason for the enclosing stone walls which led to the excavation of this site, evidence of agricultural activity was forthcoming from the plough marks, ridges and furrows, cow's horn and saddle querns. The other finds while not very numerous are sufficient to indicate that the two periods of activity on the site took place within Neolithic times.

It is hoped to continue the excavation in the 1973 season.

Mr. S. Caulfield, Dept of Archaeology, University College Dublin

3. Caulfield, S. 1973. Beldergbeg. *Excavations 1973.*

BELDERGBEG

Prehistoric Settlement and Field Systems

F 982410

The excavation this season concentrated on the circular "house" and the tillage plot with ridges and plough marks. It was hoped to complete the excavation of the house but continuous wet weather made this impossible. However, peat stripping of the tillage area was carried out on a more extensive scale than had been originally planned.

The plough marks have now been traced in an area 24m x 16m. The extent of the ridges discovered last year was defined on three sides (the road prohibits excavation on the fourth side) and three other contiguous tillage plots have been found. One plot does not have ridges, the second has ridges parallel to those first discovered, and the third has ridges at right angles to these.

Excavation in the house revealed an internal wall trench and a concentric ring of postholes approximately 1 .5m inside this trench and 2m apart. Other postholes and some stone filled pits were found, in particular in the SE quadrant. In one of the pits small flecks of bone survived. Two further saddle querns and portions of three rubbers and a polished stone disc were the only finds from within this structure.

Some new evidence of the second period of habitation on the site came to light. The second period wall built on peat with stones robbed from the earlier pre-bog wall terminated after running approximately 70m to the south but the oak posts associated with the final 40m of this wall continued on independently for at least a further 5Om into the deep bog. (Are the pointed stakes so commonly found in bogs simply some form of fencing as they certainly are in this case?). The other structural evidence of second period occupation, a late trench with the upcast thrown on to approximately 10cm of bog was located at another part of the site 40m from where it was first discovered. Close by but not directly related to it sherds of a broken pottery vessel were found. This pottery vessel with flat rim and body ornament is totally different to that previously found. Up until the discovery of this pottery none of the archaeological objects could be definitely isolated into groups to tie in with the clearly differentiated structural features as all the material could be Neolithic in date. This new pottery differing in form, grit and decoration should eventually prove of value in the cultural identification of the second occupation. The occupation of what was obviously a poor agricultural site when the site was already covered by bog is difficult to explain if this happened in Neolithic times. But if this second occupation was in Bronze Age times no explanation is required as the rich vein of copper ore in the cliff face 1 mile to the NW could be sufficient reason for these people to occupy such a poor agricultural site. The wedge tomb three-quarters of a mile east of the site already points to the presence of Bronze Age people in Belderrig valley.

It is hoped to continue the excavation in the 1974 season.

Site 26 Appendix.

7 Radiocarbon determinations for the site have been provided by the Smithsonian Institute. Five samples of wood from the site suggest that the 1st pre-bog occupation is earlier than the mid—3rd Millennium BC and that the 2nd occupation is of Mid—2nd Millennium BC date.

1. Pine stump near pre bog wall at S. end of site	4290 ± 95 BP
2. Oak stump at SE end of site	3835 ± 85 BP
3. Pointed oak post from late wall	3220 ± 85 BP
4. Pointed stake from late wall	3210 ± 85BP
5. Burnt block of wood from round house	317O ± 5BP

Two charcoal samples yielded dates inconsistent with the archaeological evidence

6. Charcoal from wall trench within round house

7. Charcoal from area which produced number of flint scrapers

S. Caulfield, Dept of Archaeology, University College, Cork.

4. Caulfield, S. 1974. Beldergbeg. *Excavations 1974.*

BELDERGBEG

Prehistoric Settlement + field system

F982410

The aim this season was to complete the excavation of the house and to try to define the overall limits of the settlement to the north and south.

The round house was totally excavated apart from one small segment where the stratification was left intact. The rubber of a saddle quern and the fragment of another were found. The external trench which surrounds the house is not continuous as it stops just short of an unexcavated baulk on the western side. The trench in the neighbourhood of the ridge is filled with a disturbed peaty soil.

Excavation at the extreme northern end of the site showed a large spread of charcoal in which shells of hazel nut were found. A large cutting within the boundary of the stone walls at the extreme south end of the site uncovered a very stony area in which were found sherds of pottery with sharply-angular quartz grit very similar to pottery from the Glenulra enclosure. Elsewhere on the site at a number of places there was found pottery with a non-quartz grit similar to the cord-ornamented pottery discovered in 1973.

In a non-ridged area contiguous to the ridge plots further traces of plough marks were revealed. This new evidence shows that ridging was not necessarily the reason for the ploughing and it is possible that the two indications of tillage are unconnected and could in fact belong to the two well-separated occupations of the site.

(NOTE. The appendix to the 1973 report gives a series of radio carbon dates supplied by the Smithsonian Institution. The dates published were the uncalibrated dates and to conform to the normal convention should have been published with lower case b.p.)

Mr. S. Caulfield, Department of Archaeology, University College, Dublin.

5. Caulfield, S. 1975. Beldergbeg. ***Excavations 1975***

BELDERGBEG

Prehistoric Settlement & Field System

F 982 410

The excavation concentrated on the tillage area and its relationship to the round house. It would seem that the ploughing and clearance of stones from the tillage plots pre-dated the round house because (i) the house was built on a stony headland between two such plots, (ii) there was a break in the external house trench where it met the stones of the headland and (iii) plough marks were found very close to the house. There was tillage also after the house was built as the trench near the ridges is filled with a disturbed soil which suggests digging close by. The specialized function of the round house was further emphasised by the finding of another saddle quern and two rubbers in its immediate vicinity. The average width of a ridge and "seoch" combined is around one metre.

At the western end of the ridge-plots an extensive charcoal spread contained shells of hazelnut, a few broken flint scrapers and numerous sherds of pottery. The pottery is in extremely poor condition but it is possible to identify its grit as being non-quartz and similar to that in some cord ornamented pottery discovered in 1973.

S. Caulfield, Department of Archaeology, University College, Dublin.

C6 1976

BELDERGBEG

Prehistoric Settlement and Field Settlement

F 982 410

The excavation concentrated on an oval-shaped enclosure at the W. side of the site. The enclosure which was bounded by a low field wall had been partially robbed during the Bronze Age to provide stones for a later field wall built on a varying depth of peat.

An area approximately 700 sq. m. was uncovered but proved to be surprisingly barren of finds and structural features. Traces of burning at the pre-bog level and in the basal peat need be no more than the general burning evidence which occurs over a widespread area in the region of the site. There were no traces of any postholes or other structural evidence while the very stony nature of the enclosure rules out the possibility that it could have been an enclosed tillage plot.

One struck chert flake, a small amount of pottery and a few as yet unidentified seeds were the total finds from within the enclosure. A few sherds of poorly preserved pottery were also found immediately outside the enclosure wall.

The negative results from this area of the settlement have helped to define the main focus of occupation which is now seen to be confined within certain contour levels across the site.

S. Caulfield, Department of Archaeology, University College, Dublin.

Appendix C

Pollen analysis – additional notes

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1. Identification and differentiation criteria

Identification of certain commonly misidentified taxa followed the most detailed keys available:

Cerealia

Size details of all pollen falling into the cereal-type classifications recognised by Andersen (1979) and reprinted by Moore *et* al (1991) were noted and photomicrographs taken in most instances. An eyepiece with graduated reticle was used and a micrometer was used to confirm that the graduations represented 2μm.

Corylus/Myrica

Corylus and *Myrica* were differentiated on the basis of *Corylus* possibly exhibiting some (but not complete) nexine thinning and sexine thickening adjacent to the porus, and *Myrica* exhibiting nexine absence and sexine thickening in the porus area (Moore *et al* 1991, 103). Reference material was also used in differentiation.

Ericaceae

Differentiation of Ericaceae was made primarily upon reference to type slide material after reference to Moore *et al* (1991) and additionally, in cases of uncertainty, to Oldfield (1959). Although Oldfield (1959) intimates that differentiation of taxa within the Ericaceae family is possible, this degree of confidence has subsequently been questioned, particularly with reference to imperfectly preserved grains (Moore *et al* 1991, 88). Primary differentiation criteria were:

Calluna vulgaris: Tetrads with all grains in one plane, or tetrad lobed and often irregularly shaped. Surface sculpturing scabrate-verrucate-gemmate. Colpi short and often irregularly spaced.

Erica cinerea: Tetrad almost globular in shape and sized >45μm. Colpi sharp edged and often widening towards the grain equator. Pori elliptical-acute or represented by a transverse endocolpus.

Erica tetralix: Grain lobed, size usually 38-43μm, often with flattened apocolpia. Coarse scabrate-verrucate sculpturing. Colpi often open and widen toward the equator. Costae to the colpi.

Vaccinium: Tetrad lobed to globular, varying size. Grain apocolpia not as flattened as in *Erica*. Costae to the colpi absent or insignificant.

Empetrum nigrum: Tetrad triangular-obtuse, size 30-34μm. Tetrad has thick inner walls. Colpi short and narrow.

Andromeda potifolia: Tetrad large; 44-57μm; and sub-globular to triangular-obtuse. Colpi usually narrow.

2. Nomenclature

Explanation of classification system (after Birks 1973).

Poaceae (=Gramineae)	Family determination certain, types or subgroups undetermined or indeterminable.
Thalictrum	Genus determination certain, types or subgroups undetermined or indeterminable.
Plantago lanceolata	Species determination certain.
Sedum cf. *S. rosea*	Genus determination certain, species identification less certain because of imperfect preservation of fossil grain or spore, inadequate reference material, or close morphological similarity of the grain or spore with those of other taxa. In each case, the reason is explained in the notes on the determination.
Plantago major/ P. media	One fossil type present; only two taxa are considered probable alternatives, but further distinctions are not possible on the basis of pollen or spore morphology alone. In view of their modern ecology and/or distribution, the occurrence of both taxa is considered equally likely.
Angelica type	One fossil type present, three or more taxa are possible alternatives, but further distinctions are not possible on the basis of pollen or spore morphology alone. The selection of the taxon name is based on modern ecological and/or phytogeographical criteria. The notes on the determination list all the known possibilities.
Rosaceae undifferentiated (undiff.)	Family determination certain, some morphological types distinguished and presented separately. Curve represents fossil grains or spores that were not or could not be separated beyond family level.
Stellaria undiff.	Genus determination certain, some morphological types distinguished and presented separately. Curve represents fossil grains or spores that were not or could not be separated beyond genus level.

Appendix D

Sediment-stratigraphic descriptions of transect cores

Table 1: Sediment stratigraphies of Transect 1 cores

Core	Depth cm	Description	Unit
E8	0-23	Fresh pale brown very poorly humified fibrous herb peat. Sharp (peat cut) to:	
	23-87	Dark brown moderately humified fine fibrous herb peat with very rare small wood fragments.	
	87	Bedrock	
E7	0-5	Fresh moss peat	a
	5-93	Moderately humified herb peat with common roundwood pieces with bark and larger wood fragments. Gradual to:	b
	93	Bedrock	
E6	0-5	Fresh moss peat	a
	5-52	Moderately humified herb peat with common roundwood pieces with bark and larger wood fragments. Gradual to:	b
	52-70	Mid brown moderately humified amorphous peat with rare very fine fibrous stems and rare silt disseminated throughout. Clear to:	c
	70	Bedrock	
E5	0-12	Reddish brown poorly humified moss peat. Sharp to:	a
	12-91	Moderately humified herb peat with common roundwood pieces, bark and larger wood fragments. Gradual to:	b
	91-100	Mid brown moderately humified amorphous peat with rare very fine fibrous stems and rare silt disseminated throughout. Clear to:	c
	100-103	Grey-brown structureless silty clay with vertical fine fibrous rootlets and with rare small charcoal flecks. Gradual to:	
	103-107	Creamy grey fine, structureless sandy silt. Sharp to:	
	107-114	Cream structureless well-sorted medium sand, changing to green-grey down unit.	
	114	Bedrock	
E4	0-24	Dry dark to reddish brown herb peat with occasional sedge remains. Gradual to:	d
	24-125	Brown moderately humified herb peat with rare roundwood twigs and rare fragments of bark. Common large wood fragments. Gradual to:	e
	125-140	Not sampled	
	140	Bedrock	
E3	0-24	Dry dark to reddish brown herb peat with occasional sedge remains. Gradual to:	d
	24-43	Dry dark to reddish brown moderately humified herb peat with occasional sedge remains. Gradual to:	
	43-125	Brown moderately humified herb peat with rare roundwood twigs and rare fragments of bark. With large wood remains	e

		and large charcoal fragment at 50cm. Gradual to:	
	125-141	Not sampled	
	141	Bedrock	
E2	0-18	Dry dark to reddish brown herb peat with occasional sedge remains. Gradual to:	d
	18-45	Brown moderately humified herb peat with rare roundwood twigs and rare fragments of bark. Gradual to:	e
	45-112	Dark brown moderately to well humified herb peat with common wood: large roundwood twigs with bark preserved of deciduous trees [birch/alder]; no inwash. Gradual to:	f
	112-142	Not sampled	
	142	Grit	
E1	0-5	Lost	
	5-35	Brown poorly humified herb peat with common stratified sedge remains. Gradual to:	
	35-132	Dark brown moderately to well humified herb peat with common wood: large roundwood twigs with bark preserved of deciduous trees [birch/alder]; no inwash. Gradual to:	f
	132-140	Dark brown moderately to well humified herb peat with occasional wood, almost all roundwood twigs, plus rare charcoal flecks. Sharp to:	
	140-153	Wood macrofossil	
	153-164	Dark brown moderately to well humified herb peat with occasional wood, almost all roundwood twigs, plus rare charcoal flecks. Rare broken wood fragments. Sharp to:	
	164-167	Yellow-grey weakly banded (waterlain) well-sorted coarse sand with rare subrounded medium (0.5cm diameter) quartz-rich rock. Clear to:	
	167-170	Mid-brown silty fine sand with amorphous organic content (too low to 14C date), structureless. Sharp irregular (erosional?) boundary to:	
	170-210	Pale grey till. Uppermost 0.25cm of till is pale grey-yellow – weathered surface?	
BEL core	See Table 4.4		
W1	0-20	Not sampled	
	20-70	Wet fibrous stratified poorly humified peat with abundant sedge remains	g
	70-93	Wood macrofossil, probably deciduous	
	93-95	Partially carbonised wood	
	95-162	Sludgy, poorly structured and highly humified wood peat. Very rare fibrous plant remains and abundant wood – small branches often with bark – birch/alder and larger wood fragments.	h
	162-175	Not sampled	
	175	Bedrock	
W2	0-62	Wet fibrous poorly humified peat with abundant sedge remains, stratified, no wood, no inwash.	g
	62-80	Reddish brown poorly humified herb peat with abundant fine fibrous stems.	
	80-110	Sludgy, poorly structured and highly humified wood peat. Very rare fibrous plant remains and abundant wood – small branches often with bark – birch/alder and larger wood fragments. Gradual to:	h
	110-126	Dark brown highly humified herb peat with abundant small wood fragments including twigs. Gradual to:	i
	126-146	Dark grey brown organic rich mud with common highly	j

		decomposed plant remains and abundant silt particles. Abrupt to:	
	146-156	Yellowish brown coarse sand, well sorted, no organic matter	k
	156-170	Blue till	l
W3	0-40	Wet fibrous poorly humified peat with abundant sedge remains, stratified.	g
	40-63	Spongy fibrous poorly humified herbaceous peat. Gradual to:	
	63-81	More compact pseudo-fibrous, common wood fragments, twigs & larger fragments. Gradual to:	
	81-106	Highly humified amorphous peat with occasional herb stems and rare wood fragments. Gradual to:	
	106-118.5	Dark grey brown organic rich mud with common highly decomposed plant remains and abundant silt particles. Abrupt to:	j
	118.5-127.5	Yellowish brown coarse sand, well sorted, no organic matter	k
	127.5-136.5	Blue/grey till. Gradual to:	l
	136.5-143	Blue/grey well sorted coarse sand	
W4	0-51	Compact, dry herbaceous peat with high amorphous content. Gradual to:	
	51-117	Black poorly humified sedge peat with occasional ericaceous fragments. Gradual to:	
	117-153	Sludgy, poorly structured and highly humified wood peat. Very rare fibrous plant remains and abundant wood – small branches often with bark – birch/alder and larger wood fragments. Gradual to:	h
	153-172	Dark brown highly humified herb peat with abundant small wood fragments including twigs.	i
	172	Bedrock	
W5	0-75	Not sampled	
	75-102	Fairly well humified herbaceous peat with very rare ericaceous fragments and common herb fragments. Gradual to:	
	102-142	Wood peat – sludgy, poorly structured and highly humified. Very rare fibrous plant remains and abundant wood – small branches often with bark – birch/alder and larger wood fragments Gradual to:	h
	142-171	Dark brown highly humified herb peat with abundant small wood fragments including twigs. Gradual to:	i
	171-175	Dark grey brown organic rich mud with common highly decomposed plant remains and abundant silt particles.	j
	175	Bedrock	
W23	0-30	Poorly humified dark brown compact, dry fibrous herbaceous peat with rare ericaceous fragments and abundant herb fragments. Clear to:	m
	30-115	Dark brown highly humified herb peat with abundant small wood fragments including twigs.	i
	115	Bedrock	
W6	0-10	Poorly humified dark brown compact, dry fibrous herbaceous peat with rare ericaceous fragments and abundant herb fragments. Clear to:	m
	10-18	Poorly humified bloack, crumbly, compact, extremely dry fibrous herbaceous peat with rare ericaceous fragments and abundant herb fragments. Clear to:	
	18-68	Greasy, moderately humified fibrous peat with common	

		herbaceous fragments. Gradual to:	
	68-76	Sludgy, poorly structured and highly humified wood peat. Very rare fibrous plant remains and abundant wood – small branches often with bark – birch/alder and larger wood fragments. Gradual to:	h
	76-113	Dark brown highly humified herb peat with abundant small wood fragments including twigs	i
	113	Bedrock	
W7	0-30	Poorly humified dark brown compact, dry fibrous herbaceous peat with rare ericaceous fragments and abundant herb fragments. Gradual to:	m
	30-51	Brown moderately humified greasy herbaceous peat with rare wood fragments and common herb stems. Gradual to:	n
	51-70	Sludgy, poorly structured and highly humified wood peat. Very rare fibrous plant remains and abundant wood – small branches often with bark – birch/alder and larger wood fragments. Gradual to:	h
	70-80	Brown/dark brown well humified herb peat with common amorphous matter, rare twigs and larger broken wood fragments, occasional herb remains. Abrupt to:	
	80-81	Band of charred black amorphous peat. Abrupt to:	
	81-89	Wood macrofossil. Abrupt to:	
	89-92	Dark grey brown organic rich mud with common highly decomposed plant remains and abundant silt particles. Gradual to:	j
	92-95	Grey structureless silty sand with rare amorphous matter and very rare charcoal flecks.	
	95	Bedrock	
W8e	0-34	Poorly humified dark brown compact, dry fibrous herbaceous peat with rare ericaceous fragments and abundant herb fragments.	m
	34-40	Dark brown well humified amorphous peat with rare herb stems. Gradual to:	
	40-56	Brown moderately humified greasy herbaceous peat with rare wood fragments and common herb stems. Sharp to:	n
	56-65	Reddish-brown wood peat with common very large fragments. Abrupt to:	
	65-68	Brown amorphous structureless peat. Gradual to:	o
	68-73	Dark grey smooth, greasy highly organic structureless silt with rare mica grains. Gradual to:	p
	73-78	Grey-brown silt with sand and lower organic content, no plant macrofossils. Gradual to:	
	78-87	Brown silty sand with rare small rounded stones.	
	87	Bedrock	
W15	0-90	Moderately humified herb peat with common fine fibrous herb stems & rare ericaceous fragments. Sharp to:	q
	90-95	Dark grey-brown silt with high amorphous organic content and rare fine fibrous stems. Sharp to:	p
	95-100	Dark brown amorphous highly humified peat with rare fine fibrous herb stems, common silt and fine sand throughout. Weakly developed bands (1 mm thick) of orange-yellow fine sand. Sharp to:	
	100-103	Dark brown amorphous highly humified peat with rare fine fibrous herb stems, with rare yellow fine sand. Sharp to:	
	103-105	Yellow well-sorted fine sand	
	105	Bedrock	
W9	0-8	Unhumified fresh *Sphagnum* peat. Sharp to:	

	8-39	Dark brown poorly humified herb peat with abundant herb stems. Gradual to:	r
	39-40	Inwashed yellow well-sorted medium sand with rare charcoal flecks. Sharp to:	
	40-70	Dark brown, moderately humified herb peat with rare ericaceous fragments and common herb stems. 53-56cm= peat with common diffuse yellow medium sand with gradual upper and lower boundaries. Gradual to:	q
	70-110	Brown well humified herb peat with common herb stems. Gradual to:	s
	110-112	Brown amorphous structureless peat. Common silt grains. Gradual to:	o
	112-115	Dark grey smooth, greasy highly organic structureless silt with rare mica grains.	p
	115	Bedrock	
W16	0-37	Mid-brown poorly humified herb peat with rare ericaceous fragments. Gradual to:	
	37-76	Brown poorly humified herb peat with common ericaceous fragments. Gradual to:	
	76-104	Dark brown moderately to well humified amorphous peat with common herb fragments. Sharp to:	s
	104-113	Dark grey-brown silt, structureless except for a single discontinuous horizontal band at 110.5-111.0cm of orange fine sand. Abrupt to:	p
	113-138	Orange-yellow, largely structureless fine-medium sand. Weakly horizontally banded in uppermost 1cm, no organic matter except isolated coarse wood fragments at 134cm [roots penetrating into material] Possible weathered bedrock	t
	138	Bedrock	
W10	0-28	Dark brown poorly humified herb peat with abundant herb stems. Gradual to:	r
	28-46	Reddish-brown poorly humified crumbly herb peat. Abrupt to:	
	46-65	Dark brown well humified herb peat with common herb stems and common amorphous matter, rare small twigs with bark. Gradual to:	
	65-85	Dark brown moderately to well humified amorphous peat with common herb fragments. Gradual to:	s
	85-90	Reddish brown – orange well humified amorphous peat with common broken wood fragments. Gradual to:	
	90-96	Brown amorphous structureless peat. Common silt grains. Gradual to:	o
	96-105	Grey structureless medium sand with red-orange mineral grains, coarsing to base.	
	105	Bedrock	
W17	0-86	Dark brown moderately humified herb peat with common herb stems and rare ericaceous fragments. Broken wood fragments at 71cm and 82cm.	q
	86	Bedrock.	
W18	0-20	Unhumified fresh fibrous red-brown peat. Gradual to:	u
	20-112	Dark brown moderately humified herb peat with common herb stems and rare ericaceous fragments. Large charcoal flecks at 95 and 105cm, larger bark fragments between 108 and 110cm. Gradual to:	q
	112-121	Dark brown highly humified amorphous peat with very rare plant remains and rare silt disseminated throughout.	v

		Gradual to:	
	121-124	Dark brown highly humified amorphous peat with very rare plant remains and with rare to common orange fine sand particles disseminated throughout. Sharp to:	
	124-130	Orange-yellow, largely structureless fine-medium sand.	t
	130	Bedrock	
W11	0-33	Unhumified fresh fibrous red-brown peat. Occasional sedge stems. Gradual to:	u
	33-56	Mid-brown moderately humified herb peat with abundant herb stems and occasional sedge stems and rare silt disseminated throughout; rare small twigs with bark but no larger wood fragments. 46-47cm = grey medium sand within peat, gradual upper & lower boundaries. Gradual to:	w
	56-77	Dark brown highly humified amorphous peat with very rare plant remains and rare silt disseminated throughout. Very rare mica. Gradual to:	v
	77-86	Brown amorphous structureless peat. Common silt grains. 78-80cm = yellow-orange medium sand within peat, gradual upper & lower boundaries. Gradual to:	o
	86-95	Compact orange-brown coarse-medium silty sand with small rounded pebbles and occasional amorphous organic matter.	
	95	Bedrock	
W19	0-33	Unhumified fresh fibrous red-brown peat.	u
	33-68	Dark brown moderately to well humified amorphous peat with common herb fragments. Band of *Sphagnum* at 46-51cm. Abrupt to:	s
	68-77	Black hard charred apparently herb peat with rare uncharred (intrusive) fibrous stems. Abrupt to:	
	77-78	Brown-orange medium sand (altered surface of sand). Gradual to:	
	78-87	Orange-yellow, largely structureless fine-medium sand.	t
W12	0-16	Unhumified fresh fibrous red-brown peat. Occasional sedge stems. Gradual to:	u
	16-48	Dark brown moderately to well humified amorphous peat with common herb fragments. Rare charcoal flecks. Common silt and fine sand disseminated throughout and concentrations at 26-30cm within peat. Clear to:	s
	48-55	Very dark brown amorphous peat with no plant macrofossils, rare charcoal flecks and common silt and fine sand.	
	55-70	Not sampled	
	70	Bedrock	
W20	0-28	Dark brown moderately to well humified amorphous peat with common bleached fine to medium sand grains disseminated throughout and abundantly in concentrations within peat at 15-16cm, 18-19cm, 21-22cm, 24-26cm and 28cm. Gradual to:	s
	28-54	Dark brown moderately to well humified amorphous peat with common herb fragments. Gradual to:	s
	54-63	Dark brown very highly humified amorphous peat with very rare plant remains and rare silt disseminated throughout. Abrupt to:	v
	63-70	Orange-yellow, largely structureless fine-medium sand.	t
	70	Bedrock	
W13a	0-63	Dark brown very highly humified amorphous peat with very rare plant remains and rare silt disseminated throughout.	v

		Abrupt to:	
	63-72	Orange/brown structureless medium well-sorted sand with some organic matter, very rare charcoal flecks, common highly degraded rounded pebbles broken to medium-coarse sand. Gradual to:	
	72-79	Mid-brown compact, slightly organic structureless fine-medium sand, very rare charcoal flecks, rare degraded sandstone pebbles.	
	79	Bedrock	
W13	0-20	Unhumified fresh fibrous red-brown peat. Occasional sedge stems. Gradual to:	u
	20-38	Dark brown moderately to well humified amorphous peat with common herb fragments. Rare charcoal flecks. Common silt and fine sand disseminated throughout and concentrations at 22-24cm = prominent yellow medium well sorted sand with common charcoal flecks, quite sharp upper and lower boundaries; 33-36cm = diffuse yellow medium sand within peat and gradual upper & lower boundaries. Gradual to:	s
	38-63	Dark brown very highly humified amorphous peat with v rare plant remains and rare silt disseminated throughout.	v
	63	Bedrock	
W21	0-14	Unhumified fresh fibrous red-brown peat. Occasional sedge stems. Silt disseminated throughout. Gradual to:	x
	14-40	Dark brown humified amorphous peat with common herb stems, rare broken wood fragments and common silt and fine sand throughout. Concentrations of bleached fine sand particles within peat at 25-26 and 29-30cm strong band of fine to coarse sand between 37 and 38cm containing rare charcoal flecks.	y
	40-82	Light brown brown humified amorphous peat with common herb stems and rare broken wood fragments.	w
	82-85	Yellow sand – possible weathered bedrock	
	85	Bedrock	
W14	0-15	Unhumified fresh fibrous red-brown peat. Occasional sedge stems. Gradual to:	u
	15-37	Mid-brown moderately humified herb peat with abundant herb stems and occasional sedge stems and rare silt disseminated throughout; rare small twigs with bark. Clear to:	w
	37-45	Brown amorphous peat with common to abundant yellow medium sand throughout.	
	45	Bedrock	
W22	0-17	Unhumified fresh fibrous red-brown peat. Occasional sedge stems. Silt disseminated throughout. Gradual to:	x
	17-25	Dark brown moderately humified coarse fibrous peat with very rare silt throughout. Gradual to:	
	25-40	Dark brown well humified herb peat with occasional herb stems with common medium charcoal flecks (<3mm diameter) at 31-34cm. Clear to:	
	40-50	Dark brown very highly humified amorphous peat with very rare plant remains and rare silt disseminated throughout.	v
	50	Bedrock	

Table 2: Sediment stratigraphies of Transect 2 cores

Core	Depth cm	Description	Unit
N1	0-15	Coarse fibrous peat with no inwash	z
	15-30	Coarse fibrous peat with inwashed sand	aa
	30-31	Charcoal rich peat surface	bb
	31-45	Mineral soil	cc
	45	Bedrock	
N2	0-30	Coarse fibrous peat with no inwash	z
	30-52	Fine fibrous peat with no inwash	dd
	52-60	Mineral soil	cc
	60	Bedrock	
N3	0-65	Coarse fibrous peat with no inwash	z
	65-105	Fine herb peat	dd
	105	Bedrock	
N4	0-35	Coarse fibrous peat with no inwash	z
	35-55	Fine herb peat	dd
	55	Bedrock	
N5	0-35	Coarse fibrous peat with no inwash	z
	35-55	Fine herb peat	
	55	Bedrock	
N6	0-30	Coarse fibrous peat with inwashed sand	aa
	30-85	Red-brown poorly humified herb peat with rare ericaceous fragments and very rare silt	
	85-90	Fine herb peat	dd
	90-95	Not sampled	
	95-98	Greasy black peat	ee
	98	Bedrock	
N7	0-25	Coarse fibrous peat with inwashed sand	aa
	25-35	Red-brown poorly humified herb peat with no inwash	ff
	35-45	Highly humified dark brown peat with rare silt and with charcoal band at 40-42cm	
	45	Bedrock	
N8	0-10	Coarse fibrous peat with no inwash	z
	10-20	Red-brown herb peat with rare fine sand	
	20-23	Charcoal rich herb peat, common medium sand including concentration at 21-22cm	
	23	Bedrock	
N9	0-15	Coarse fibrous peat with no inwash	z
	15-19	Red-brown poorly humified herb peat with no inwash	ff
	19-22	Charcoal rich peat	gg
	22-27	Mineral soil with rare charcoal flecks	cc
	27	Bedrock	
N10	0-21	Coarse fibrous peat with inwashed sand at 5cm and 10cm, charcoal at 12cm	
	21-23	Charcoal rich peat	gg
	23-27	Red-brown poorly humified herb peat with layer inwashed medium sand at 27cm	ff
	27-32	Very well humified brown herb peat with very rare silt. Band of medium sand at 32cm.	hh
	32-40	Soil with rare charcoal flecks	cc
	40	Bedrock	
N11	0-35	Coarse fibrous peat with no inwash	z
	35-37	Charcoal rich peat surface	bb
	37-40	Very well humified brown herb peat with very rare silt.	hh
	40-43	Mineral soil with rare charcoal flecks	cc

	43	Bedrock	
N12	0-28	Red-brown poorly humified herb peat with inwashed medium sand at 2-4cm and 13-14cm	ff
	28-30	Charcoal rich fine sand	
	30-40	Moderately humified herb peat with very rare silt	
	40-50	Well humified herb peat	ii
	50-60	Mineral soil with rare charcoal flecks	cc
	60	Bedrock	
N13	0-10	Coarse fibrous peat with rare inwashed fine sand	aa
	10-19	Very well humified brown herb peat with very rare silt and occasional charcoal.	hh
	19-20	Medium sand inwash	
	20-23	Mineral soil with rare charcoal flecks	cc
	23	Bedrock	
N14	0-23	Coarse fibrous peat with no inwash, with common charcoal	z
	23-35	Well humified herb peat with no silt	ii
	35-36	Mineral soil with rare charcoal flecks	cc
	36	Bedrock	
N15	0-8	Coarse fibrous peat with common inwashed sand	aa
	8-17	Coarse fibrous peat common medium sand with occasional charcoal and occasional ericaceous fragments	
	17-25	Greasy moderately humified herb peat with rare silt	
	25-29	Organic rich mineral soil	
	29	Bedrock	
N16	0-21	Coarse fibrous peat with no inwash, charcoal at 12-15 and 20-21cm	z
	21-25	Moderately humified light brown herb peat with no silt	jj
	25-27	Greasy black peat	ee
	27-37	Mineral soil with rare charcoal flecks and common small-medium subangular pebbles	cc
	37-45	Yellow-brown fine sand	
	45	Bedrock	
N17	0-20	Coarse fibrous peat with no inwash	z
	20-31	Moderately humified light brown herb peat with no silt	jj
	31-38	Mineral soil with rare charcoal flecks and common small-medium subangular pebbles	cc
	38	Bedrock	